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INTELLIGENT GRID

RESEARCH CLUSTER-PROJECT 6

The Intelligent Grid in a New Housing Development

University of South Australia

UniSA | Barbara Hardy Institute

iGrid intelligent grid

an Australian research collaboration

Disclaimer

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EXECUTIVE SUMMARY

Climate change, diminishing resources and escalating cost of energy have been on the forefront of social, economic and environmental challenges in Australia. Reducing the energy consumption and greenhouse gas emissions of homes through good design, energy efficiency and local solar energy utilisation is being considered around the world. In Australia, various levels of government have used building or planning regulatory instruments to reduce the greenhouse gas impact of new buildings.

The concept of low or zero energy homes has entered the international policy debate and is under consideration as the future regulatory standard for new dwellings. This concept embraces levels of energy efficiency and local renewable energy production significantly above that incorporated in Australian building energy regulations.

The report focuses on the Lochiel park green Village, a world leading new Australian housing development where 106 low energy homes are being built and enjoyed. It outlines the process followed for planning and executing the development and for setting and validating ambitious targets in reduced energy consumption and greenhouse gas emissions. It also describes the lessons learnt during the implementation process. As the Lochiel Park Green Village is seen as the forerunner of new Australian low carbon housing suburbs, many of the lessons learnt will be useful in implementing similar developments at reduced time and costs.

The project demonstrates that zero and negative emission housing is possible with current technology and building practices. It also highlights the need to develop the regulatory framework and educational programs for all involved in the implementation process. It has also demonstrated that regardless of the technology used, it is the residents that determine the energy and emission levels. Without the provision of necessary information to users, many of the new features and appliances cannot operate according to the designers’ perceived use pattern.

A feature that sets this project apart is the level of rigour implemented in monitoring the energy use to enable detailed performance evaluation of individual houses as well as specific appliances and features to enable thorough evaluation of the overall impact on the grid. The monitoring of electrical systems, natural gas and water use provides unique details of patterns of use of appliances and their energy use as well as house solar system performance under real conditions. The aggregated results for some 30 households provide reliable data on the overall impact of low energy housing generating solar power on the electrical grid.

On the basis of data analysis for some 30 houses, monthly average electricity and gas consumption results were evaluated for 18 months. In addition, the average monthly solar electricity generation is provided. The average Lochiel Park home consumes 5520kWh of electricity per annum (15.1kWh per day) of which 57% is locally generated and only 2340 kWh per year (6.4kWh/day) is supplied by the grid.

The project demonstrates the interaction of a cluster of homes having local solar generation with the local grid. Operating under the Adelaide climate, the study has shown that on average, the domestic solar electrical energy generated ranges from 2.4kWh/kW$_p$ in June to 5.5kWh/kW$_p$ in January with an annual average of around 4.0kWh/kW$_p$. While only one house consistently produced excess energy and negative emissions, 50% of the monitored dwellings produced more electricity than they consumed and 40% of them produced negative net emissions during the period October to April due to the high performance of the photovoltaic systems during that period.

Twenty seven gas boosted solar hot water systems were monitored. The analysis showed that on average the daily hot water consumption rate varied between 60 litres during summer and 100 litres in winter. The number of occupants had direct influence on the total household consumption. While solar heat provided most of the hot water energy, the results showed considerable potential for reducing the auxiliary gas consumption through better commissioning and operation information to households.

The significant feature of air conditioning system usage is the relatively low hours when air conditioning was needed in comparison with similar Adelaide homes with the worst of the houses investigated needing a maximum of 3 kW of electrical power with some systems needing below 1kW. This is well below typical air conditioning systems with the air conditioning demand requiring about half the previously measured values. This has a significant impact on peak demand during hot spells and cost of associated with transmission/distribution infrastructure.

Considering the breakdown of energy consumption in houses, having reduced the air conditioning, hot water and lighting demands, other appliances including laundry (10.4%) and fridge/freezer (12.8%) assume more significance and require more attention for achieving lower energy consumption. The use of energy for computers and entertainment (43%) becomes the most prominent contributor to the overall energy consumption. Further attention needs to be payed to the energy consumption of appliances associated with current lifestyle such as televisions, computing facilities and home office equipment.

Considering the impact on the greenhouse gas emissions, the highest emitting homes were responsible for emitting 1.2 tonne of CO_2 per month in winter and 0.4 tonne of CO_2 in autumn. The corresponding lowest emitters produced zero emissions in winter and a negative net emission (-0.4 tonne per month) in summer. The average emissions of the monitored Lochiel Park homes ranged between 0.1 tonne in May and 0.5 tonne in the winter months. This is substantially lower than the SA and Australian averages.

The total annual monitored energy use of Lochiel Park homes amounts to 18.9GJ. This is a reduction of 53% in comparison with the Australian average. The corresponding reduction of greenhouse gas emissions is 66%. In addition to the significant environmental benefits, the outcome provides a considerable impact on energy bills to households at a time of escalating energy costs.

The report presents results of a primarily qualitative investigation of the social influences on green attitudes and household practices of residents, or intending residents, in Lochiel Park. Comfort, convenience and cost emerge as the biggest influences on the behaviour of residents of Lochiel Park, and these are in turn affected by a range of factors that arise in the domains of work, home and community life, and the ways in which these domains intersect. The project has also demonstrated the need for providing better information for households to enable them to interact better with the new technologies in use in their dwellings.

The data analysis provides real world evidence to support the development of energy regulatory framework and future energy policy directions in the housing and appliance sectors. The monitoring of current and new dwellings, including a number of smaller units will continue for the next three years and beyond.

The lessons learnt from this project, while significant along the path towards zero energy housing, demonstrate the need for better design integration to ensure the achievement of low energy dwellings which are also affordable, comfortable and aesthetically acceptable. The project also highlights the need to develop educational material to inform all those involved in designing, building and living in the new generation of sustainable dwellings.

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ABBREVIATIONS

A	-	Analogue
ABS	-	Australian Bureau of Statistics
AC	-	Air Conditioning / Air Conditioner
AEMO	-	Australian Energy Market Operator
APA	-	APA Group
BIOS	-	Basic Input Output System
BOM	-	Bureau of Meteorology
CO_2	-	Carbon Dioxide
CSV	-	Comma Separated Variable
D	-	Digital
D/S	-	Downstairs
DCCEE	-	Department of Climate Change and Energy Efficiency
DFC	-	Department of Families and Communities
EAUE	-	European Academy of the Urban Environment
ESCOSA	-	Essential Services Commission of South Australia
ESIPC	-	Electricity Supply Industry Planning Council
ETSA	-	Electricity Trust of South Australia
EV	-	EcoVision
Gen	-	Generation
GHG	-	Greenhouse Gas
IHD	-	In Home Display
kW	-	kilo watt
kWh	-	kilo watt hour
kW_p	-	kilo watt peak
LCD	-	Liquid Crystal Display
LED	-	Light Emitting Diode
LP	-	Lochiel Park
NW	-	Northwest

ONT - Optical Network Terminal
PLC - Programmable Logic Controller
PPP - Private Water Meter
PV - Photovoltaic
QLD - Queensland
RCAC - Reverse-Cycle Air Conditioning
RH - Relative Humidity
SA - South Australia
SAGovt - South Australian Government
TBC - to be confirmed
Temp - Temperature
UniSA - University of South Australia
UTC - Universal Time Code
U/S - Upstairs
USB - Universal Serial Bus
VPN - Virtual Private Network

1. INTRODUCTION AND BACKGROUND

1.1. Background

Growing demand for energy in all sectors of human activity has resulted in unprecedented reliance on fossil-based non-renewable energy resources with consequent production of greenhouse gas emissions. A significant amount of the world's energy is consumed in the operation of buildings. In the United States, by 2007 buildings accounted for 70 per cent of electricity use and over 38 per cent of CO_2 emissions (Brown 2008). The Organisation for Economic Cooperation and Development (OECD) found that buildings consume between a third and a half of all materials, and up to 40 per cent of energy for member countries (OECD 2003). In Australia, the operation of buildings is responsible for over 27 per cent of national greenhouse gas emissions, and when combined with emissions embodied in the materials used throughout the building's lifecycle, the impact is estimated to be between 32 and 40 per cent of national emissions (Australian Greenhouse Office 2006).

The residential housing sector represents 20% of Australia's greenhouse gas emissions and is largely responsible for the escalating peak electrical power demand. The Australian building sector constructs on average around 140,000 new dwellings per year (Australian Bureau of Statistics 2010). A study by the Department of Environment, Water, Heritage and Arts - DEWHA (2008) indicates that an increase of 61% of occupied residential household from 6 million to 10 million is expected to occur between 1990 and 2020. Total residential floor area is also expected to increase by 145%, from 685 million m^2 to 1682 million m^2 for the same period. Household energy (electricity, gas, LPG and wood) consumption is predicted to increase by 56% from 299 PJ in 1990 to 467 PJ in 2020. The study also anticipates a 6% decline in energy consumption per household in 2020 compared to the 1990 levels. The reason for this, according to the study, is the impact of current energy programs directed to increased efficiency of domestic appliances and the building shell. However there is considerable reluctance in justifying the use of energy efficiency features and distributed generation in residential buildings. This is due to the lack of hard evidence of the impact of demand side management and distributed generation on energy use and demand pattern and a lack of integrated technical and socio-economic evaluations.

Each additional building is increasing the need for additional electricity generation capacity and associated energy supply infrastructure, and adds to global greenhouse gas emissions. This problem should be seen in the context of the Australian Government emissions reduction target of 80 per cent below 2000 levels by 2050 (Department of Climate Change and Energy Efficiency 2011).

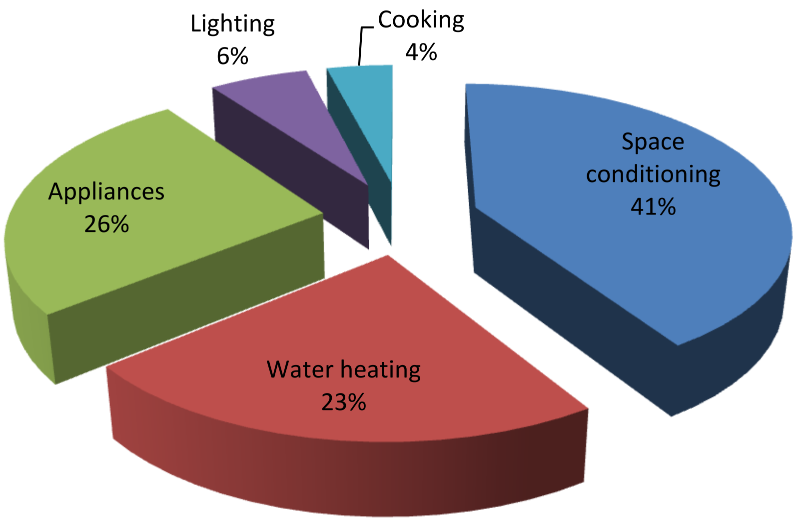
The University of South Australia (UniSA) Intelligent Grid Project aims at investigating the impacts of the introduction of energy efficiency measures and distributed generation on energy use patterns, greenhouse gas emissions, the electrical grid and consumer. The research also investigates the issues of ownership and control of distributed energy resources (i.e. local generation and loads) in residential houses, occupants' attitude towards this new type of energy generation.

The focus of the research is the Lochiel Park Green Village, which represents a world leading example of a new housing development designed and implemented with ambitious targets for reducing energy and water use and greenhouse gas emissions. UniSA has been involved in this development from the early planning stages. In addition to providing technical advice in developing and adhering to the environmental guidelines to enable the achievement of the set targets, a comprehensive energy and water monitoring program has been developed and implemented which will provide details of energy and water quantities and patterns of use, as well as peak demands for individual home as well as the overall development.

1.2. Energy use in Australian housing

Annual energy use per household in Australia was estimated to be around 13,500 kWh in 2010/2011, although regional differences are significant and new homes, which on average are larger in floor area, typically have higher energy use (Department of the Environment Water Heritage and the Arts 2008). The largest share of this energy consumption is used for space heating and cooling, while appliances and equipment, which includes the fast growing computing and communications area, represent a rapidly increasing share. Figure 1.1 shows the average disaggregation of energy use per major end use.

Figure 1.1: Australian average energy use by end use category. Source: Department of the Environment Water Heritage and the Arts (DEWHA) 2008.



Since the early 1990s, Australian Governments have assessed the energy performance of homes using the Nationwide House Energy Rating Scheme (NatHERS), which estimates the required amounts of heat energy to be added or removed from a home in order to maintain thermal comfort. The relative performances are communicated in NatHERS stars. Energy used for lighting, water heating, refrigeration, cooking and other plug loads are not covered by NatHERS stars, but are addressed through separate minimum energy performance or appliance star rating schemes. The NatHERS scale starts at 0 stars, which equates to a poorly performing building (frequently thermally uncomfortable), and reaches a maximum of 10 stars for an outstanding building that requires little energy for heating/cooling in the local climate.

As energy efficiency has not, until recently, been a high priority for the building industry or new home buyers, Australian housing is regarded as having relatively low energy performance, as compared to those of other developed nations. For example, a study of the energy rating of houses sold in the Australian Capital Territory found that before the mid 1990s, houses were typically built to a standard lower than 2 stars, with the average performance just below 1.7 stars (DEWHA 2008). Research in Victoria established that houses built before insulation regulations were introduced in 1991 had an average thermal performance equivalent to less than 1 star, and those built in the 1990s averaged around 2.2 stars (Australian Greenhouse Office 2000).

The policy imperative for improving thermal comfort and reducing energy consumption and associated emissions, agreed under successive national greenhouse and energy strategies, has led to the introduction and tightening of regulatory frameworks. This began with the introduction into the Building Code of Australia of minimum energy efficiency standards, approximating 4 stars in 2003, 5 stars in 2006, and 6 stars in 2010. Although substantial progress has been made in raising the energy performance of new Australian homes, our building standards are well below those of similar economies. A study of building regulatory standards in force during 2004 in the United States, Canada and the United Kingdom found that the median rating for a sample of homes was 7.5 stars (Horne et al. 2005). Most regions have since increased their building energy standards.

Energy costs have played a large role in shaping energy consumption in housing. Australian electricity prices have for many years been lower than in most of the European Union (Wells and Donaldson 2005). The Australian energy pricing regime, which is set lower than the full environmental and social costs of supplying that energy, has resulted in higher than optimal consumption by end users (Productivity Commission 2005). The result is significant energy wastage through poor building energy performance, wasteful behaviour by residents and the overuse of inefficient energy-consuming appliances and equipment (Department of Climate Change and Energy Efficiency 2010).

In recent years, due a variety of reasons including the shift to private ownership of energy assets, the need to renew and enlarge energy related infrastructure, the escalating use of air conditioning and consequent effect on peak electricity demand, growing international demand for local natural gas and coal, and the need to decarbonise electricity generation, Australian energy prices have been increasing rapidly and households now find they are wasting very expensive energy.

1.3. Low Energy Housing Benchmarks

This section reviews the definitions and benchmarks applied to Low Energy Housing adopted in a number of countries.

1.3.1. LEED, United States

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System was developed by the U.S. Green Building Council (USGBC) to provide a sustainability benchmark for the design, construction and operation of high performance green buildings. LEED Rating systems are available for different types of buildings (homes, existing buildings, schools, retail, health care, etc.). In the LEED scheme, building energy performance is only one of the categories which need rating; others are: innovation and design process, site sustainability, water efficiency, materials and resources, indoor environment quality and awareness and education (US Green Building Council Website, 2008).

For the energy performance, the LEED® for Homes Rating Systems manual lists some prerequisites and minimum point requirements for homes as summarised below in Table 1.1

Table 1.1: Prerequisites and Minimum Requirements for LEED® for the Home Rating System

Credit category	**Prerequisites (mandatory measures)**	**Minimum point requirements**	**Maximum points available**
Innovation & Design process (ID)	3	0	11
Location & Linkages (LL)	0	0	10
Sustainable Sites (SS)	2	5	22
Water Efficiency (WE)	0	3	15
Energy & Atmosphere (EA)	2	0	38
Material & Resources (MR)	3	2	16
Indoor Environment Quality (EQ)	7	6	21
Awareness & Education (AE)	1	0	3
Total	**18**	**16**	**136**

As seen, although the minimum point requirements set for the Energy & Atmosphere (EA) criterion is nil, the prerequisite is 2, which means that certain measures are mandatory. These prerequisites are: basic insulation, reduced envelope leakage, good windows, reduced distribution losses, good HVAC design and installation, Energy Star lights, and refrigerant charge test.

Once scores of each category appearing in Table 1.2 have been determined, the building performance level is determined from the following 4 certification levels:

Table 1.2: *LEED for Home* Certification Levels and Number of Points Required.

LEED for Home Certification Levels	**Number of *LEED for Home* Points required**
Certified	45 – 49
Silver	60 – 74
Gold	75 – 89
Platinum	90 – 136
Total available points	**136**

1.3.2. PassivHaus, Europe

PassivHaus is an energy benchmark developed by the PassiveHaus Institute Darmstadt, Germany (PaasivHaus website, 2008). The Institute defines the 'Passive House' as: "*a building in which a comfortable interior climate can be maintained without active heating and cooling systems (Adamson 1987 and Feist 1988).*

The PassivHaus concept has now been adopted by 5 European countries (Austria, Denmark, France, Germany, Switzerland) through CEPHEUS (**C**ost **E**fficient **P**assive **H**ouses **E**uropean **S**tandards) – a project involving the construction and scientific evaluation of 250 housing units built to Passive House standards in those countries (CEPHEUS Website, 2008).

In the PassivHaus concept, the house energy consumption is set by following criteria:

- maximum Constant heating load: 10 W/m^2
- maximum space heating requirements: 15 kWh/(m^2)
- maximum total amount of active energy input: 42 kWh/(m^2)
- maximum total energy requirement for space heating, domestic hot water and household appliances: 120 kWh/(m^2)

1.3.3. Minergie, Switzerland

MINERGIE-P® is a low energy label developed in Switzerland in 2002 (Mennel et al., 2007). It entails a massive decrease in heating energy demand (up to 80%) while guaranteeing a high quality of indoor air. MINERGIE-P® essentially adopts the German PassivHaus concept with some adjustment to Swiss conditions.

MINERGIE-P® label requires that the maximum heating demand is 15 kWh/$m^2{}_{ERA}$ (where ERA is 'energy reference area' or 'conditioned zone'). The second requirement is that the maximum total energy for domestic hot water, auxiliary energy for pumps and ventilation is 30 kWh/$m^2{}_{ERA}$. The last requirement is that the outer shell is very airtight (an air change rate less than 0.6/h at 50 Pa pressure difference).

1.3.4. NatHERS, Australia

NatHERS (Nationwide House Energy Rating Scheme) is a scheme for rating the energy requirements of houses in Australia to achieve thermal comfort. It relies on a computer program which calculates the energy requirement of a house based on its fabric and form alone. It currently does not include the effects of the cooling / heating system performance or other appliances used in the house. This rating system is mandatory for new Australian houses. Currently, NatHERS relies on AccuRate, FirstRate and BERS energy rating software packages based on the work developed by CSIRO. The outcome of AccuRate are: (1) a text file containing hourly values of heating and cooling requirements of every zone, and (2) energy rating of the house in terms of number of stars (between 0 – 10) where higher number of stars indicates lower total heating and cooling requirements for the particular zone (10 star means no external heating or cooling is required).

The star energy rating system has been incorporated into the Building Code of Australia (BCA). From 1 May 2006, all new homes (and alterations to existing homes) in South Australia were required to achieve a 5 star rating. In addition, after 1 July 2006 the following requirement need to be met: (a) 1000 L rainwater tank plumbed to the house, (2) A solar or heat pump water heater or a gas water heater with an Energy Rating label of 2.5 stars or greater. (House Energy Rating website, 2008). The requirement was raised to 6 stars from July 2010.

In Victoria, from July 2005, new class 1 buildings were required to achieve a house energy rating (HER) of 5 stars. Furthermore, a solar hot water system producing a minimum energy saving of 50% when installed between 1 July 2004 and 30 June 2005 compared to conventional water heater, and 60% when installed after 1 July 2005 are required (Sustainability Victoria website, 2008). This requirement was also raised to 6 stars in 2010.

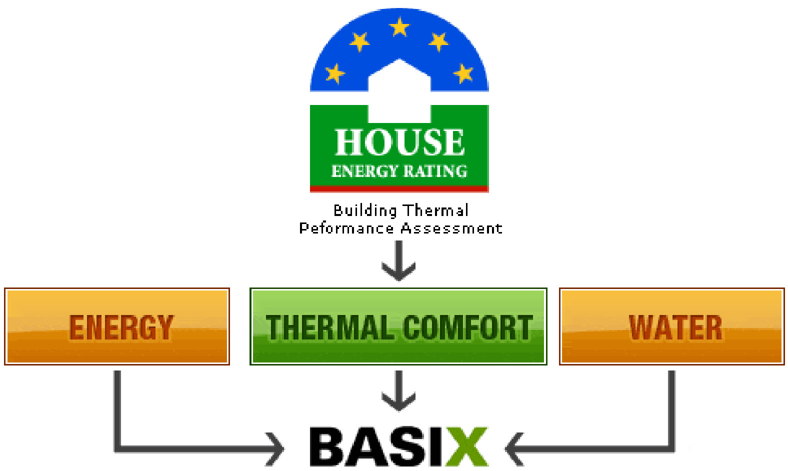
Australian Capital Territory (ACT) has its own energy rating scheme called: ACT House Energy Rating Scheme (ACTHERS) which conforms to the national benchmark, NatHERS. For Class 1, 2, 3 and 4 buildings (ie Residential – Single detached dwellings and multi-unit developments). The standard required is an ACTHERS 4 star rating (ACT Palling and Land Authority, 2003). ACT has also mandated the disclosure of the house rating when the residence is offered for sale.

According to the House Energy Rating website, all new houses and extensions in Tasmania are required to comply with the 4 star energy rating as calculated by FirstRate, NatHERS, or AccuRate building simulation software. For a building to pass with the local council or certifier, it needs to have either (a) a 4 star certificate from FirstRate or AccuRate; or (b) demonstrated compliance with the BCA 'deemed to satisfy' conditions.

In Western Australia, new houses built after 1 September 2007 must meet minimum standards for energy and water efficiency: 5 Star Plus. This scheme "*builds on the energy efficiencies of 5 Star and adds the benefits of water reduction measures for homes right across the State. 5 Star Plus is based around two new building codes, the Water Use in Houses Code and the Energy Use in Houses Code which help to improve the water and energy efficiency of new homes*." (Department of Housing and Works Website, 2008).

New South Wales has its own sustainability rating tool called BASIX (Building Sustainability Index). The BASIX was introduced "*to ensure that all new homes that are built are more energy efficient and use less water*". BASIX is an online computer software to determine the energy and water performance of buildings. Thermal comfort is also one of BASIX rating elements as shown in Figure 1.2 (Greenview Consulting Website, 2008).

Figure 1.2: Elements of BASIX rating.



BASIX goes beyond the heating and cooling energy needs. Areas assessed in the Energy Section are: hot water, heating and cooling, ventilation systems, natural lighting, artificial lighting, pool and spa, alternative energy and appliances. However, the relative weights of these areas have not been based on monitoring evidence. In the Water Section, the assessed areas are: landscape, fixtures, rainwater tank, stormwater tank, greywater / wastewater reuse and pool and spa. However, BASIX overall rating is based on subjective weighting factors for various elements involved in the calculation.

1.4. Overview of some Low Energy Housing Projects

Several local governments in a number of countries have been setting energy consumption targets, developing low energy housing estates and / or setting up guidelines for achieving low energy housing. Some examples are described below:

1.4.1. City of Freiburg, Germany

The City Council of Freiburg, Germany, developed the “Low Energy Housing Construction” project in which “new, energy-efficient housing construction standards” are incorporated into all lease and purchase contracts (EAUE Website, 2008). The new policy, which came into effect in June 1992, mandated the reduction of household energy consumption. Specifically the policy sets the maximum heating energy at 65 kWh/m^2-yr. With this, only houses satisfying this requirement can be built in the jurisdiction of Freiburg City Council. This is a considerable reduction, keeping in mind that typical houses in Germany consume 220 kWh/m^2-yr. Freiburg is considering a new law limiting the heating energy requirements to 55, 50 or even 40 kWh (Post Carbon Cities Website, 2008).

The cost associated with achieving this goal is around 3 – 8% of the total construction cost. For a single family house, this translates into an additional construction cost of US$ 12,883. For the same house an estimated annual savings is 19,000 litres of heating oil and reductions of 6.5 kg SO_2, 3.4 kg nitrogen, 3.1 kg carbon, 0.3 kg hydrocarbon, 0.001 kg dust and 5 tons CO_2.

1.4.2. Vitali-Velti House, Switzerland

Pahud et al (2001, 2002) report on the thermal performance monitoring of two low energy houses built in the village of Monte Carasso, Switzerland, called: “Vitali-Velti” house (see Figure 1.3). The houses (A and B) have massive construction, with 260 m^2 and 234 m^2 heated floor areas, respectively, and external walls insulated with 15 to 18 cm insulation. Thermal bridges are minimal. They have air controlled ventilation with heat recovery and large windows mounted in south-east façade (see Figure 1.3).

Figure 1.3: South-east and north-west façade of the Vitali-Velti house.

The low energy target is achieved through improved building envelopes, installation of heat recovery ventilation units and solar hot water systems, and avoidance of installation of conventional heating systems.

The one year monitoring conducted showed that, generally indoor air temperatures are within thermal comfort limits, i.e. below 26.5°C in summer and above 19°C in winter. Indoor air quality measurement (CO_2 concentration) also showed that the minimum requirements for hygienic air conditions were achieved.

The heating demand for house A was 56 MJ/m^2-a and 64 MJ/m^2-a for house B. The higher annual heating demand of house B was attributed to lower passive solar gain (due to smaller windows compared to house A which has large window in the south-west facade).

Although the energy performance of house B failed to achieve *PassivHaus* requirement (of 15 kWh/m^2-a = 54 MJ/m^2), it is still better than Freiburg city low energy houses (65 MJ/m^2).

1.4.3. Terraced Houses, Sweden

Papers by Isaksson & Karlsson (2006) and Karlsson & Moshfegh (2007) report on detailed interdisciplinary investigation on 20 low energy terraced houses constructed south of Gothernburg, Sweden. Each house consists of a kitchen, living room and toilet in the ground floor and three bedrooms and a bathroom on the upper floor. Each house has a total floor area of 120 m^2 including 60 m^2 ground floor area, with ground floor-ceiling height of 2.5 m and upper floor ceiling height ranging from 2.2 – 4.3 m. The low energy target of the houses is achieved through reliance on emission of heat from appliances, occupants' body heat and solar radiation. However, on cold days a 900 W electric heater, integrated into the ventilation system, could be used. In addition, the houses are well insulated and air tight. Domestic hot water is provided by an electric boosted solar system with 5 m^2 collector area. Each house has a skylight which is used for ventilation during summer.

The research found that indoor temperatures in the middle houses were generally within the comfort range compared to those in the gable houses. There were also temperature differences between the floors which were more obvious in gable houses. These resulted in the installation of radiators in each gable house to improve comfort. The occupants' main reliance on local heat sources for heating makes them less affected by power outage. The average annual energy consumption of the middle houses was about 62.5 kWh/m^2 which includes 12.8 kWh/m^2 for comfort heating (without the solar panel, the consumption would increase to about 70.8 kWh/m^2-a). The minimum demand was found to be 49.2 kWh/m^2-a whilst the maximum was 101.7 kWh/m^2-a, reflecting the effects of occupants' activities in each house.

1.4.4. CEPHEUS Passive Houses

The CEPHEUS passive houses project aims to construct 250 housing units in five European countries whose energy performances comply with Passive House standards described in Section 1.3.2 (CPHEUS Website, 2008). The project is backed up with scientific evaluation of building operation through systematic measurement programs.

Countries and cities/states involved in this project are Germany (Hannover-Kronsberg and Kassel-Marbachshöhe), Sweden (Göteborg), Austria, France (Rennes Beuregard), and Switzerland (Nebikon/Luzen). General features of the houses constructed under the CEPHEUS projects are listed in Table 1.3.

Table 1.3: General information on the CEPHEUS Passive Houses.

	Hannover-Kronsberg	**Kassel-Marbachshöhe**	**Austria**	**Göteborg**	**Rennes Beuregard**	**Nebikon /Luzen**
Building type	Terrace house 4 in rows	apartment	Housing units – at 10 sites in 4 Austrian states	Terraced units, 4 + 1 rows	Apartment (2, 3, 4, 6 rooms)	Terraced units
No of buildings	32	2 – total 40 units (23 + 17)	116	20 + 6	40	17
Floor area, m^2	81, 108, 130	23 units: 1662+723 17 units: 1253+164	9200	120/unit	2 rooms: 46 3 rooms: 64 4 rooms: 77 6 rooms: 117	12
No. of storeys	1	3	1	1	6	2
Const. Materials	Dividing walls, floor slabs & building service-cum-staircase core: prefabricated concrete elements. Insulating building envelope: prefabricated lightweight timber elements.	Solid construction (lime-sand bricks with 30 cm thermal insulation), reduced thermal bridging through use of insulating 'Purenit' blocks as first course above floor.	Vary greatly. Solid construction in 3 projects, others: mixed construction with solid load-bearing systems and prefabricated timber walls and roof elements.	Timber, lightweight, super-insulated external walls, partition walls and floors. Timber façade with traditional whitewash	Mixed: concrete skeleton, use of local ecologically sound material	Timber, prefabricated elements with insulation

Green systems	Solar collectors. Climate neutral through Euro 1250 share in wind energy facility integrated in house purchase price.	Not specified	Not specified	Solar hot water, 50% solar fraction. Power connection to wind energy facility in Göteborg.	Solar hot water	Subsoil register, controlled ventilation with heat recovery, heat pump
Heating system, ventilation, Appliances	Supplementary heat supply from local district heat system fed by CHP units.	District heating, ventilation system: 3 – 6 units have joint HX, each unit having separate fans with automatic airflow control.	Not specified	High-efficiency HX in ventilation system	Supplementary heat supply from district heating	Each house has its own, separate ventilation and heat supply system.

1.4.5. Australia

Australia has been following a path to sustainable housing through progressively incorporating a larger number of energy-efficient and solar technologies into housing estates. Each step on the path has allowed industry to address a widening range of building performance issues, develop new skills and knowledge, and develop supply chains to provide better-performing materials and systems. Some key examples are the Mawson Lakes housing and land development, the Newington solar village for the 2000 Sydney Olympic Games, and Christie Walk, a sustainable community opened in Adelaide in 2002.

At Mawson Lakes, situated 12 kilometres north of the Adelaide CBD, the South Australian Government and developer Delfin (later Delfin Lend Lease) decided to create a more sustainable suburb through the application of passive and active solar technologies and improved water management. A house design scoresheet, covering all the key energy and water end uses, was developed and applied to homes with an expectation of achieving a 35 per cent energy and greenhouse gas emission saving against similar developments. Although the monitored saving was only around 25 per cent, the use of the scoresheet successfully introduced many passive solar and energy-efficient technologies and practices to the local building industry (Saman and Mudge 2006). A significant lesson learnt from observing energy-use at Mawson Lakes is that overall energy consumption reduction should also be accompanied by a reduction in peak demand, which is linked to air-conditioning use during hot summer conditions.

A significant milestone along the road to sustainable housing in Australia was the construction of the first solar village at Newington for the 2000 Sydney Olympics. Over 600 homes at this development incorporate solar hot water, 4 star designs, and a grey water recycling system for irrigation and toilet flushing. The 1kW peak photovoltaic systems installed on each home were connected to the grid and have provided around 20% of the total energy demand for residents since the Olympics. Although that level of contribution is relatively small per home compared to photovoltaic systems typically installed today, the application of solar and energy-efficient technologies at Newington gave the building industry valuable experience in designing and constructing sustainable homes and is recognised as changing Australia's housing development paradigm (Andersen, Cook and Marceau 2004).

Christie Walk is seen as another significant step on the path to sustainable homes. The medium-density inner-city development in Adelaide integrates passive solar design with low embodied energy materials, solar water heating, community vegetable gardens, black and greywater treatment, and solar photovoltaics to create an ecologically sustainable urban village. Significant annual and peak load energy savings have been achieved.

1.5. Economics of low energy homes

While requiring some additional initial cost, low-energy homes provide several key direct and indirect energy related economic benefits. Firstly, they use much less energy to maintain human thermal comfort, to provide artificial lighting, and to heat water, which provide significant cost savings. Secondly, the excess renewable electricity generated on-site is typically sold at a premium to the local energy market, producing an ongoing revenue stream. Thirdly, the energy required by zero-energy homes at times of climate-related peak energy demand such as heatwaves is significantly less than by the average home, therefore reducing the need for expensive peaking infrastructure and resulting in lower energy costs to the regional economy (Langham et al. 2010).

There are a number of direct and indirect non-energy-related economic benefits associated with low-energy homes, particularly those related to the strong relationship between building thermal comfort and human health (Bi et al. 2011). In addition to providing comfortable environments throughout the year without resorting to mechanical heating/cooling, research has established that thermally comfortable homes can decrease the impacts of extreme weather events, such as heatwaves, on human mortality and morbidity, reducing demand on often overloaded health systems.

With such benefits associated with low energy homes why doesn't the market provide a steady stream of such homes? There are a number of price and non-price barriers preventing efficient market processes (Productivity Commission 2005; Garnaut 2008). Firstly, currently energy is sold below the full environmental and social cost of its supply, thus artificially reducing the attractiveness of energy-efficient homes. Secondly, in most cases house buyers have insufficient information about the likely ongoing energy and cost performance of a home in order to make a decision. And thirdly, organisational or cultural factors have resulted in skills and knowledge gaps in the building and house design industries, reducing the ability of the market to supply higher-performing homes. For these reasons Australian governments have sought to address market failures by establishing financial incentives to make renewable energy more attractive, as well as regulatory standards to eliminate the impact of information barriers, and industry education, and training schemes to improve the ability of the building sector to supply low-energy housing. Other policies could also be applied to address specific barriers - such as putting a price on carbon could reduce price barriers, and mandatory energy performance disclosure could reduce information related barriers.

A research report released by the Victorian Building Commission indicates that a direct cost of complying with 5 star standard for new housing in Victoria including both energy efficiency and water conservation measures is only 2% of the total cost (see Table 1.4).

Table 1.4: Direct cost of compliance with 5 star standard, Victoria (Building Commission Website, 2008)

House Type	Average List price $	Direct cost for 5 star compliance ($)
Single storey house: 100 – 160 m^2	118,000	2840
Single storey house: 160 – 250 m^2	150,000	3450
Single storey house: 250 – 380 m^2	209,000	3950
Double storey house: 250 – 380 m^2	311,000	5910

1.6. People Awareness, Attitude and Behaviour in Relation to Comfort, Energy Use and Energy Performance of Buildings

It is a common knowledge that people awareness, attitude and behaviour affect the way they consume energy in dwellings. The success of any program aiming at reducing or minimising energy use and the consequent greenhouse gas emissions will depend largely on people's attitude and behaviour. For example, a study by Wilhite & Nakagami (1996) as referenced by Isaksson & Karlsson (2006) compared and analysed how occupants at 16 houses in Japan and 18 houses in Norway use energy for space heating. It was found that "*Japanese households tend to heat only the room they usually occupy, while the Norwegian households heat almost every room in the house*".

The UniSA team conducted a survey on attitude and behavior of owners/occupants of the Mawson Lakes housing development as part of the main report on the development, implementation and promotion of a greenhouse rating tool (Saman & Mudge, 2003). The main findings of the survey are as follows. The residents' self assessment of their own understanding of the greenhouse effect and energy conservation issues is moderate. They ranked the environment as the third most serious issues after education and health, and more serious than crime, unemployment and poverty. The majority said that their knowledge of energy conservation information was from media and own personal experience; internet was the least influential (this might have been different had the survey been conducted more recently). Based on the survey, it was also concluded that Mawson Lakes residents have a smaller number of solar hot water systems compared to the overall Australian population. The initial cost of the system was the main cause for this; the significant proportion of residents seemed unaware of the subsidy/rebate schemes offered by the government in this area. Concern over the aesthetic appearance of the house was another reason for some residents deciding not to purchase the system. The situation has changed dramatically at the Mawson Lakes development where solar hot water systems are now mandatory. Differences between attitudes and behaviour were observed by comparing the residents' responses to certain statements and questions in the survey. While the majority of respondents indicated that their decisions to purchase each different type of appliances were influenced by energy-efficiency star ratings, a significant proportion of residents use relatively low energy efficiency appliances.

Occupants behaviour is particularly influenced by information made available in the media and through specific printed and web based resources (e.g. Your Home). The Australian household environmental awareness and actions have improved in the last view years (Ashworth & Gardner, 2006)).

Research carried out by Isaksson & Karlsson (2006) on the Swedish low energy houses found that the main motives of the house owners to purchase these houses were not the ‘low energy profile’ of the houses but the *location* and the *house type* (terraced houses) which “*were good value for money*”. However, most were positive about the low energy performance of the house. Other findings include the occupants’ preferred level of thermal comfort and complaints about low temperatures at certain locations of each house.

Poortinga et al. (2004) investigated the role of values (value dimensions) in the people environmental behaviour in the field of household energy use using the concept of quality of life (QOL). These value dimensions are: *self enhancement*, *environmental quality factor*, *self direction*, *openness to change*, *maturity*, *traditional values* and *achievement*. These value dimensions were regressed against two other variables: the *New Environmental Paradigm* (NEP) as ‘world views’ and the *Concern about global warming* (CGW) as ‘specific beliefs’. The results found that the *environmental quality factor* correlates positively with environmental concern but negatively with the self enhancement value (enjoyment, power and hedonism). On the more practical level, the study found the correlation between the socio-demographic variables (income and household size) with the home and transport energy use.

Ashworth & Gardner (2006) carried out a research to *better understand public perceptions of low emission technologies across New South Wales* and *to explore regional differences that may exist in certain locations*. The research suggests that the public is very much aware of climate change implications to Australia and therefore feel the need to address it. They tend to see the solutions in solar and other renewable energy, although they are also aware of problems currently associated with the resources such as storage, security of supply and affordability. The public also acknowledge the burning of coal in power stations as the main source of greenhouse emissions. They are not, however, very well informed about technologies that make coal less harmful to environment. They are also eager to adjust their behaviour and they would be prepared to pay higher electricity cost for the sake of the environment. For this, they also expect government to lead by example through government buildings and behaviour.

Japan’s Cool Biz initiative, launched on 1 June 2005 demonstrates how a government policy can effectively influence the society’s behaviour in relation to energy use. The initiative aims at reducing energy consumption of office air conditioning by encouraging people to wear thin clothes, no tie and no jackets. As a result, temperature set points of offices have increased to up to 28□C with a significant reduction in energy use for air conditioning. The Cool Biz initiative initially created shocks among the Japanese in terms of change of dressing habits and its social implications, people’s comfort, work productivity, etc.(National Public Radio Website, 2008). The campaign, however, was eventually accepted by the Japanese society. Since 2006, South Korea and UK have set their own ‘Cool Biz’ programs (Wikipedia, 2008).

This overview provides us with a number of interesting insights. First, there seems to be a global awareness of the impact of human activities on the environment. However, the people’s awareness and attitude towards the global concern does not always translate into their behaviour. The evolutionary (gradual/slow) nature of climate change threat to the environment and humanity makes it harder to push for drastic action. Therefore government initiatives are called upon to influence how people act and behave in regards to energy use. This is being achieved in Australia both through financial inducements and regulation.

1.7. Interaction with the Grid

The main feature of intelligent grid over the conventional grid is the infusion of the digital intelligence throughout the grid. This infusion is believed to result in improved method of energy delivery and use (Xcel Energy, 2008). Digital intelligence makes it possible to introduce the grid-friendly appliances with the ability to sense grid stress and reduce their power use to prevent grid emergencies (Zheng, 2007). On the other hand, the interaction between the grid and the distributed energy resources (DER) may results in the reduction of the quality of electrical power at the consumer level – in this case the DER (Bollen & Hager, 2005). The power quality in this case means both voltage and current quality which – in the case of deterioration – may lead to reduction in equipment lifetime or damage to the equipment.

An extensive literature search has not found published information on the impacts of interaction between the DER in a housing development and the grid. However, in order to understand the reasons cited for installation of DER connected with the grid, the results of survey carried out by Poore et al. (2002) are briefly presented. The study surveyed a number of DER plants across the United States and presented 4 case studies of DER plants interconnected with the grid namely: (1) Narrow Coastal Island DER, (2) Magic Valley Foods Cogeneration Plant, (3) Brookfield Zoo Cogeneration and Standby, and (4) Vanderbilt University Power System. The survey noted that the cited reasons for installing DER are: cogeneration, technology demonstration, improved reliability, reduced costs, reduced peak demand, rate structure, price protection, burning of waste product, increased capacity, fuel flexibility, reduced emissions, reduced transmission constraints, market speculation, production of green power and elimination of CFS.

Dwellings' reduced reliance on the grid energy is also anticipated to ease the peak demand problems faced by electricity utility in South Australia and therefore help reduce the need for peaking plants. While in the past heat waves like the one experienced by South Australia in March 2008 and January 2009 often resulted in blackouts as the supply could not cope with the electrical demand. The introduction of distributed generation and particularly solar electricity will in fact ease the peak demand by sending the excess energy to the grid during the peak day time periods.

2. THE LOCHIEL PARK GREEN VILLAGE

2.1. Introduction

The Lochiel Park (LP) green village (http://www.lochielpark.com.au/lochielpark/home.htm, http://www.lochielparkonline.com.au/), located eight kilometres from the Adelaide CBD, is a world-class ecologically sustainable development. The South Australian Government, through the Land Management Corporation, set ambitious ecological targets to be delivered through a comprehensive set of design guidelines. The 106-dwelling development, which comprises 83 detached dwellings and 23 apartments, requires aspiring minimum standards, including high levels of thermal comfort of at least 7.5 stars, solar water heating, photovoltaic electricity generation linked to the size of the dwelling, energy-efficient lighting and appliances, a load management system to control peak demand, energy and water use feedback monitors, rainwater water harvesting, and the recycling of stormwater for toilet flushing.

The sustainable design standards required for Lochiel Park are not only the highest ever set for an Australian housing development, but they give us an insight into the standards required for zero-energy homes. Lochiel Park has also provided the local building industry with an opportunity to upgrade skills and knowledge, to develop supply chains for sustainable products and services, and to communicate new sustainable housing products to the local community.

In the energy area, the Village target is a 66% reduction in energy use and a 74% reduction in consequent greenhouse gas emissions in comparison with the average Adelaide household. The reductions are being achieved through the use of the following features:

- optimising allotment design to maximise benefits from environmental elements
- reducing building energy requirements through passive design (7.5 star rating, minimum)
- specified energy efficient appliances for heating and cooling
- use of renewable energy (1kW photovoltaic system per 100m^2 of living area)
- installing electricity load limiting devices
- special bundled tariff incorporating green power
- smart metering and energy usage display
- solar hot water systems (gas boosted)

Many other innovations will be utilised in specific homes with some being designed as net zero energy homes.

The University of South Australia and many other stakeholders have been contributing to the development of Lochiel Park. UniSA activities include the provision of technical support for the creation of the environmental guidelines, ongoing technical advice and consumer research, and the monitoring of the estate's environmental performance. Detailed monitoring of the energy and water performance of all Lochiel Park homes, and associated behavioural research, will provide a unique opportunity to establish a sound understanding of the actual performance of environmentally sustainable homes, and the interaction between a diverse cross-section of households and various energy use and renewable energy generation systems.

While all homes at Lochiel Park are being monitored for total energy use and renewable energy generation, a small number of houses are also being monitored at a more detailed level, allowing researchers to gain a thorough understanding of where the energy is used, when the energy is used, and how that consumption impacts peak network loads. For these houses, separate monitoring is being carried out for lighting, heating and cooling, water heating, laundry services, refrigeration, cooking equipment, renewable electricity generation, and general plug loads. Monitoring of all homes at Lochiel Park is planned to continue for nine years.

2.2. Targets and features:

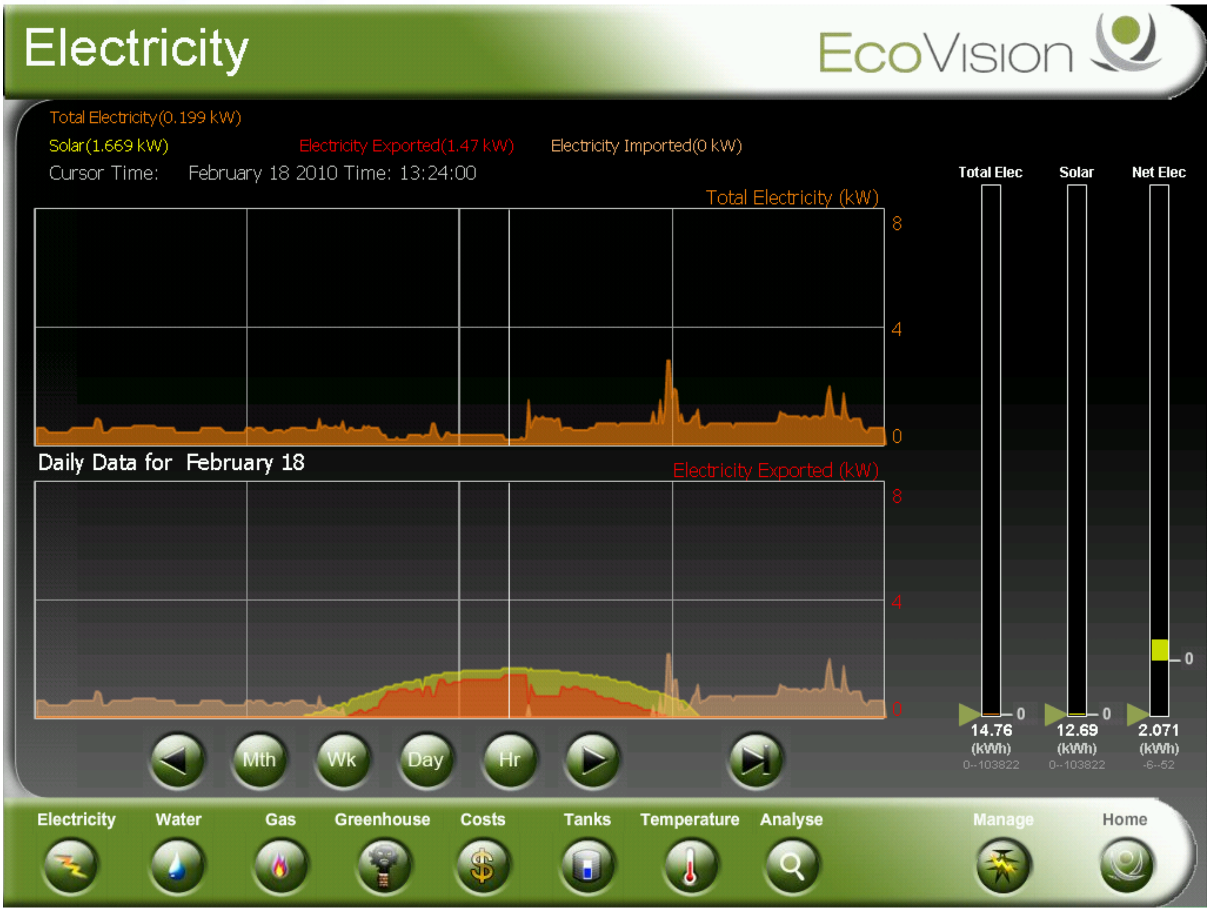
In terms of energy, the Village target is a 66% reduction in overall energy use and a 74% reduction in consequent greenhouse gas emissions, in comparison with the average Adelaide household. These reductions are facilitated through incorporation of numerous sustainable features in all dwellings. These features are described in detail in the 'Urban Design Guidelines' for the development (Land Management Corporation, 2007) and include:

- The use of photovoltaics (e.g. minimum 1kW_p photovoltaic system per 100m^2 of habitable area (Figure 2.1);
- The use of solar hot water systems with a 70% minimum annual solar contribution (Figure 2.1);
- Reduced building operational energy requirements through passive design (e.g. double glazed windows, high degree of insulation, strategically placed thermal mass, optimal shading and ventilation, etc.) to ensure that all houses achieve a minimum NatHERS star rating of 7.5;
- Allotment planning that maximises access to environmental resources (e.g. ensuring that solar access to living areas and northern roof spaces is maximised, see Figure 2.2);
- The use of only highly energy efficient appliances for heating and cooling (e.g. total allowable electrical load for air-conditioners in large houses must be no greater than 4kVA);
- Reduced lighting energy requirements through use of efficient fixtures and maximising access to natural light;
- Exclusion of electric cooktops, unless additional photovoltaic generation is installed, in excess of the aforementioned requirements;
- Smart metering with an in-home display (IHD), allowing householders to access detailed energy and water usage data in a graphical format (Figure 2.3)
- Provision of special bundled tariff incorporating green power;
- The installation of electricity load limiting devices as part of a load management trial.

Figure 2.1: Lochiel Park roof-top, showing water heating and photovoltaic solar collectors.

Figure 2.2: Lochiel Park streetscape, highlighting enhanced solar access and renewable technologies.

Figure 2.3: Screenshot of IHD, showing daily electricity profile.



The aforementioned electricity load management trial was designed to allow residents to lower their electricity demand and reduce their electricity bills. By electing to keep the total household electrical peak load below a certain threshold, participating residents were charged for their electricity under a "capacity-based tariff", which was lower than the standard rate. To assist with this process, a load limiting device was installed in all houses at no cost, with the limit chosen by a resident being easily set on the IHD. Furthermore, householders could choose which appliance circuits are shut down when the load limit is exceeded, and in what sequence. As part of the trial, if the maximum load chosen proved to be too problematic for the household, then the resident could choose to either change the limit or disable the load management system altogether via the IHD.

3. THE ENERGY MONITORING SYSTEMS

This chapter discusses the various in-home monitoring systems. The system details depend on whether the dwelling is a house or an apartment and whether the house is monitored generally or in detail. In addition, this chapter also examines the processes used to collect and prepare data for analysis.

Each of the 106 houses incorporates a touch screen computer and an in-home display, a programmable logic controller (PLC), and an array of intelligent meters and sensors, which comprehensively measure and display general electricity, water and gas usage, in real-time. Furthermore, each property has a fully customisable load management system installed, which allows devices to be deactivated during periods of peak electricity demand. In addition, 9 of the 10 designated houses are subjected to detailed monitoring. Indoor air temperature / relative humidity, individual appliance electricity usage and rain water tank levels are also monitored. A summary of the measured and calculated parameters for both the *general* and *detailed* systems, along with each sensor type, is shown in Table 3.1.

Table 3.1: Measured and calculated* parameters for the general and detailed monitoring systems. Note that (D) indicates digital, whilst (A) represents analogue.

	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	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note that the monitoring system selection was made after several monitoring system options were explored. The EcoVision system was selected as it offers a simple, robust, reliable and cost-effective monitoring system. Despite recent technological advances, hard-wired sensors were selected for this project, as they were deemed simple to install and configure, compared to wireless alternatives. An outline of the EcoVision system is shown on the EcoVision website (EV, 2010).

3.1. Data Logging at General Monitored Houses

An overview of the general monitoring system components is shown below in Figure 3.1. The figure identifies the EcoVision touch screen, the programmable logic controller (PLC), the optical network terminal (ONT), the contactors, the interconnecting cables, and the various digital sensors. A summary of the types and technical details of meters and digital sensors used is listed below in Table 3.2.

Figure 3.1: Overview of general monitoring (2015) system.

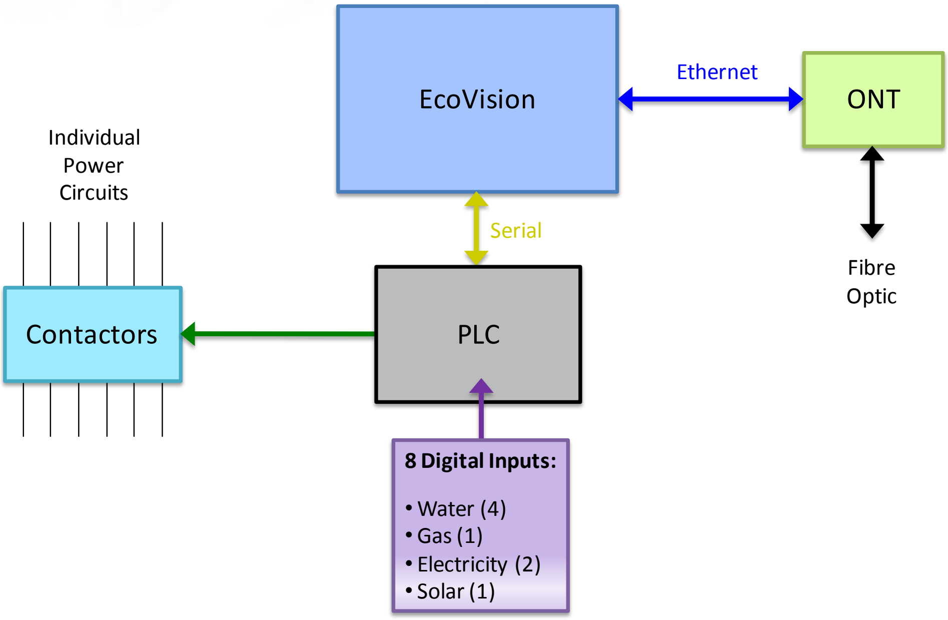


Table 3.2: Summary of digital meters / sensors used by the general monitored houses.

	Meter	Sensor	Sensor Resolution
Water	Actaris, TD8	Actaris, Cyble™	1 L
Gas	Landis + Gyr, Model 750	Elster, IN-Z61	10 L
Electricity	AMPY, EM1200	-	1 Wh
Solar	Actaris, ACE1000 SM0	-	1.25 Wh

The above figure shows that the various sensors are directly connected to the PLC. The PLC communicates back and forth with the EcoVision via a Serial cable, which allows the EcoVision to display and store the measured data. The stored data is transferred from the EcoVision to the Lochiel Park sever via the ONT and the Virtual Private Network (VPN), using Ethernet and Fibre Optic cables, respectively. This arrangement also allows the local weather data, obtained from the Bureau of Meteorology, to be displayed on each system.

3.1.1. Load Management System

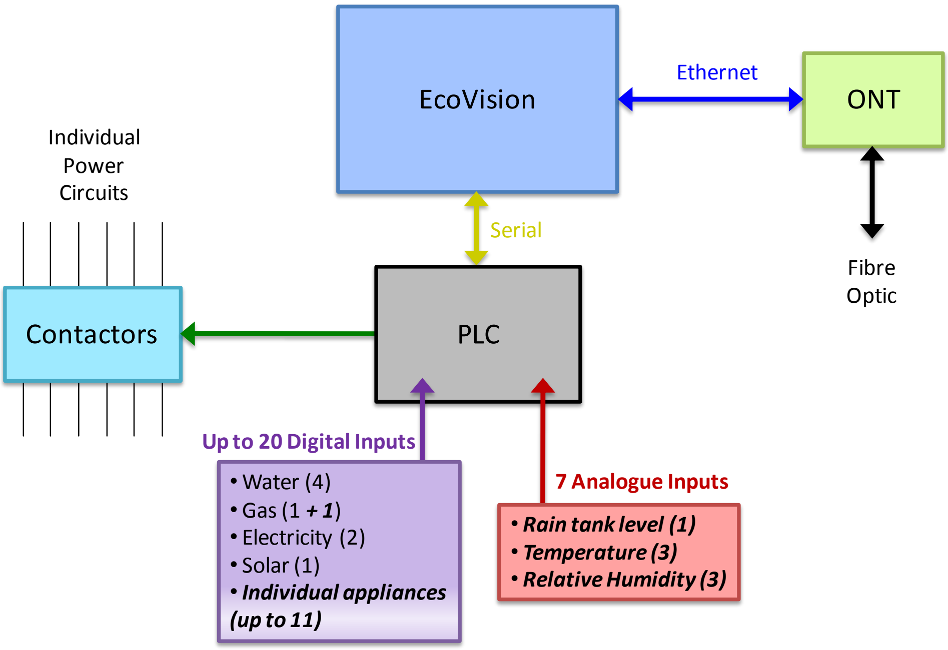
The Load Management system effectively interrupts power to up to 6 individual power circuits or appliances, and is controlled by the EcoVision system and executed by the PLC. Up to 6 contactors (seen in Fig. 2) are installed, which are typically wired in the refrigerated air conditioner, pool / spa pump, laundry, kitchen, oven and dishwasher power circuits. Note that the majority of residents do not have swimming pools or spas installed and have hence customised their load management system such that additional appliances, such as a second oven, second air conditioner, or an induction cooker can be controlled by load management system.

The load management system is activated (if enabled) once the average electricity power usage exceeds a predefined limit of 3, 4 or 5kW. In this case, up to 6 power circuits, which have an adjustable hierarchal order, will have their power interrupted. This effectively shuts down nominated appliances, until the average electricity usage falls below the predefined limit. Once interrupted, power to that circuit / appliance, will not automatically restart due to safety reasons, i.e. the resident must disable the load management system to re-energise any interrupted loads. Note that this feature is completely voluntary, and that in the past one electricity provider offered financial incentives to residents who maintained a 3kW limit at all times.

3.2. Data Logging at Detailed Monitored Houses

An overview of the detailed house monitoring system is shown below in Figure 3.2. The figure again identifies the main components, i.e. the EcoVision touch screen, the PLC, the ONT, the contactors, the interconnecting cables etc. In addition, the figure also shows the additional digital sensors (gas, and individual appliance wattmeters) as well as the additional analogue sensors, i.e. rain water tank level and indoor temperature / relative humidity sensors.

Figure 3.2: Overview of detailed monitoring (3015) system.



A summary of the additional (analogue) sensors used for collecting data for the detailed monitored houses, is listed below in table 3.3. The digital sensors used are identical to those used in the generally monitored houses (as shown in Table 3.2). Note that the temperature / relative humidity sensors are combined in one sensor (shown below), however, each have a separate input channel to the PLC (shown above).

Table 3.3: Summary of the analogue sensors used by the detailed monitored houses.

	Sensor	Sensor Resolution	Accuracy
Rain Tank Level	AQUAMETA, AN420-15	Infinite	± 0.5% (0-50°C)
Temperature / Relative Humidity (Temp. / RH)	KIMO, TH100	Temp.: 0.1°C RH: 0.1% RH	Temp.: ± 0.4°C(0 - 50°C) RH: ± 2.95% (18 - 28°C)

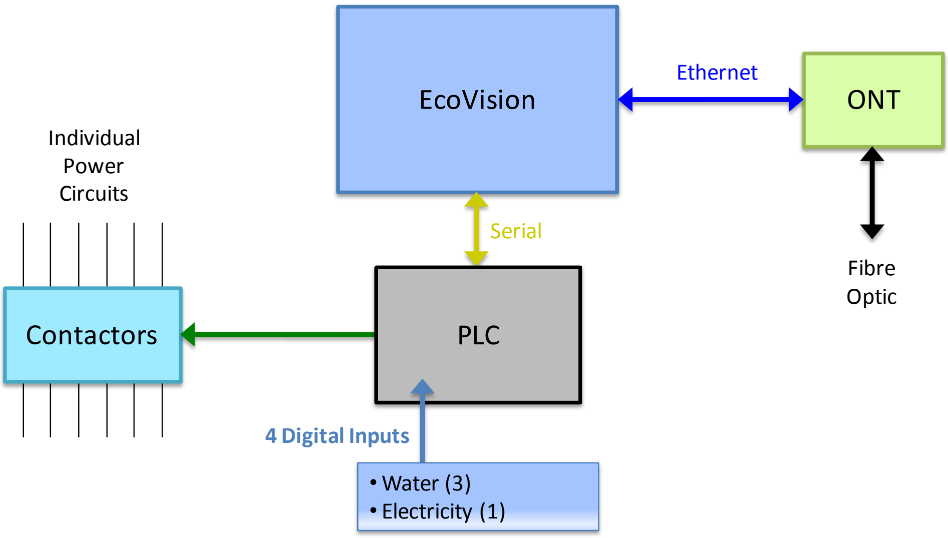
3.3. Data Logging at DFC Apartments

The in-home monitoring systems installed within the 23 Housing SA apartments built by the Department of Families and Communities (DFC) are based on the 2015 EcoVision system, however, these systems are connected to fewer digital sensors. As such, each system is also connected to a common services system, via the Lochiel Park VPN. The individual monitoring and common services monitoring systems are further discussed in sections 3.3.1 and 3.3.2, respectively. As the apartments have only been completed recently, the report does not include any monitoring data from them.

3.3.1. Individual Apartment Monitoring System

An overview of the individual apartment monitoring system is shown below in Figure 3.3, which appears similar to that for the general monitored houses (Figure 3.1). The difference is that only three water meters are installed, these measure i) mains (potable), ii) recycled, and iii) hot water usage. In addition a single-phase wattmeter is used to record electricity imported. Note that due to the lack of three-phase import/export meter and lack of appropriate grid-connected PV system meter (with pulse output), all electricity used within each apartment, appears on its monitoring system as electricity that is imported from the grid.

Figure 3.3: Overview of general apartment monitoring (limited 2015) system.



A summary of the meters / digital sensors used for collecting data for the apartments is listed below in Table 3.4. Note that unlike the water meters installed within the houses, which have a resolution of 1L, the water meters installed in the apartments have a resolution of 10L. It is also worth noting that room temperature and humidity as well as air conditioning energy use have been added to the list of monitored parameters in order to evaluate thermal comfort in 10 of the apartments.

Table 3.4: Summary of digital meters / sensors used by the DFC apartments.

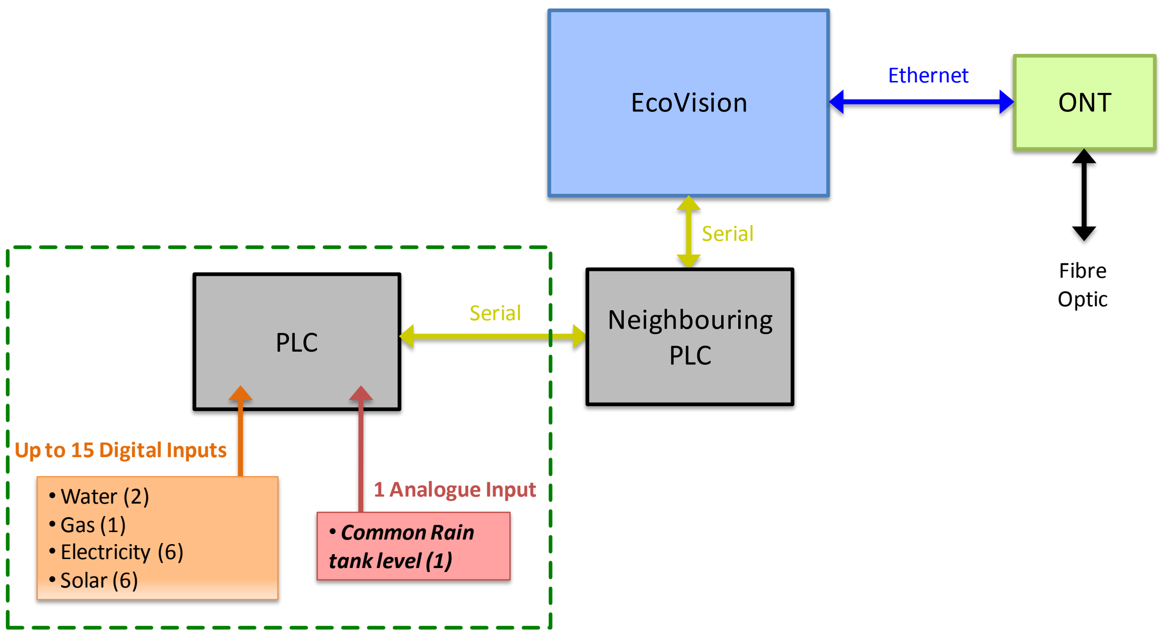
	Meter	Sensor	Sensor Resolution
Water	Watts Multi-Jet	-	10 L
Electricity	Itron, ACE2000 type 292	-	1 Wh

3.3.2. Common Services Monitoring System

The common services monitoring system details had not yet been finalised at the time of writing this report, however, the details provided here are identical to those discussed at various meetings held between EcoVision, the apartment builder and UniSA.

An overview of the common services monitoring system is shown below in Figure 3.4. This monitoring system records the apartment complex's total mains and recycled water usage, the total gas usage, the rain water tank level, the energy generated by the six PV systems and the total electricity imported/exported. The figure shows that a separate PLC is used to collate the data from up to 15 digital meters and one analogue meter. The data recorded from this system is transmitted via serial cable to a neighbouring PLC which then transmits the data to the Lochiel Park sever, via the Lochiel Park VPN using the fibre optic connection.

Figure 3.4: Overview of proposed common services monitoring (3010) system.



A summary of the meters / digital sensors used for collecting common services data for the DFC apartments is listed below in Table 3.5. The common service water and gas meters shown, differ to those seen in the houses and apartments as these measure the total water and gas volume for the entire apartment complex. The solar wattmeters also differ from those used within the houses, as these were sourced by the apartment builder. Note that the common services rain water tank level sensor is that used for the detailed monitored houses (see table 3.3)

Table 3.5: Summary of digital meters / sensors used by the common services monitoring system of the DFC apartments.

	Meter	Sensor	Sensor Resolution
Water	TBC	TBC	TBC
Gas	TBC	TBC	TBC
Electricity	Itron, ACE2000 type 292	-	1 Wh
Solar	Latronics, Static Single Phase One Module DIN rail Watt-hour meter	-	1 Wh

At the time of writing this report, it is believed that the common services data will be used in the following manner:

- The total energy generated by the six separate installed PV systems, will be divided by the number of apartments, (i.e. 23), and this amount will be equally displayed on each apartment's screen,
- The total electrical energy exported, will be calculated from the total energy generated by the combined PV systems and the total electrical energy imported. It is unclear how this will be displayed on each individual screen,
- Individual apartment gas readings will be based on the amount of hot water used within an apartment, at a rate of 1kL is equivalent to 1000MJ of heat energy (determined by Strata Water Solutions),
- Individual apartments will be able to see a percentage of how much rain water is stored in the underground rain water tanks.

3.4. Network Level Monitoring

Previous technical reports mentioned that network / distribution level monitoring of potable and recycled water, gas and electricity usage, would take place at appropriate subdivision meters. To date, however, these monitoring systems have not been implemented. Discussions with ETSA utilities have recently resumed with the view of initiating transformer level monitoring.

3.5. Data Collection, Preparation and Processing

3.5.1. Data Collection

Each EcoVision records data and stores it locally. The Lochiel Park server downloads updated information from each EcoVision system each night such that the information stored on the server is up to date; this data is separated by month and by lot number. The comma separated variable (CSV) files are retrieved by UniSA using a remote desktop connection.

Monthly data files are generally ready for collection, filtering and processing on the second day of each month. This process involves download data remotely and running a series of data management macros on each file. The macros are run to highlight and format / present data, search for missing data entries, and to calculate total and average values etc. The summary of each monthly household data, i.e. water usage, total electricity, PV generation etc. is then combined to a single summary file. This file essentially compares many data sets for each house and allows comparisons of each lot to be easily made. The charts seen in Chapter 4 are created from this summary file.

Although running the required macros is a simple, yet repetitive task, it is one that is time consuming, i.e. it takes approximately 6 hours to collect, process and format monthly CSV files for about 30 houses. This process is made more complicated and is hence more time consuming if data entries are missing. Missing data entries are unavoidable and these must be added to the processed data, as many macros that calculate totals / summaries rely on full monthly data sets.

3.5.2. Causes of Missing Data

The largest cause of missing data is power outages / black outs, followed by service provider or even resident interference. Throughout 2010, there were four blackouts. These were easily detected from missing data for each monitoring system that was functional during the month of the power outage event. In the early cases (first batch of 20 screens), the EcoVision systems would return to their previous state following a black out, i.e. if they were operating at the time the blackout occurred, they would boot up and resume monitoring once the power was restored. This setting, however, was not set for the second or third batch of screens, and as such each time a black out occurred, the EcoVision system of many houses had to be turned on manually. This was often done by vigilant residents, however, many residents were not aware of the procedure to activate their monitoring system and some of these were not confident to attempt restoring power themselves. In a few cases, some residents did not notice that their screen was not operating as it was not common practice for them to interact with their screens.

The return to previous state issue was not discovered until April 2011. It was found that a BIOS setting was incorrectly set leaving the suppliers. A solution was made available, however, this was not ideal, as it could only be done manually and involved connecting a USB keyboard to a concealed USB port, behind the screen itself. As such, gaining access to certain properties proved to be difficult, due to resident’s work / family commitments. In addition, connecting a USB keyboard also proved to be difficult as this sometimes required removing the EcoVision from the wall mount / bracket. To date, about 60% of the affected EcoVision systems have had their BIOS settings updated such that they will return to an ON state following a blackout. The settings of the remaining affected screens will be corrected in the near future.

In three cases, the fibre connecting ONT settings were modified, which terminated the link between the ONT and the central server, by service providers when connecting auxiliary services. In two of the three cases, residents EcoVision systems became disconnected from the Lochiel Park virtual private network once their home internet services were activated. These faults often take longer to correct as service providers are often unaware that they have adjusted an ONT setting that affects the EcoVision system.

There has been one case, where a resident deliberately switched off their monitoring system, as the EcoVision Ethernet connection LED was visible behind the system. The resident noticed this at night, and thought that this was a standby load and was thought to be wasting power.

3.5.3. Data Validation

Through analysing the monitoring data, it has been suspected that not all of the detailed monitored results were providing the required readings, i.e. the dishwasher power circuit may include other electrical appliances, and the refrigerator is not separately monitored. As such a wattmeter audit was performed to verify the validity of the detailed monitored collected data. The results are discussed in section 3.6.

3.6. Detailed Monitored Houses Wattmeter Audit

3.6.1. Summary of Individual Appliance / Power Circuit Audit

On the basis of individual dwelling audits, Table 3.6 below summarises how each of the major appliances, of the detailed monitored houses, were connected to the monitoring system (PLC input channels). Similarly, Table 3.7 shows how each of the power circuits, e.g. living room, general, lights etc. was wired in each of these houses.

Table 3.6 Summary of individual appliance metering in detailed monitored houses

Lot		EcoVision / PLC				
		Dishwasher	**Oven**	**Spa/Pool Pumps**	**Fridge**	**Air Conditioner**
L2OZ	**Actual**	n/a	Oven	-	-	Air Conditioning
L3TS		Dishwasher	Oven	-	-	D/S Air Conditioner
L1TS		Dishwasher **& Kitchen Island**	Oven	-	-	Air Conditioning
L4FO		Dishwasher	Oven	-	-	Air Conditioning
L6FS		Dishwasher **& Kitchen Island**	Oven/ Grill	-	-	Air Conditioning
L5SZ		-	-	-	-	-
L26ST		Dishwasher **& Microwave**	Oven	-	Fridge **ONLY (1/2)**	Kitchen Air Conditioner **ONLY (1/5)**
L22SS		Dishwasher	Oven	Induction Hot Plate	-	Air Conditioner & Heat Pump
L23SS		Dishwasher	Oven	-		Air Conditioning

Table 3.7 Summary of power circuit metering in detailed monitored houses.

Lot		EcoVision / PLC					
		Bedroom Power	Lights 2 (lights of ....)	Living Room Power	Kitchen Power	Lights 1 (lights of ....)	Laundry
L2OZ	Actual	-	Entrance, Lounge Room, Laundry, Garage & Upstairs	Entrance, Laundry, Lounge Room, U/S Landing, Bedrooms, Bathrooms & Ensuite	-	-	-
L3TS	Actual	Bedrooms, Family Room, Fridge, Kitchen, Microwave, Outside & Bathrooms	Bathroom Ceiling Heaters & Fans	Dining Room, Front Entrance, Garage, Laundry, Lounge Room, Outdoor Rain Pump	-	D/S & Ceiling Fans	-
L1TS	Actual	-	Study, Living Room, Garage, Laundry & Upstairs	Bedrooms, Ensuite, Outside, Study, U/S Bathroom	Garage, Living Room, Outside	Kitchen & Garage	Pantry and Kitchen
L4FO	Actual	-	Kitchen, Dining Room & Study	Dining & Lounge Room, Entrance, Shed, Kitchen, Laundry, Outside, Study, Bedrooms, Ensuite & Bathrooms	-	Laundry, Lounge Room, Staircase, U/S & Fans	-
L6FS	Actual	U/S Bedrooms, Garage, Laundry, Top of Stairs & Bathroom	-	Ensuite, Front Room, Kitchen, Living Room (Northern Wall), Master Bedroom, Microwave, Outside	Fridge, Living Room (Southern Wall) & Toilet	-	-
L5SZ	Actual	-	-	Bathroom, Kitchen, Living Room, Outside	-	Downstairs	-
L26ST	Actual	Ensuite, Bedrooms, Studio & Landing	U/S Lights & Fans	-	-	Kitchen, Garage, Laundry, Lounge & Toilet	Laundry
L22SS	Actual	Bedrooms, Garage, Laundry, U/S Bathroom, Rumpus Room & Study	D/S Bathroom, Living Room & Master Bedroom	Living Room (NW Corner), D/S Bedroom, Outside, U/S Bathroom	D/S Bathroom, Kitchen, Living Room	Study, Rumpus Room & D/S Bedrooms	-
L23SS	Actual	Outside, Bedrooms , Ensuite, Study, U/S Bathroom	D/S Bedrooms	-	-	Kitchen & Living Area	Laundry

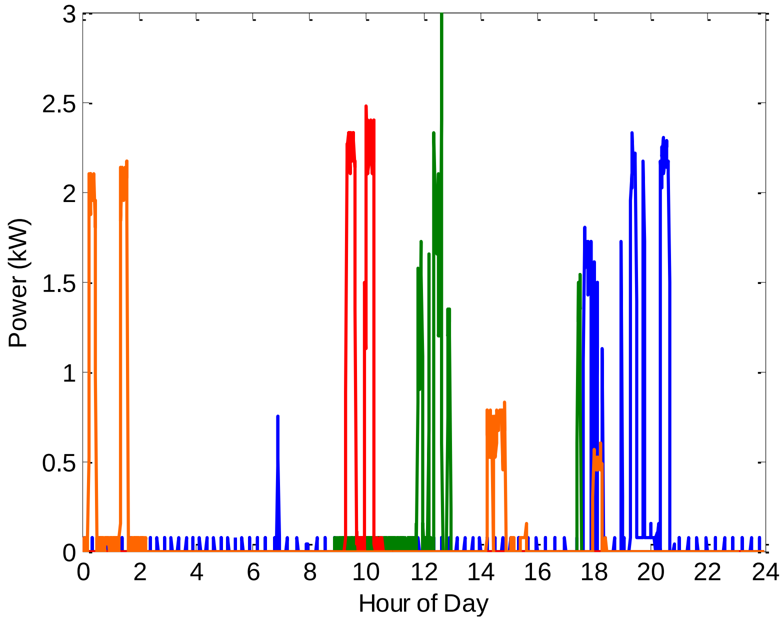
Table 3.6 shows that the major / individual appliance wattmeters are generally wired correctly to the PLC, with the exception of the air conditioner of one house, and the dishwasher in three houses. The wattmeter that measures the air conditioner energy / power usage of lot L26ST, measures only the energy consumed by one of the five multi-head outlets and one of the two compressors. As such the measured data is only a fraction of the house's total heating and cooling load.

In contrast the dishwasher wattmeter of lots L1TS, L6FS and L26ST, measures not only the dishwasher energy usage, but also additional appliances that are connected to power point outlets in close proximity to the dishwasher. In each of these three houses, the dishwasher exists in a kitchen island, and these power outlets are wired on the same electrical circuit as the dishwasher. These outlets are used by common household appliances, e.g. oven, toaster, in lots L1TS and L6FS, whilst the dishwasher wattmeter of lot L26ST also measures the energy consumed by the microwave. This is further discussed in the following section.

3.6.2. Example of Data Correction - Dishwasher Energy Usage

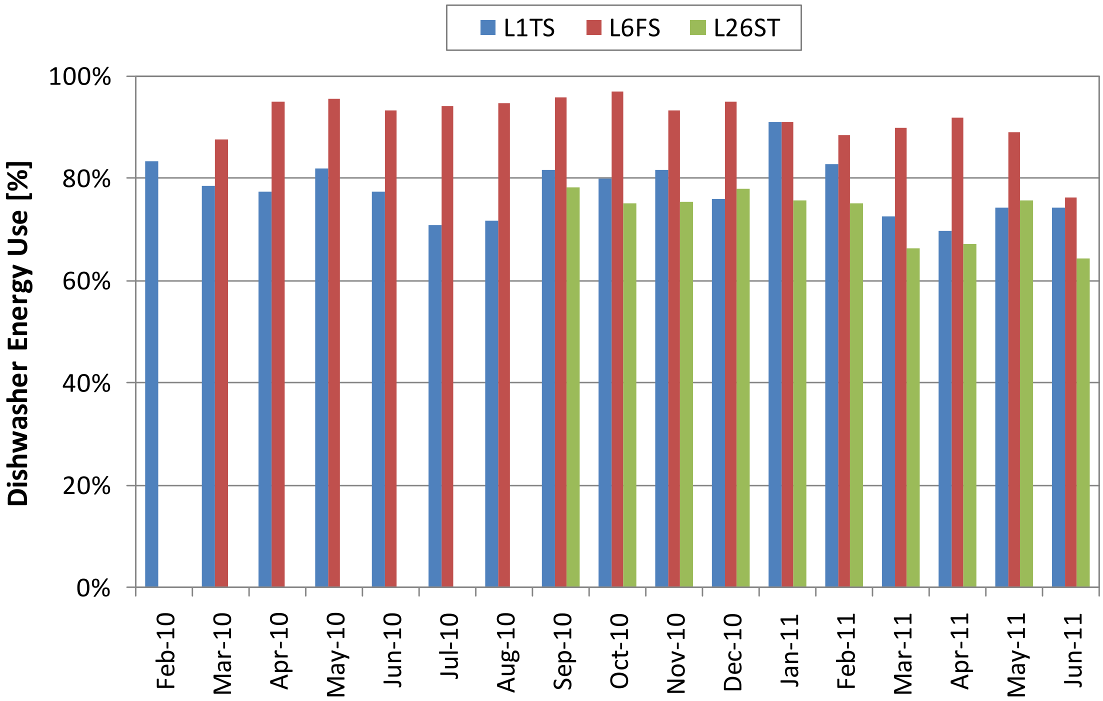
Figure 3.5 compares daily dishwasher load profiles of a house with only a dishwasher measured, i.e. lot L22SS (red), with the measured profiles of the three houses that measure additional appliances. The dishwasher load profile, as seen by the red curve, is shown as two peaks of 2kW+ with little usage between the peaks. This characteristic is found in all other curves, along with the power usage of other appliances, including standby power.

Figure 3.5 Daily dishwasher power profiles of lots L1TS (orange), L26ST (blue), L22SS (red), and L6FS.The power profile of L22SS (red) is that of a dishwasher.



The dishwasher load profile is clearly shown above for each house, with the additional power consumed by various appliances, including standby loads. This additional data is hence subtracted from the monthly data files to accurately gauge the dishwasher energy consumption. A summary of the energy used by the dishwasher (alone) is shown below in Figure 3.6. Note that this is expressed as a percentage of the recorded data and the actual energy usage (kWh) is used for total energy consumption, as shown in chapter 4 (data analysis).

Figure 3.6 Monthly dishwasher energy usage of the total dishwasher circuit energy usage.



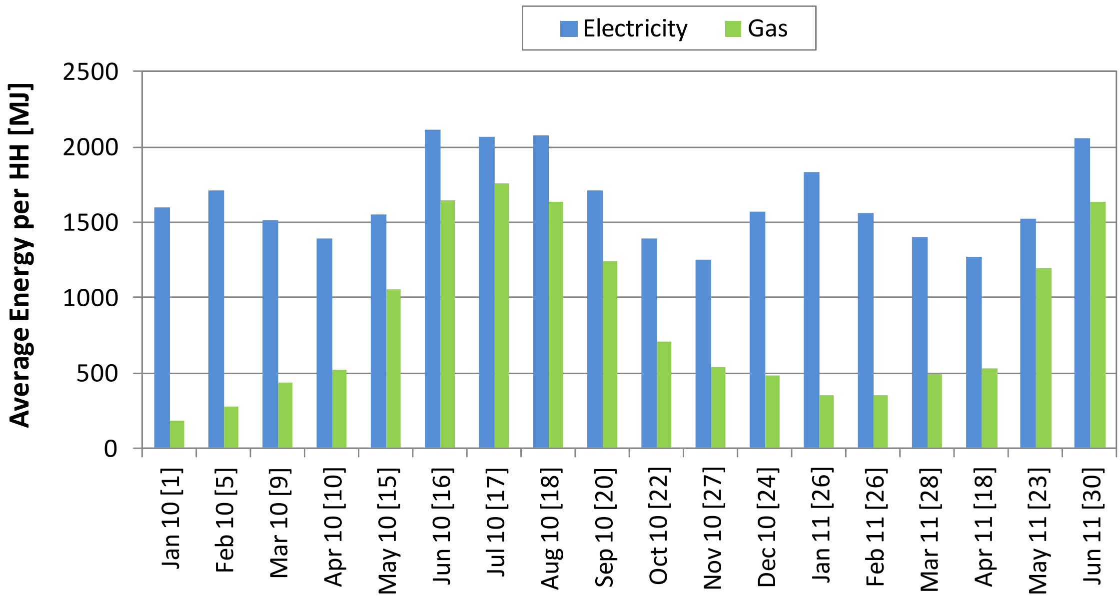
4. ANALYSIS OF MONITORING DATA

The results shown in this section are shown as averages unless otherwise specified. The square brackets shown in the x-axis label of the figures indicates the number of houses, which the average is based on. This number has increased with time as more houses were occupied.

4.1. Total Energy Consumption

The average monthly total energy consumption per Lochiel Park household (HH), i.e. the gas and electricity consumption, is shown below in Figure 4.1. The figure clearly shows the seasonal effects of gas consumption, i.e. minimal use during the summer months (as used only for cooking and supplementary water heating), whilst the peak usage occurs during the winter months. This peak consumption is mainly caused by i) smaller solar gain (shorter days, less sunlight etc.), of the gas-boosted solar hot water heater systems and hence the need for more gas boosting, and ii) the use of gas space heating; the latter occurs only in a small minority of houses.

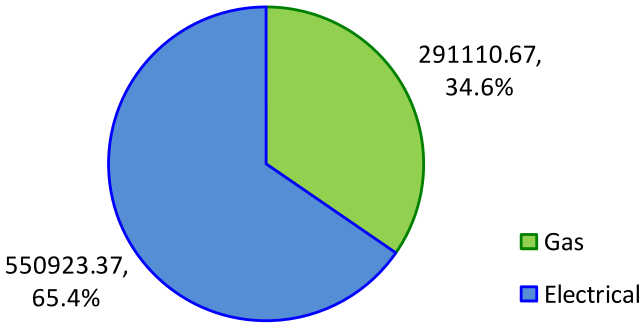
Figure 4.1: Average monitored monthly total (gas + electrical) energy used per household (HH) per month. The chart indicates energy amounts by fuel type.



The above figure also shows the variation of electricity consumption by month and hence season. The seasonal electricity consumption is somewhat more consistent per month than the corresponding gas consumption. This is due to somewhat consistent average electrical loads throughout each month. An increase of between 30% and 40% during the summer and winter months, respectively, was noted which corresponds to electrical cooling and heating loads. The figure indicates that the peak Lochiel Park electricity consumption usage occurs during the winter months, which is consistent for South Australia (SA). Note that of the houses monitored, each house uses electric air conditioners / evaporative coolers for cooling, whilst the majority of these also use reverse-cycle air conditioners (RCAC) for heating.

A breakdown of total energy consumption, by fuel type, is shown in Figure 4.2. This figure indicates that approximately 35% of all energy consumed within Lochiel Park was consumed by gas appliances, whilst the remaining 65% total energy was consumed by electrical devices. Note that i) gas fuel is a primary energy source, whilst electricity is a secondary source of energy, and that ii) of the electrical energy consumed, a significant portion of this is generated locally by the roof-mounted photovoltaic (PV) systems. More information regarding PV contribution is shown in Figure 4.9 (see section 4.2).

Figure 4.2: Breakdown of accumulative total energy used at Lochiel Park. Note that the values shown for each fuel type have units MJ.



4.2. Photovoltaic Systems and Solar Energy Generation

4.2.1. Summary of Photovoltaic Systems

Figure 4.3 - Figure 4.5 summarise the major characteristics of the installed PV systems within Lochiel Park, specifically showing the number of systems installed by peak power rating, inclination angle and azimuth angle, respectively. Figure 4.3 indicates that the majority of PV systems are sized between 2.0 and 2.4kW$_p$, due to the minimum requirement of 1kW$_p$/100m^2 of conditioned floor area. Note that a small number of houses have larger peak rated PV systems, as these houses have larger electrical loads, e.g. electric hot-plate or solar-boosted hot water system, and the increase in PV sizing should offset the additional electrical energy consumption by these additional electrical appliances.

Figure 4.3: Summary of peak rated power of the installed photovoltaic (PV) systems.

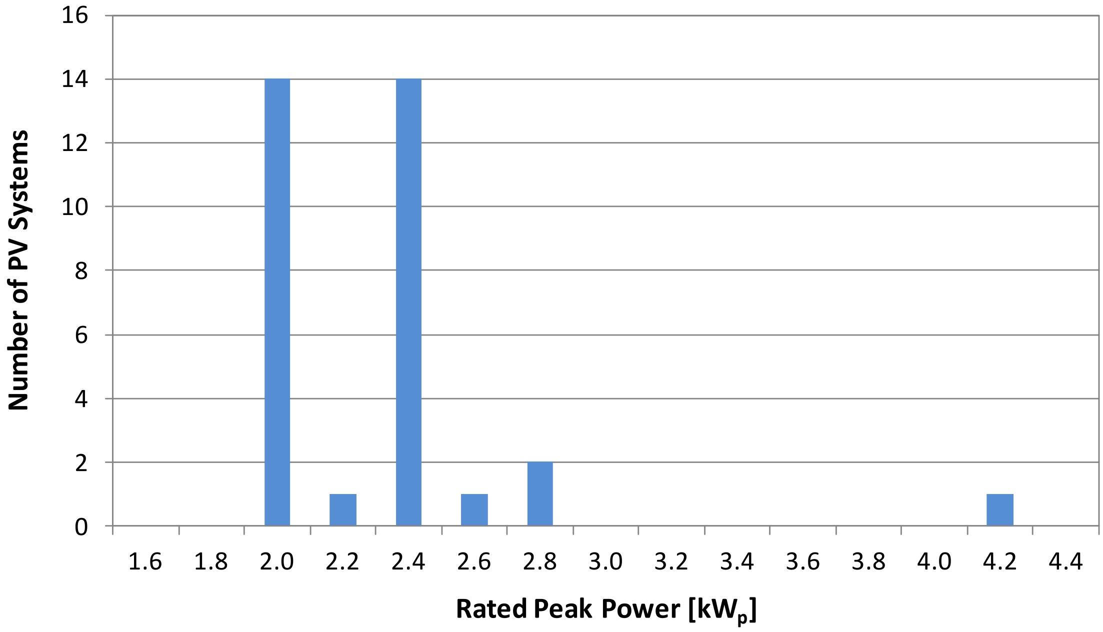


Figure 4.4 shows that the majority of houses have their PV systems installed with an inclination angle of between 15 and 45° to the horizontal, which is within the generally recommended range of latitude ± 20°; the Lochiel Park latitude is approximately 35° South. Note that inclination angles equal to the latitude offer good year-round performance, whilst angles less than the latitude, as seen by the majority installed at Lochiel Park, offer improved summer performance.

Figure 4.4: Summary of inclination angles of installed PV systems (0° represents the horizon).

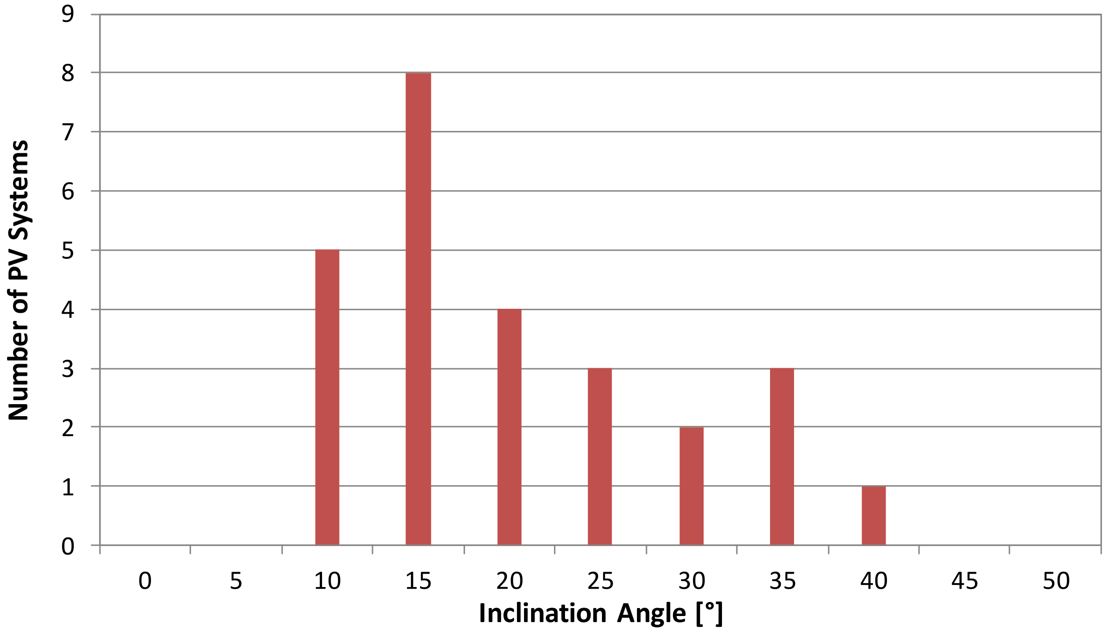


Figure 4.5 shows the azimuth angles of the installed PV systems, i.e. their orientation relative to solar North (0°). The figure indicates that the majority of PV systems have panels facing North to Northwest, which should allow the system to perform marginally better in the mid-late afternoon compared to a system that is facing directly North or Northeast.

Figure 4.5: Summary of azimuth angles of resident’s PV systems (0° represents solar North).

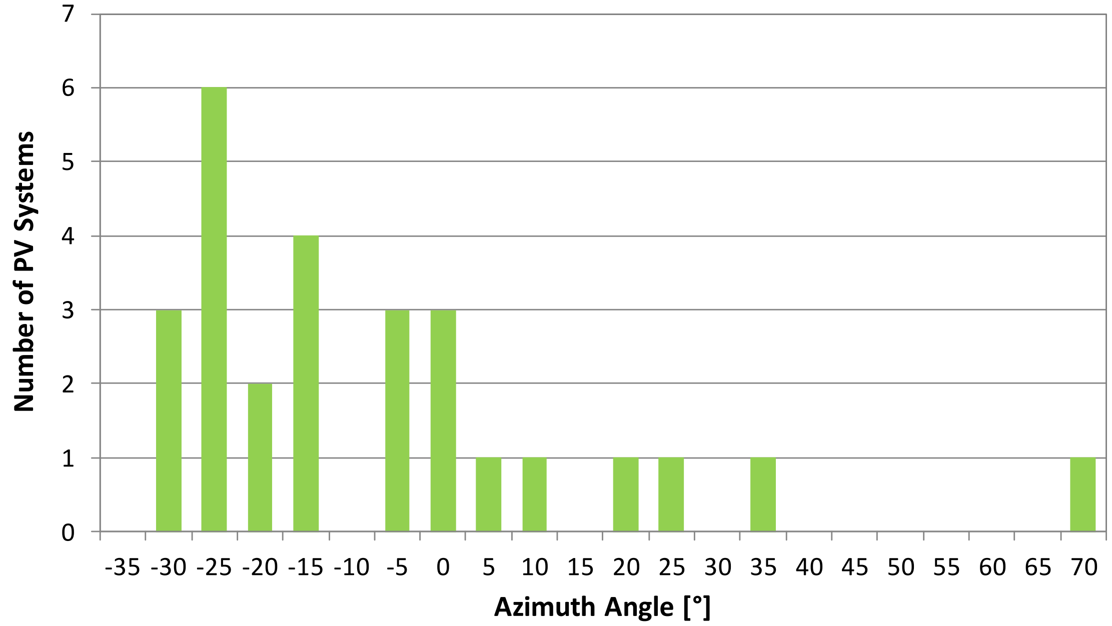
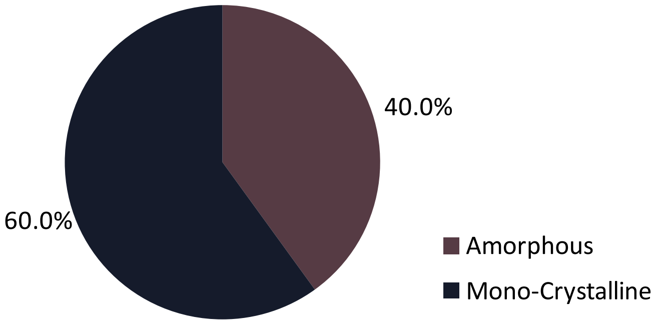


Figure 4.6 summarises the types of panels installed within the Lochiel Park development, i.e. 40% of all systems use the amorphous cell type, whilst the remaining 60% use crystalline structures. Note that amorphous cells are more shade and heat tolerant and cheaper than their crystalline counterparts, and, however, these are less efficient (per unit area).

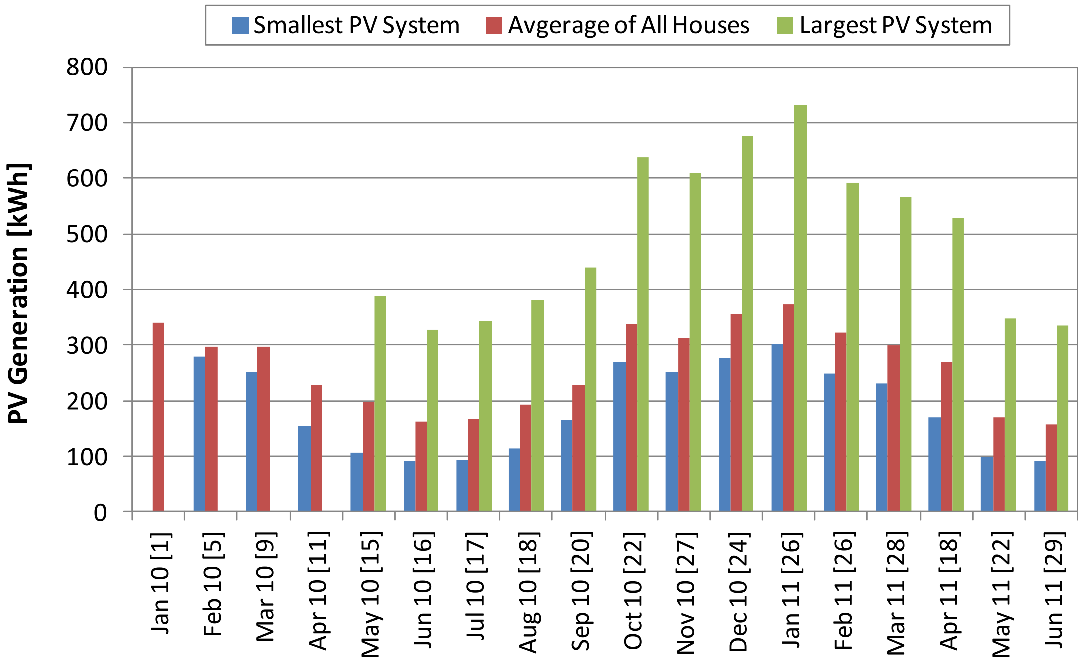
Figure 4.6: Breakdown of PV cell technology installed at Lochiel Park.



4.2.2. Solar Energy Generation

Figure 4.7 below summaries the monthly average solar energy generation per household, as well as the smallest and largest amounts generated by the installed systems per month. The figure shows that the average solar energy generated per month is slightly higher that of the smallest system, whilst the largest system consistently generates between 90 and 95% more energy than the average system per month. This is expected as the largest system has a peak power rating of 4.2kW$_p$, compared to the development wide average of 2.2kW$_p$ (see Figure 4.3). Note that the ratio of largest to smallest solar energy per month (not shown), varies month by month, which not only reflects the peak rated power ratio, but also the influence of the inclination and azimuth angles.

Figure 4.7: Measured monthly solar (PV) energy generated, showing the energy produced by house with the smallest and largest installed systems, and the average of all houses.



The above figure also clearly shows the seasonal effects, i.e. the PV systems generate far more energy during the summer months compared with the winter months. This is due to a number of factors, including: higher intensity beam irradiation, more sunshine hours (due to the Sun's path that it takes across the sky), smaller difference between beam radiation and solar panel inclination angle (peak performance occurs when beam radiation is perpendicular to the panel surface).

The effect, and hence impact of the solar energy generation is clearly seen in Figure 4.8 below, which shows the monthly average consumed electrical, solar and net energy per household. The figure shows that the average monthly consumed electrical energy is about 460kWh, of which only 195kWh is imported from the grid (net electricity). The solar systems effectively have a combined average saving of 265kWh per month, which represents an average reduction of grid bought (net) electrical energy of 57%. This is verified in Figure 4.9, which shows the total electrical energy during the monitoring period, and the quantity supplied by local solar systems and imported from the grid.

Figure 4.8: Measured average electrical energy i) consumed, ii) generated, iii) provided by the grid (Net) per household (HH) per month.

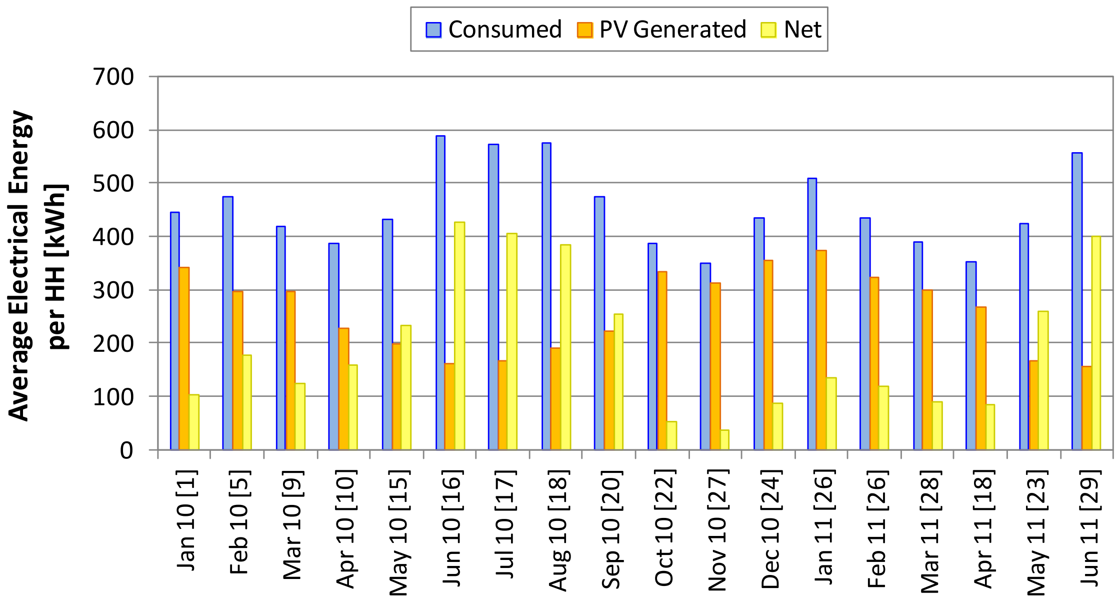
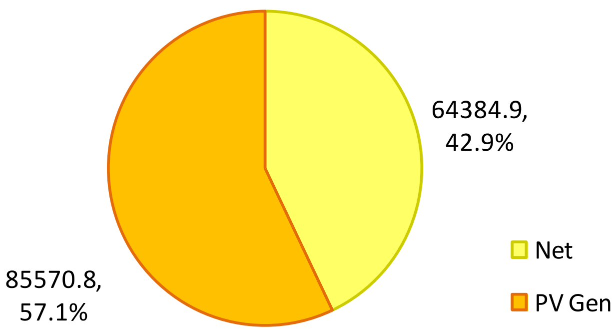


Figure 4.9: Percentage of total electrical energy used at Lochiel Park, i) generated by the PV systems (PV Gen), and ii) that supplied by the grid (Net). Note that the values shown have units of kWh.



4.2.3. Net Electrical Energy

The net electricity, of Figure 4.8 above, is the difference between the consumed and solar generated electricity. This amount of energy is also equal to the difference of the electrical energy imported and that exported from the grid. This is summarised in Figure 4.10, which shows average electrical energy imported, exported and the net energy per household. This figure shows the seasonal effects on the imported, exported and hence the net energy. Recalling Figure 4.8, which shows that the average Lochiel Park electricity consumption is highest during the winter months and combining with reduced solar energy generation; this accounts for a reduction in energy exported to the grid. Consequently, the amount of energy imported from the grid increases during these cooler winter months. In contrast, the amount of energy exported is somewhat constant during the warmer months, i.e. between October 2010 and February 2011 despite the average amounts of solar and imported energy fluctuating; the latter is mainly caused by fluctuating air conditioner usage. Perhaps the key aspect of the above figure is that the average net energy per household is lowest during the months of October and November 2010. During these months, a total of 17.9MWh was consumed within the Lochiel Park houses, of which only 12.1% (2.16MWh) was relied upon from the grid.

Figure 4.10: Measured average electrical energy i) imported, ii) exported and iii) provided by the grid (Net) per household (HH) per month.

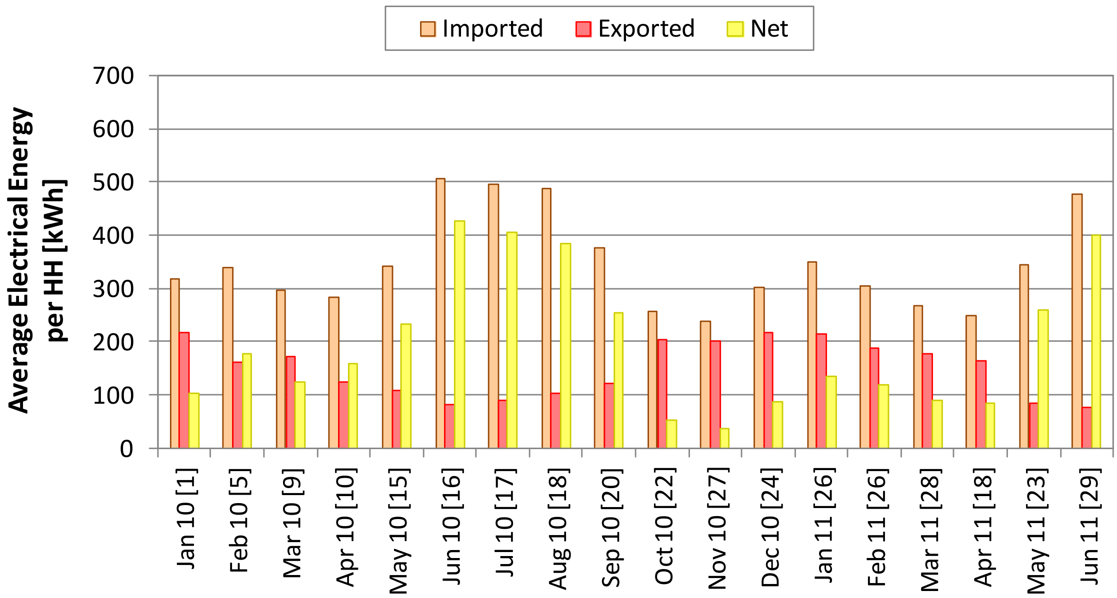
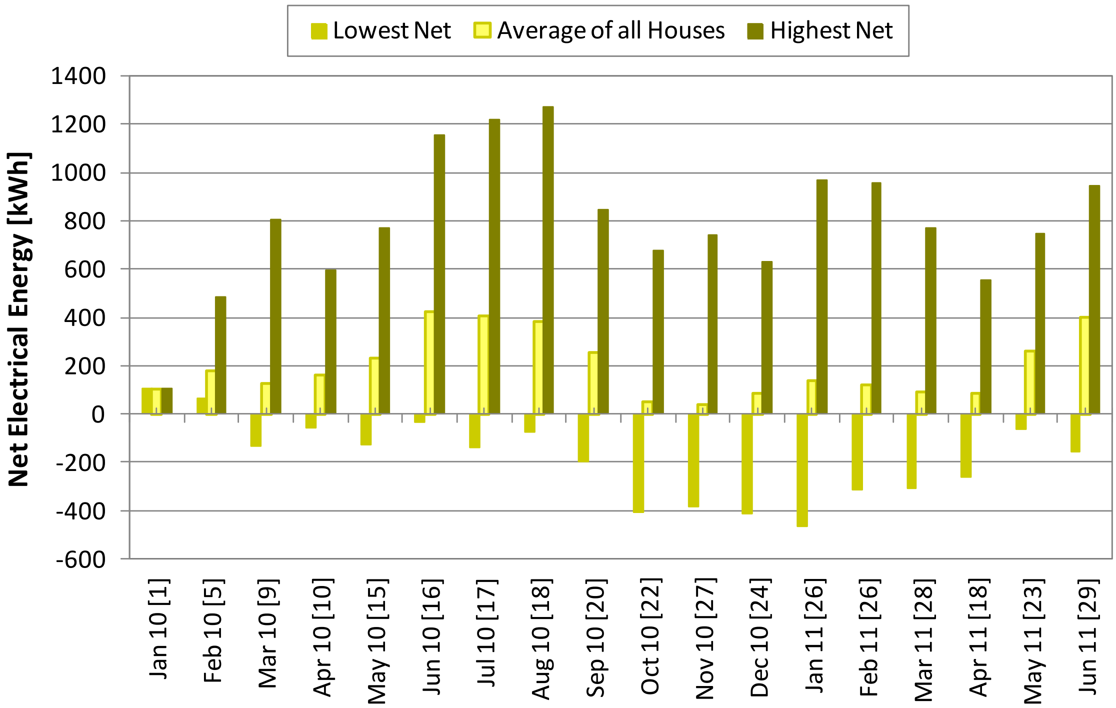


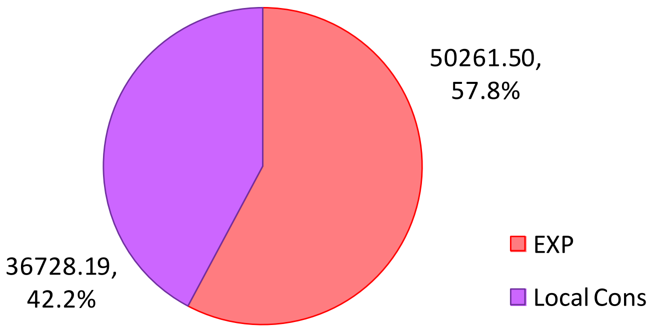
Figure 4.11 below summarises the average net electrical energy consumption per household, as well as both the smallest and highest monthly net electrical energy consumptions for the duration of the monitoring period. Note that the averages shown in the figure correspond to the averages seen in Figure 4.8 and Figure 4.10. From May 2010 onwards, the highest monthly net electrical energy is drawn by one specific house. Similarly, during the aforementioned period, the lowest monthly net electrical energy corresponds to another specific house. Note that the smallest net electrical energy is negative throughout the monitoring period, which indicates that this particular house consistently generates more electrical energy than it consumes. Not surprisingly, this house has the largest peak rated PV system installed.

Figure 4.11: Measured average, lowest and highest net electricity per household.



A summary of where the instantaneous usage of the generated solar electrical energy is shown in Figure 4.12. The figure indicates that approximately 42% of the total solar energy generated was consumed locally, i.e. within the houses at Lochiel Park, whilst the remaining approximate 58% was exported to the grid and was sold by the household as per the South Australian net feed in tariff ($0.44/kWh).

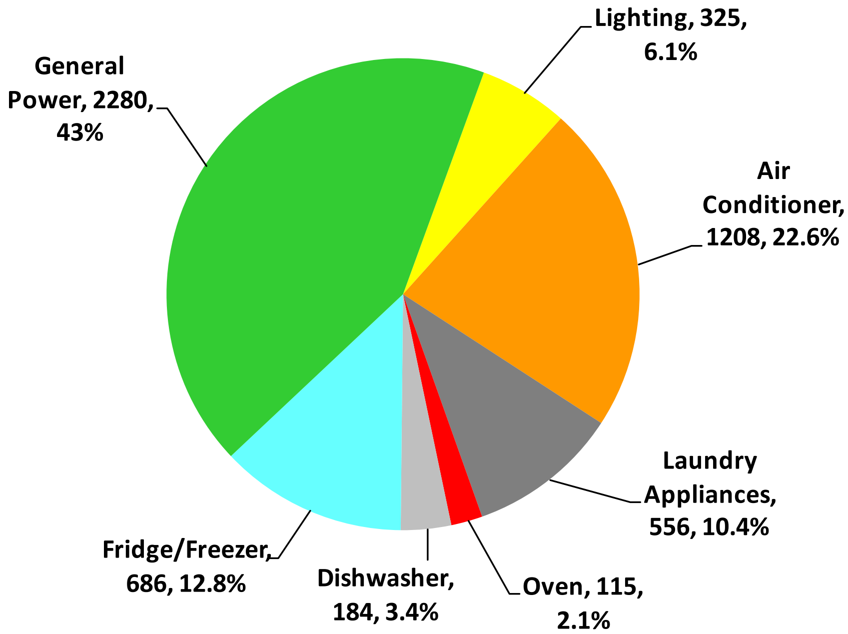
Figure 4.12: Summary of where the total measured solar energy, was consumed, i.e. locally (Local Cons) or exported (EXP) to the grid. Note that the values shown have units kWh.



4.3. Energy Consumption Breakdown by Appliance

A breakdown of annual electrical energy consumption by appliance type at the detailed monitored Lochiel Park households is shown below in Figure 4.13. Note that the figure shows only the major appliances and or power circuits that have been audited and verified as correct following a wattmeter audit of the detailed houses (see section 3.6). The figure shows that air conditioning makes up less than one quarter of all electrical appliance consumption, whilst kitchen appliances, such as dishwasher, oven and refrigerators/ freezers, make up nearly 20%. Laundry and lighting appliances account for about 10% and 6% energy consumption, respectively, whilst 43% is attributed to general power loads. Note that ceiling fans of all houses, and bathroom heaters of houses that have these installed, are connected to lighting circuits, as this is the current common electrical practice.

Figure 4.13: Breakdown of annual electrical appliance energy usage for the detailed monitored LP houses. Note that the values shown have units of kWh.



The above figure indicates that a large portion of the electrical load is accounted for by general appliances, which includes vacuum cleaners, irons, entertainment systems (e.g. widescreen televisions, home-theatres etc.), personal computing, general standby loads and in some cases small office/home-office equipment. This general energy usage portion is somewhat higher than previously reported data. This is not only due to the reduced demand on energy for hot water and heating and cooling which traditionally make up more than half of the energy use, but also due to the recent trend of increased ownership of electrical appliances, particularly televisions and IT equipment (Petchey 2010). Petchey reports that between 1989-90 and 2007-08, household energy consumption of space cooling and standby power, grew annually by 8 and 16%, respectively. Based on observation of various residents' appliances, it is likely that the standby power load has increased at Lochiel Park, however, the space cooling load is unlikely to have increased, as the strict guidelines are enforced, which permit only the installation of highly energy efficient reverse-cycle air conditioners.

Petchey (2010) also reports that the energy consumption of household appliances has grown 28% and 7%, for IT equipment and televisions, respectively. The increase of the former has been observed at Lochiel Park, with every household owning a desktop or laptop personal computer, and at least two specific households having five or more computers / servers, along with home-office equipment, e.g. printers, operating at any one time. The increase in television energy consumption is driven by the trend to purchase larger televisions screens and newer technologies (Petchey 2010), which has also been observed in the majority of residents' houses. The most popular current technologies, plasma and LCD screens, consume more energy than the cathode ray tube televisions, which were predominantly used until the mid 2000's. Surprisingly, a lower energy high definition television, based on LED technologies, has not been seen to date inside any residents' house.

4.4. Greenhouse Gas Emissions

4.4.1. Emission Coefficients by Fuel Type

The greenhouse gas emission of Lochiel Park houses is calculated from net electricity and gas energy consumption. The relevant greenhouse gas emission coefficients used in these calculations are obtained from the Department of Climate Change and Energy Efficiency (DCCEE09, DCCEE10), and are summarised in Table 4.1. Note that the coefficient for net electricity is the summation of scope 2 and scope 3 coefficients, whilst that for gas is the summation of direct and scope 3 coefficients.

Table 4.1: South Australian greenhouse gas emission coefficients for gas and electricity.

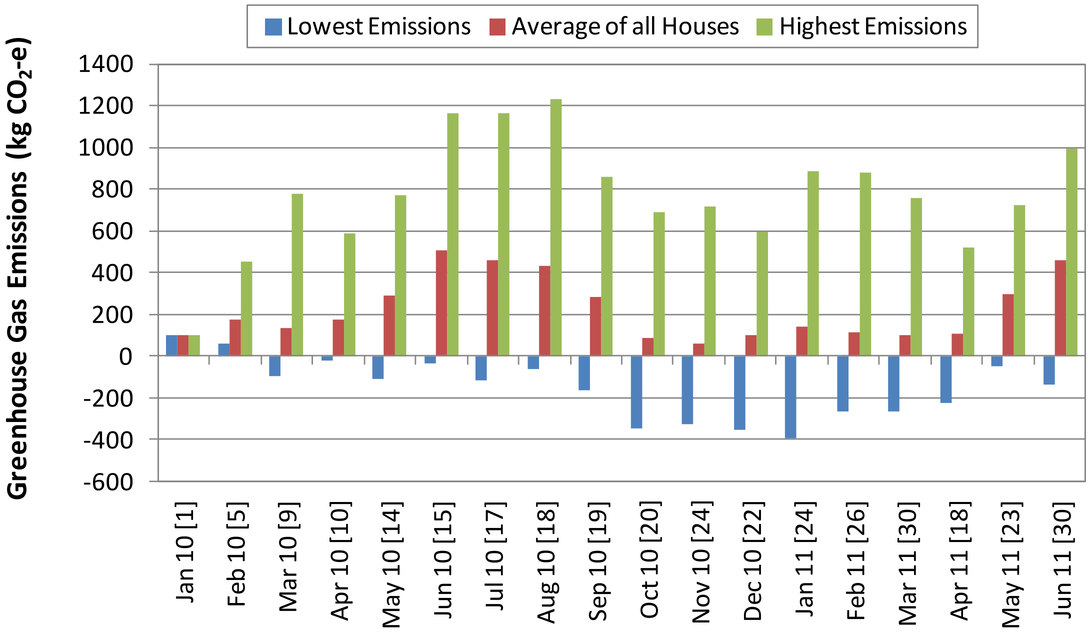
Fuel	2009-2010	2010-2011
Electricity (kg CO_2-e/kWh)	0.92	0.85
Gas (kg CO_2-e/m^3)	2.564	2.426

It should also be noted that the greenhouse gas emission coefficients used by EcoVision are static, i.e. they are not updated each year. Their electricity coefficient matches that for SA for 2009, whilst their coefficient for gas consumption does not match any of the values from the above table. As such, it is the belief of UniSA staff that the greenhouse gas emissions displayed on EcoVision screens (seen by residents) is incorrect. For the purposes of greenhouse gas emission analysis, the coefficients from the above table are used.

4.4.2. Operational Emission Analysis

The average monthly greenhouse gas emission per Lochiel Park household is shown in Figure 4.14, along with the houses that contribute the lowest and highest emissions. The peak average emissions are highest in the winter months, due to higher usage of gas for hot water heating and in some cases, space heating, but predominantly due to increased net electrical energy consumption. The latter occurs as electrical loads increase in winter, and PV systems generate (and hence export) less energy.

Figure 4.14 Measured monthly greenhouse gas (GHG) emissions for the houses that produce the lowest and highest emissions, and the average for each house within the development.

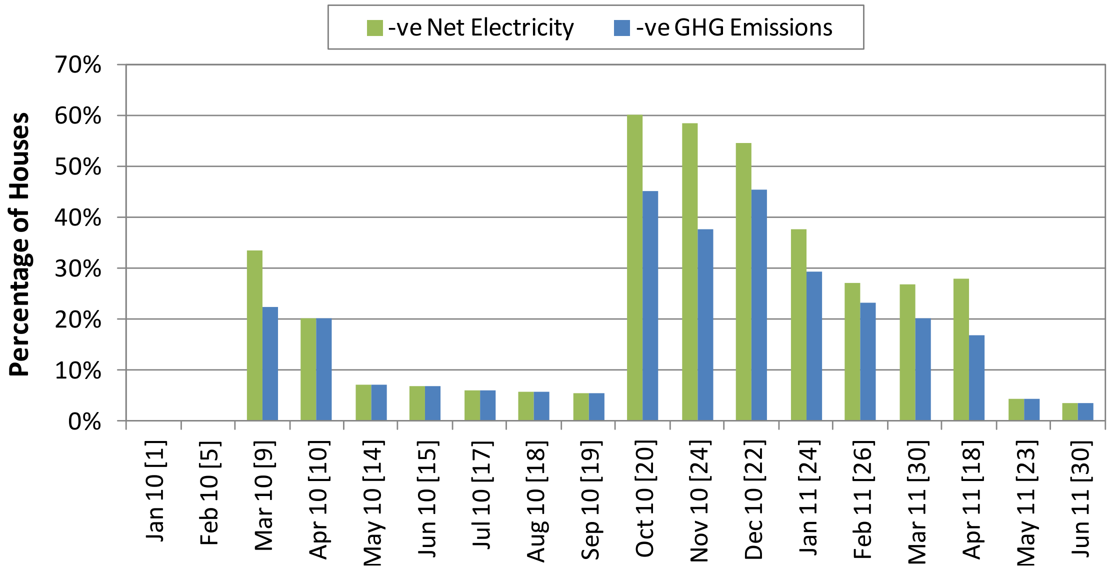


The above figure is similar to that showing average, highest and lowest net electrical energy per month (Figure 4.11). This is not surprising as the greenhouse gas emissions are calculated from gas and net electrical energy; where net electricity is the main contributor. As seen in Figure 4.11, from May 2010 onwards, the same specific house contributes to the highest monthly emissions, and that another specific house contributes to the lowest monthly emissions.

It should be noted that the house that emits the lowest greenhouse gas emissions has had negative emissions since they have moved in. This implies that their house has zero operational emissions and is net zero carbon. This has achieved this by i) using less electrical energy than the average Lochiel Park resident, and ii) avoiding a gas connection. Note that the lack of gas connection has forced the residents to use an electric-boosted solar hot water heater system, which is permitted as their PV system peak rating was significantly increased beyond the required 1kW/100m^2 conditioned floor area. This house has the largest rated peak PV system, i.e. 4.2kW$_p$.

Figure 4.15 shows the percentage of houses that generate more solar electricity than they consume within that month, and similarly the portion of houses that have zero operational emissions, i.e. they generate more solar energy than total energy (gas + electricity) they use in a month. The figure shows an impressive 55-60% of house produce more electrical energy than they consume, between October and December 2010, whilst during the same period, 38-46% of the Lochiel Park houses have zero operational emissions. This trend decreases after December, as the days become gradually shorter and usage of air conditioners generally increases during January and February (as these are statistically the hottest months in Adelaide).

Figure 4.15 Proportion of Lochiel Park houses that generated more solar energy than i) electricity consumed (-ve Net Electricity), and ii) total energy, gas + electricity consumed (-ve GHG Emissions).



Note that the above figure shows that there is at least one house per month that generates more solar energy than it total energy it consumes; this is the electric only house that has the largest peak rated PV system.

4.5. Solar Hot Water Systems

Through analysing the detailed monitoring data of solar hot water systems in Lochiel Park, it was possible to investigate the details and evaluate the energy consumption of these hot water systems. The Lochiel Park Environmental Guidelines mandate the use of natural gas for auxiliary water heating. The hot water usage profile is based on monitoring results for 27 systems while the energy consumption results are taken from 10 systems. Six of the 10 monitored systems were of the storage type, whilst the remaining four systems were instantaneous gas boosted. All six storage systems (system A) were identical, whilst the four instantaneous units (system B) were identical; Table 4.2 provides the details of the systems. More details of the hot water analysis and monitoring are shown in Saman et al., 2011.

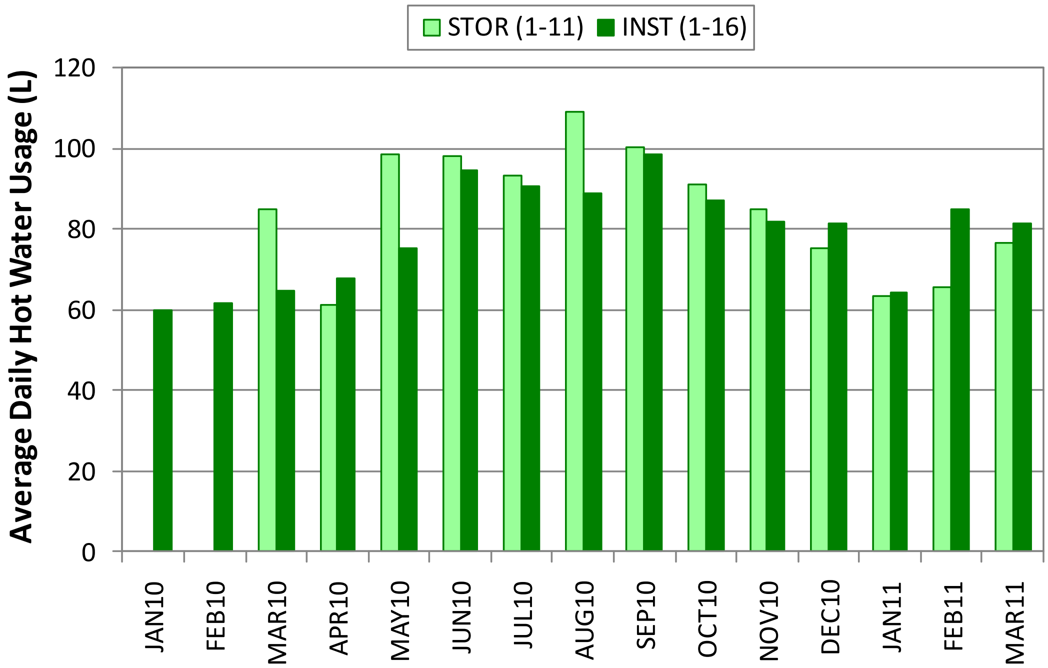
Table 4.2: Technical details of solar water heating systems considered under this study.

System	A (storage)	B (inst)	Units
Tank volume (physical not delivery)	260	259	L
Booster capacity (maximum gas input)	26	199	MJ/hr
Thermostat set temperature	60	65	°C
Type of collector			
η_o =	71.03	73.2	%
a_1 =	451.85	309.6	W/(m^{2}K)
a_2 =	4.7304	2.458	W/(m^{2}K^2)
Collector area	1.86	1.82	m^2
Number of collectors	2	2	

4.5.1. Average Hot Water Usage Profiles

The average daily hot water usage profile as delivered by the hot water system is shown in Figure 4.16. The figure separates the usage by the type of hot water system used. The figure shows that residents use approximately the same amount of hot water on a daily basis, regardless of which type of hot water system is installed in the house. As expected, the chart also shows that more hot water is used per day in the winter months.

Figure 4.16: Average daily hot water usage profile comparison of storage and instantaneous systems.



Note the legend indicates the range of number of houses that are used to calculate the average hot water usage over the 15 month period. The early months (JAN-MAR10) had the fewest number of houses, whilst the average shown for the latter months (JAN-MAR11) is based on the most number of houses.

The hot water load profiles are further examined by type. In addition, the impact of the number of residents living within the houses is examined. The hot water load profile for the storage systems is shown in Figure 4.17, and that for the instantaneous systems is shown in figure 4.18.

Note that both figures also show the ORER reference load profile used for estimating the amount of conventional energy saved. For the installed systems, Figure 4.17 shows that the houses using the storage system have between one and four occupants, and plots their associated daily average hot water load profile. The figure shows that the single monitored house with one occupant uses slightly less than those with two occupants (2-7 houses), as expected. The figure also shows that the one or two houses monitored with three occupants require, on average, less hot water load than those houses with two occupants, whilst the two houses with four occupants require significantly larger hot water loads than both the houses with two occupants and their demand profile is closest to the ORER model profile. The sample size in this study is too small to enable meaningful conclusions on the occupants' impact on the load profile.

Figure 4.17: Daily average hot water load profile for storage systems based on the number of residents within a house, showing the calculated profile, based on measured Lochiel Park data and that assumed by ORER.

Note the number within the brackets indicates the range of number of houses used to calculate the average value over the 15 month period shown. PPHH represents the number of people per household.

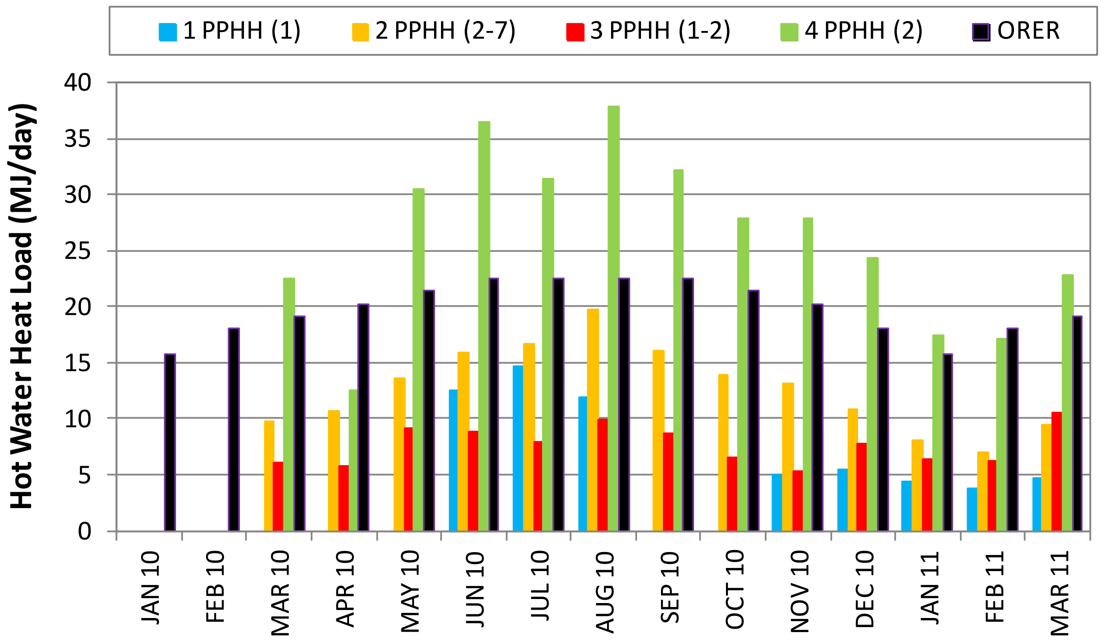
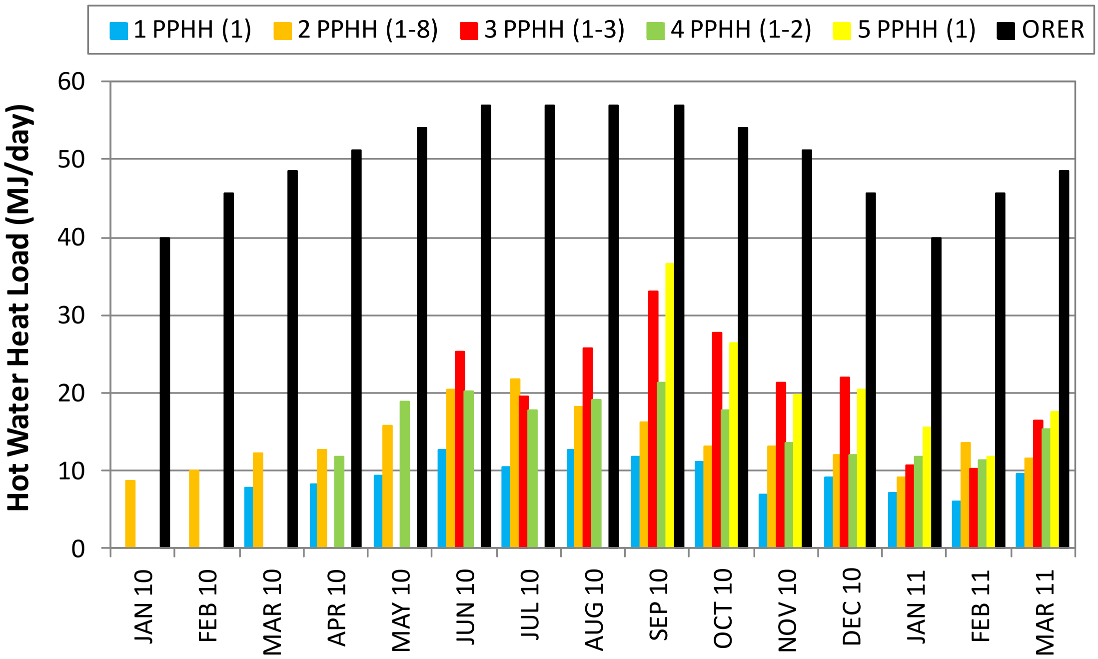


Figure 4.18: Daily average hot water load profile for instantaneous systems based on the number of residents within a house, showing the calculated profile, based on measured Lochiel Park data and that assumed by ORER.

Note the number within the brackets indicates the range of number of houses used to calculate the average value over the 15 month period shown.



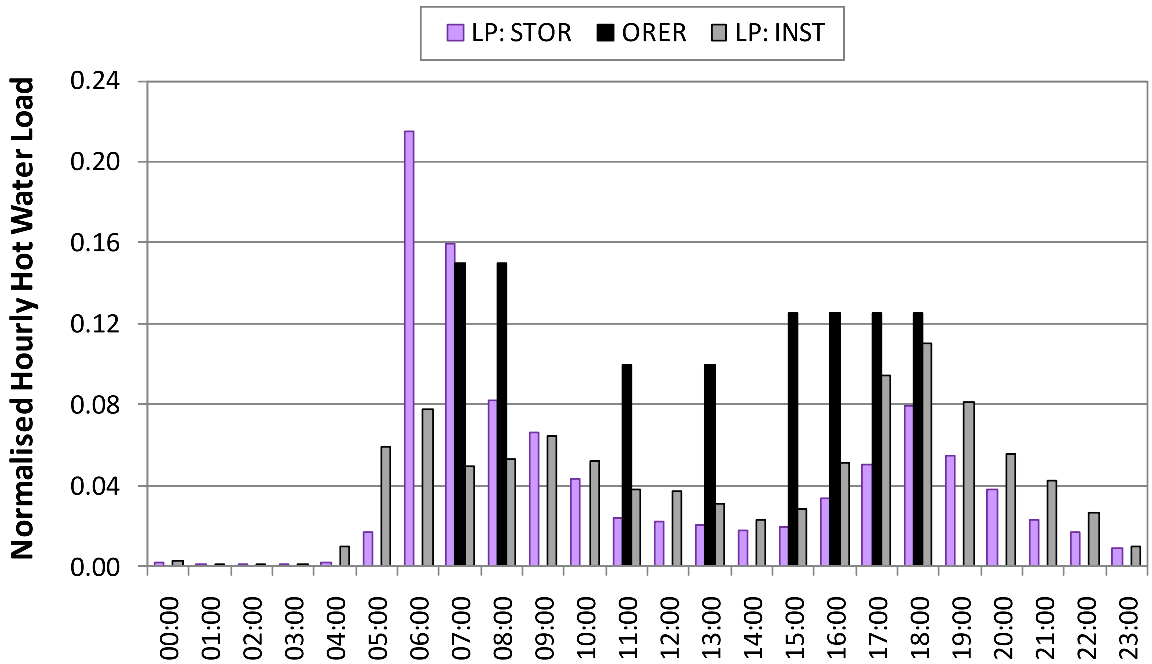
Now consider figure 4.18, which shows the heat load requirement of houses with instantaneous systems. Despite the general trend which shows that the heat load requirement increases with the number of occupants, the load requirements of even the largest households generally falls well short of that used as the reference load by ORER. Although the trend shows that the heat load requirement increases with the number of occupants, this is not found in the houses with four occupants. The small sample size confirms the inability to draw concrete conclusions linking the number of occupants to loads in this study.

Figure 4.18

4.5.2. *Average Hourly Hot Water Load Profiles*

In addition to calculating the Lochiel Park average daily hot water load profile, the average hourly load profile is also calculated to facilitate a comparison with the profile used in the ORER evaluation. The hourly profile is normalised to its total load throughout the monitoring period. The normalised hourly profile for both the storage and instantaneous systems is shown in Figure 4.19 along with the values assumed in the ORER calculation procedure.

Figure 4.19: Normalised hourly average hot water load profile for both the storage and instantaneous systems based, and the ORER profile. Note that i) each data set is normalised to its total usage, and ii) LP, STOR, and INST are acronyms for Lochiel Park, storage and instantaneous systems, respectively.



The above figure shows that the ORER hourly profile differs from both the storage and instantaneous hourly profiles which extend beyond 7.00am to 7.00pm as assumed in the ORER profile. The above profiles indicate that the residents with storage systems have a higher hot water load during the morning, whilst those residents with instantaneous systems have higher hot water loads during the afternoon and early evening. The results are based on monitoring up to 11 storage systems and 16 instantaneous systems. The number of systems steadily increased from 2 as more and more residents occupied their houses during the monitoring period.

On comparing the ORER daily load profiles with 27 systems being monitored at Lochiel Park, SA, the results have demonstrated that the small load profile assumption is realistic for the storage systems investigated. However, the assumption of large system with peak of 57MJ/day for instantaneous systems was unjustified as the measured load profile resembled that of a small system having a peak load of 22.5MJ/day for zone 3. Note that the load profile study is based on a limited number of systems and measured hot water usage data as used by residents. The behaviour/attitude of these residents may not be representative of those who live in other climate regions of Australia.

4.5.3. Monitoring results: Instantaneous System

The solar / gas water heater gas consumption is calculated from the minute by minute gas and hot water usage data. The gas consumption during this (minute) period is divided by the volume of hot water used in the same time frame to determine a ratio of gas to hot water consumed (L/L). Note that analysis of total gas usage and hot water data indicates that while boosting typically uses 10-20L of gas per minute.

Figure 4.20 below shows the average gas usage per unit hot water usage (L/L) for each month for each of the houses fitted with instantaneous gas boosted solar hot water systems. It is clearly seen that more gas per litre of hot water is consumed during the winter months than the summer months. This is due to a smaller solar contribution, and higher consumption of hot water during this period. The figure also shows that houses which consume higher quantities of hot water also have higher average gas usage per hot water usage readings, i.e. house B-TE uses more hot water than house B-FS. This is clearly seen in figure 4.21 which shows the actual gas consumed by the instantaneous water heaters per household, using the method described above. Note that house B-SZ appears to use less gas for hot water heating than house B-TE during the winter months; however, it attracts higher average gas per hot water usage figures. This is most likely accounted for by the almost continuous usage of a gas space heater in the living room, i.e. some of the hot water gas consumption data may include gas usage consumed by the space heater. This uncertainty can be eliminated in the future by installing and monitoring a second gas meter solely for the hot water system.

Figure 4.20: Average gas usage (L) per hot water usage (L), per month, for the instantaneous systems.

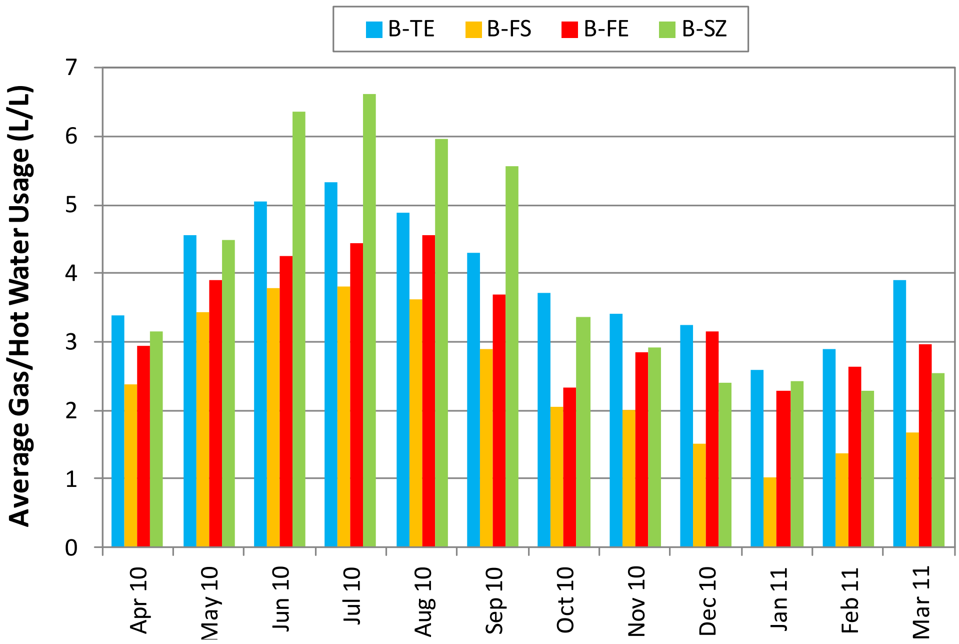


Figure 4.21: Gas consumed by instantaneous hot water systems.

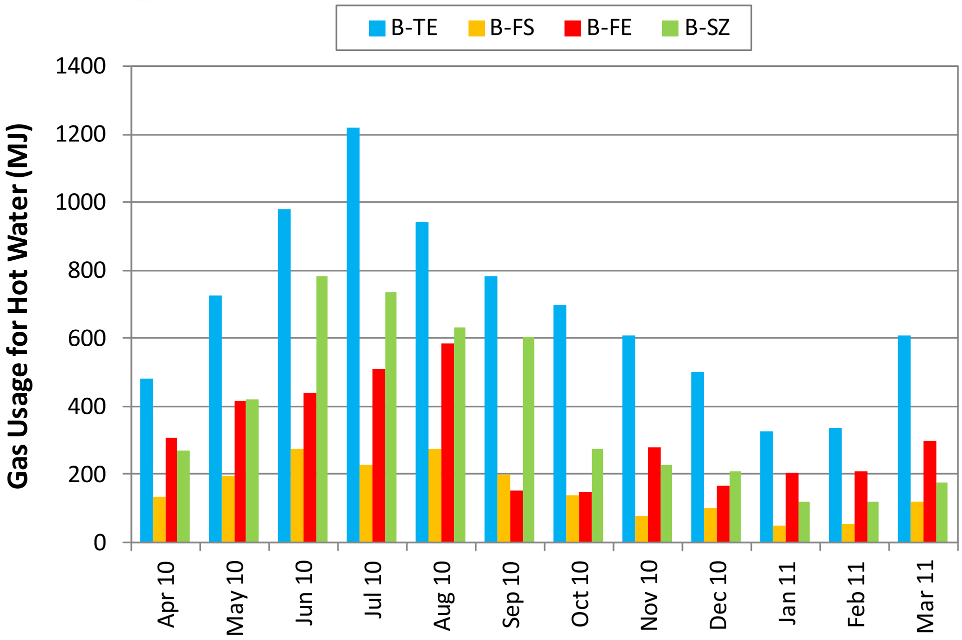
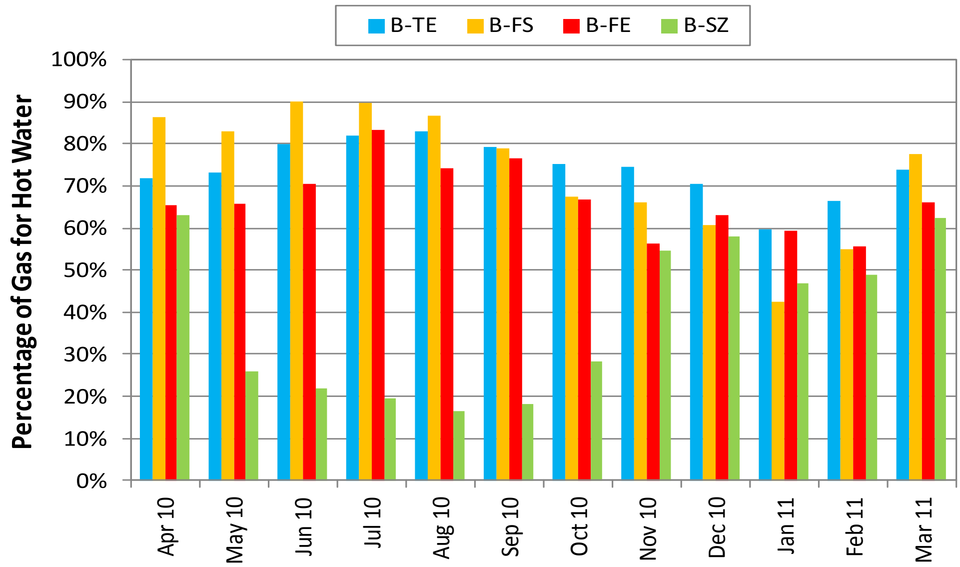


Figure 4.22 below shows the percentage of total gas usage that is consumed by the solar water heater. It is seen that all houses (except one) follow a similar pattern that fluctuates between 40% and 80%, for the summer and winter months, respectively. The lower gas pattern usage during the summer months is expected to be due to the higher solar gains, and lower hot water loads. The only house that does not conform to this pattern during winter is house B-SZ, which as discussed above uses a gas space heater almost continuously throughout the winter months. Despite this, the amount of gas used for hot water heating of house B-SZ is similar to the remaining houses during the summer months, instilling confidence in the method used to determine the actual volume of gas consumed by the hot water heater.

Figure 4.22: Percentage of gas used within each house by the instantaneous systems.



4.5.4. Monitoring results: Storage Systems

In contrast to the instantaneous gas hot water systems, the storage type hot water systems are more difficult to determine the volume of gas consumed by the hot water heater. This is mainly due to the use of boosting windows that heat the tank water to values ranging from 50 to 68°C, if there is insufficient solar gain. Note that manual overrides were used in each house and that boosting windows (time and duration) are customisable. A summary of the different boosting window settings are listed below,

- Most residents used more than one window per day;
- All residents used the manual override function, outside of their normal boosting windows;
- Two houses did not have specified boosting windows, essentially treating the solar water heater as a gas storage system;
- One household set up to 6 boosting windows per day;
- One household adjusted the system clock for day light savings;
- One household set different boosting windows for weekdays and weekends.

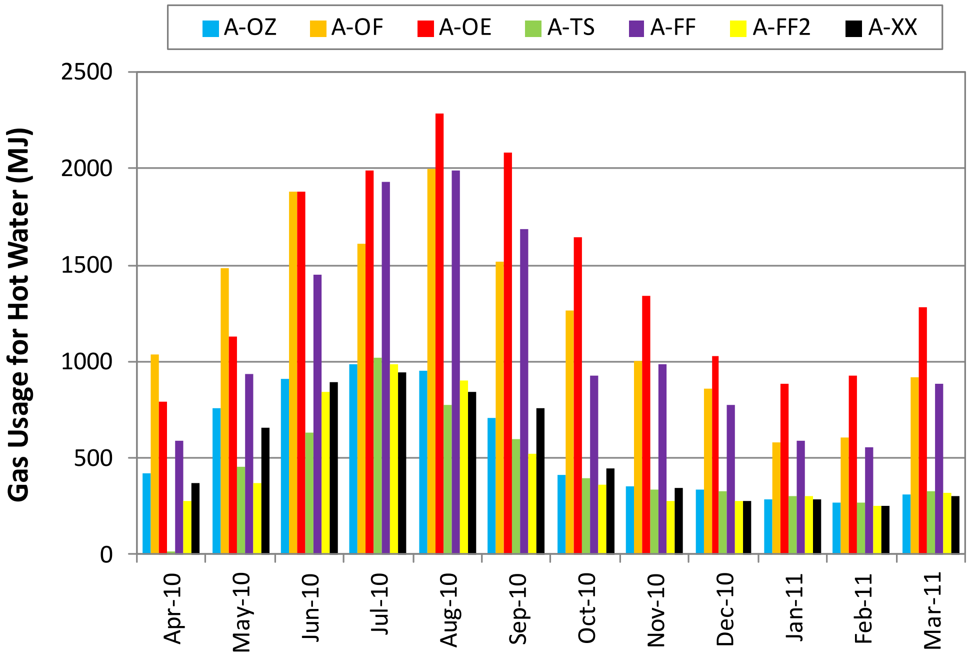
Table 4.3 below summarises the range of boosting window settings found, along with a summary of any other main connected gas appliances.

Table 4.3: Summary of storage system boosting window settings and other gas appliances used in the house.

House	Boosting windows (per day)	System Clock Adjusted for Day light savings?	Boosting periods different for weekends?	Manual Overrides used	Mains BBQ	Gas Stove / Oven
A-OZ	1	No	No	Yes	No	Yes
A-OF	0	No	No	Yes	No	Yes
A-OE	0	No	No	Yes	Yes	Yes
A-TS	2	No	No	Yes	Yes	Yes
A-FF	3+3	Yes	Yes	Yes	Yes	Yes
A-FF2	1	No	No	Yes	No	No

For these systems, a calculation methodology was developed that sampled minute by minute total gas usage data and compared this to gas consumption values both one and two minutes before and after its current value. This method proved to be very reliable as the storage systems tended to use gas at a rate of approximately 10L per minute, and in continuous blocks. This method is also able to filter out gas usage consumed by stove tops and some small sized barbeques, which were found to use gas a rate of less than 10L per minute. Figure 4.23 below shows the calculated gas consumption of each of the six houses, per month.

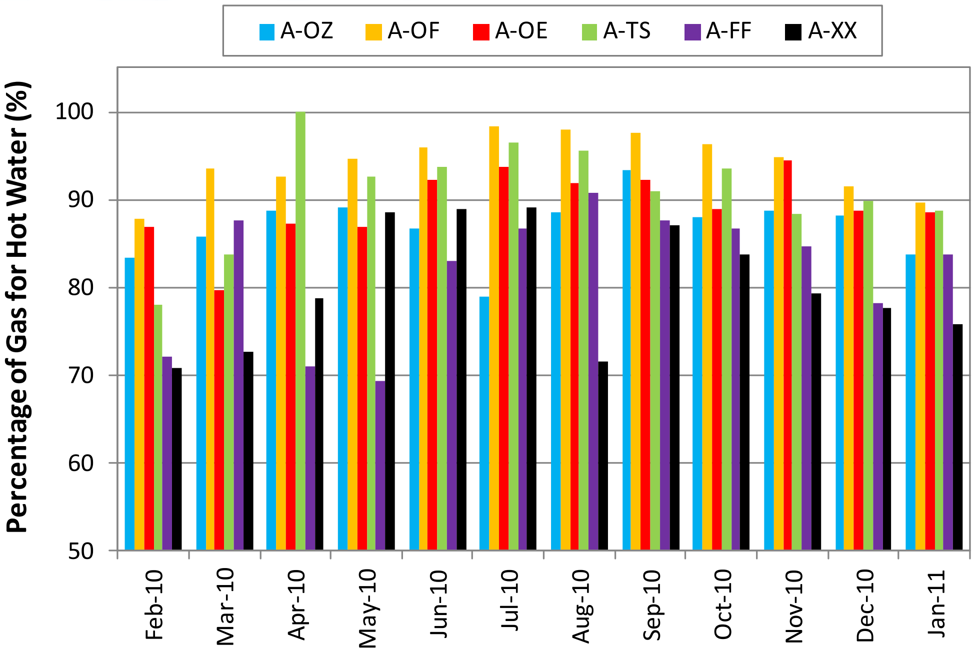
Figure 4.23: Total gas usage for each household storage solar water heater.



Note that house A-XX represents the directly monitored gas consumption for hot water as it is the only Lochiel Park house to have a second gas meter installed, which monitors only the hot water system consumption. Despite this, this house is excluded from other analyses as its hot water usage pattern / load profile could not be determined, due to water metering issues. Despite this, this house data can be used to compare the gas consumption of the hot water heater to the overall (total) gas consumption of the house. Houses A-OF, A-OE and A-FF consistently show larger consumptions of gas than the remaining houses. This occurs as houses A-OF and A-FF have four residents in these houses, compared to two residents in each other house. It should also be mentioned that house A-OF and A-OE are the two houses that do not have boosting windows specified, i.e. each of these systems essentially operate as gas storage systems.

Figure 4.24 shows the proportion of gas used to heat water for each house on a monthly basis. Note that house A-FF2 is not included in the chart below, as 100% of the total gas usage corresponds to that consumed by the water heater, i.e. the gas storage system is the house's only gas appliance. As such the algorithm developed to calculate the hot water heater gas usage was benchmarked against this house's total gas data. The algorithm calculated hot water heater consumption with a 0.5% error, which gives confidence in the algorithm.

Figure 4.24: Percentage of total gas consumed by the storage systems water heaters.



The above figure indicates that each house displays a similar percentage of gas usage for heating water. As with the instantaneous systems, the proportion of gas used for water heating increases in the winter months, whilst it decreases during the summer months. In contrast, the storage systems appear to use a larger proportion of gas overall than their instantaneous counterparts, ranging from approximately 70 - 90% (storage), compared to 40 - 80% (instantaneous). This indicates that more gas is consumed by the storage systems compared to the instantaneous types for the same amount of hot water consumed.

4.6. Heating / Cooling Systems – Detailed Monitored Houses

4.6.1. Overview of the Heating / Cooling Systems

Of the nine detailed monitored houses, five houses (lots L) rely on heating and cooling from reverse-cycle split or ducted air conditioners (AC). The reaming four houses rely on various other means of heating and cooling, these are briefly described below:

- **Lot L1TS** uses their AC for cooling only. The residents of this house heat their home with an underfloor heating system that is connected to their solar gas boosted instantaneous water heater. Note that in anticipation of a high winter water heating load, this house has 60 evacuated tubes installed in the circulation loop of the solar hot water heater system, and these tubes are optimised for winter conditions by having an inclination angle approximately 58° (L+23.5°, where the latitude, *L*, of Adelaide is 35° South). With this in mind, it would be difficult to separate the water and living space heating energy.
- **Lot L5SZ** uses an evaporative air conditioner during the summer months and relies on gas space heating to heat their house during the cooler months. It should be noted that the electrical energy consumption of the evaporative cooler is not currently being monitored. In addition, a second gas meter intended for the solar / gas storage hot water system has not

yet been installed and subsequently the gas consumption of the space heater could not be directly monitored.

- **Lot L26ST** does rely on reverse-cycle ACs to heat and cool various sections of their house, however, it was only recently discovered (during an audit) that only the electrical energy consumption of one of the two split-system compressors was being monitored. In addition, it was also found that only one of the five split-system heads was being monitored. As such the AC energy by the monitoring system corresponds to the heating and cooling loads of the kitchen only.
- Lot **L22SS** uses a heat pump for both heating and cooling. This heat pump cools the downstairs living spaces during the warmer months and provides underfloor heating during the cooler months. In addition, an evaporative cooler is used to cool the upstairs living spaces. The residents prefer to use the their evaporative cooling system (upstairs) to cool the downstairs living spaces as they believe the heat pump is unable to provide satisfactory cooling.

4.6.2. Gas Space Heating

Lot L5SZ is the only detailed monitored house that uses gas to heat living spaces. Despite the lack of a second gas meter, which is for the purpose of solar / gas water heater gas consumption, an algorithm has been developed to calculate the gas consumption of this device. As such, the difference between the total gas consumption and that calculated for the hot water system represents the amount of gas consumed by living space heaters and cooking. Cooking energy can be extracted from this data easily providing only a stove-top is used, however, in this house an outdoor mains connected barbeque is installed, which is often used simultaneously with the gas space heating. As such it is difficult to accurately disaggregate the space heating and cooking loads. For this reason, gas space heating analysis is not further discussed in this report.

Air Conditioner Usage

This section of the analysis is based on the measured AC electrical energy usage of the five houses that exclusively use reverse-cycle air conditioner (RCAC) systems for cooling and or heating. The AC usage during both the hottest and coldest weeks of the last 18 months is examined below.

Summer AC usage

Analysis in this section will focus on AC usage of the aforementioned households over a period of approximately one week during the hottest part of the monitoring period. Table 4.4 below shows the extreme variations in daily minima and maxima throughout the period of interest. This table also shows the fluctuation of minima and maxima in this period, therefore it would be anticipated that the most extreme behaviour would be seen over this period.

Table 4.4: Daily minimum and maximum ambient air temperatures (Ta), obtained from the Bureau of Meteorology (BOM), during Adelaide's hottest period throughout the monitoring period.

Date	28/01/2011	29/01/2011	30/01/2011	31/01/2011	1/02/2011	2/02/2011	3/02/2011	4/02/2011
Min. Ta (°C)	15.8	18.5	25.8	28.2	28.7	19.4	23.6	25.4
Max. Ta (°C)	31.8	37.7	42.5	42.9	33.2	36	32.7	34.5

(Note that the highlighted cell shows the peak daily maximum ambient air temperature, which corresponds with the state peak electrical load).

Figure 4.25 Measured average indoor temperatures, during Adelaide's hottest period in 2011 during the monitoring period.

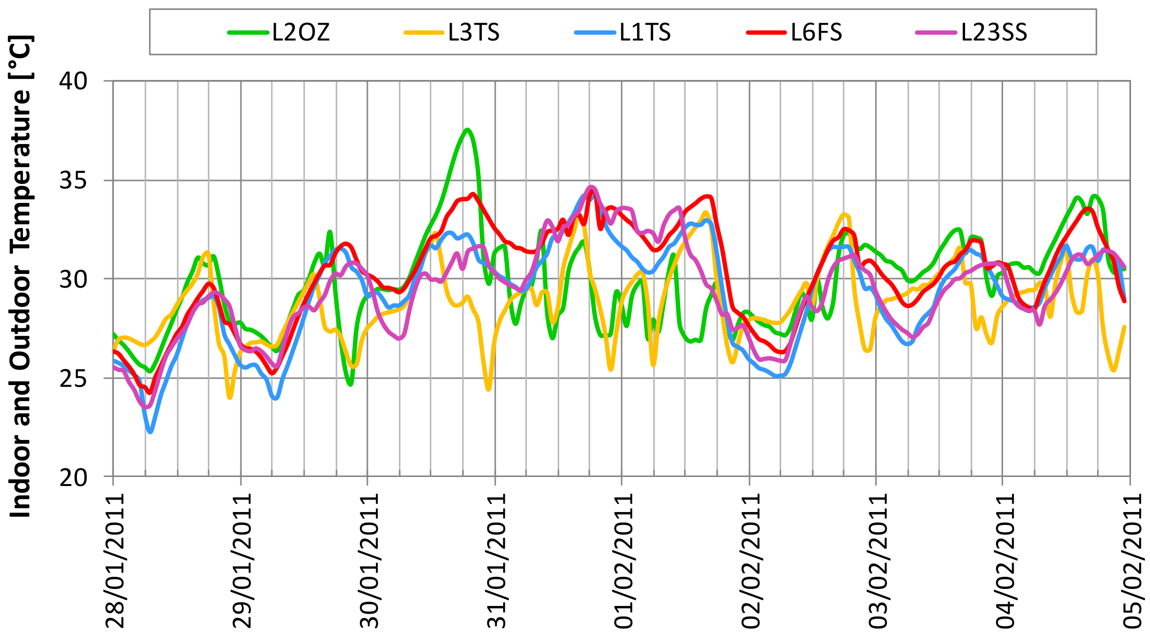


Figure 4.25 above shows the avrage indoor temperature response of Lochiel Park households during the heat wave period. This figure highlights similarities in the way that the buildings respond to elevated temperatures, but also in the way that residents condition their houses in response to this, given reference to Figure 4.26, which shows the air-conditioner load for the same period. It is worth noting that the lines indicate the average of 3 temperature readings including temperature of the upper bed rooms. The uncharacteristic response of house L2OZ during one of the hottest days (Sunday, 30th January) where the average indoor temperature rose considerably above comfort levels can be explained by the fact that the residents were not home during the day, but later returned and proceeded to use more energy for air-conditioning than others (also see Figure 4.27). It should also be noted that the L2OZ household have a baby, are subsequently home much of the time and have increased thermal comfort requirements in certain areas of the home.

Figure 4.26 Measured hourly average air conditioner (AC) power consumption, during Adelaide's hottest period throughout the monitoring period.

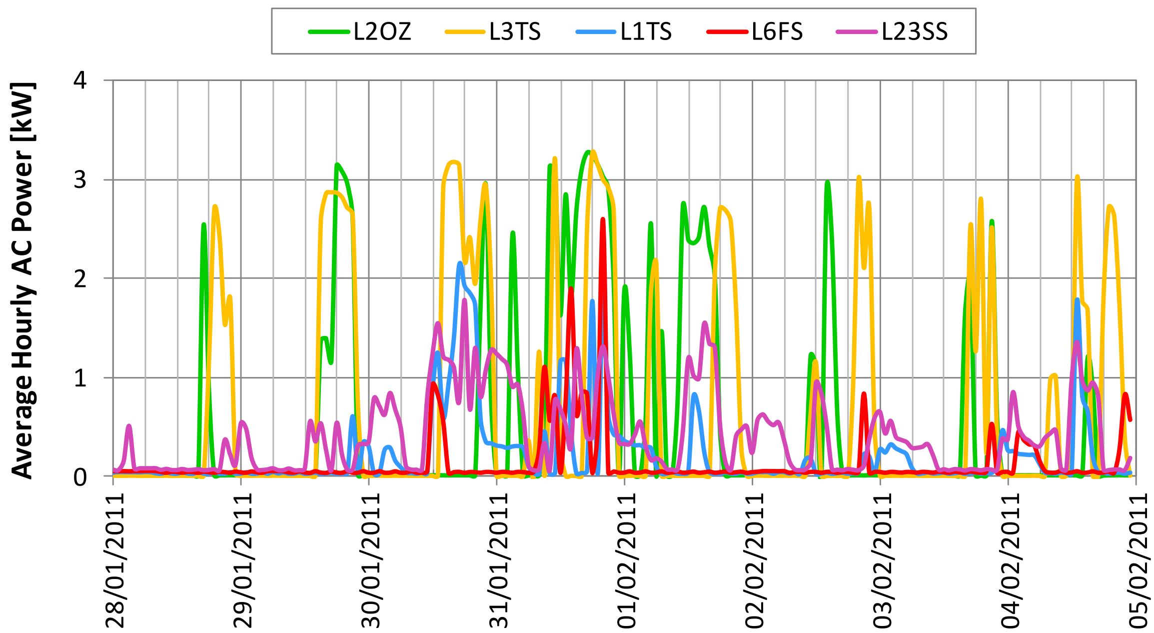


Figure 4.26 above shows a large variation in power demand across the monitored households, however most importantly in this expected peak demand period, it can be seen that the maximum demand is only slightly higher than 3kW and, on average, it is considerably lower. This demonstrates the impact of both limiting the size of AC's and improved thermal design of houses at Lochiel Park. Figure 4.26 also shows that the duration of demand for most of the monitored households is relatively infrequent, considering the extreme nature of the climate over this period, with most cooling being limited to afternoons and evenings, rather than continuing throughout the night as would have been the case in typical homes during this period. Specific attention should be paid to house L6FS, which has the least cooling energy over both this hottest period and the entire cooling season. The uncharacteristically low energy consumption for air-conditioning in house L6FS appears to relate to a behavioural based tolerance to higher indoor air temperatures, even throughout the hottest days (refer to Figure 4.25), noting that more detailed analysis of data revealed that the resident were absent for extended times during this period. This behaviour may be uncommon from a national perspective.

Figure 4.27 Measured daily air conditioner energy usage, during Adelaide's hottest period throughout the monitoring period.

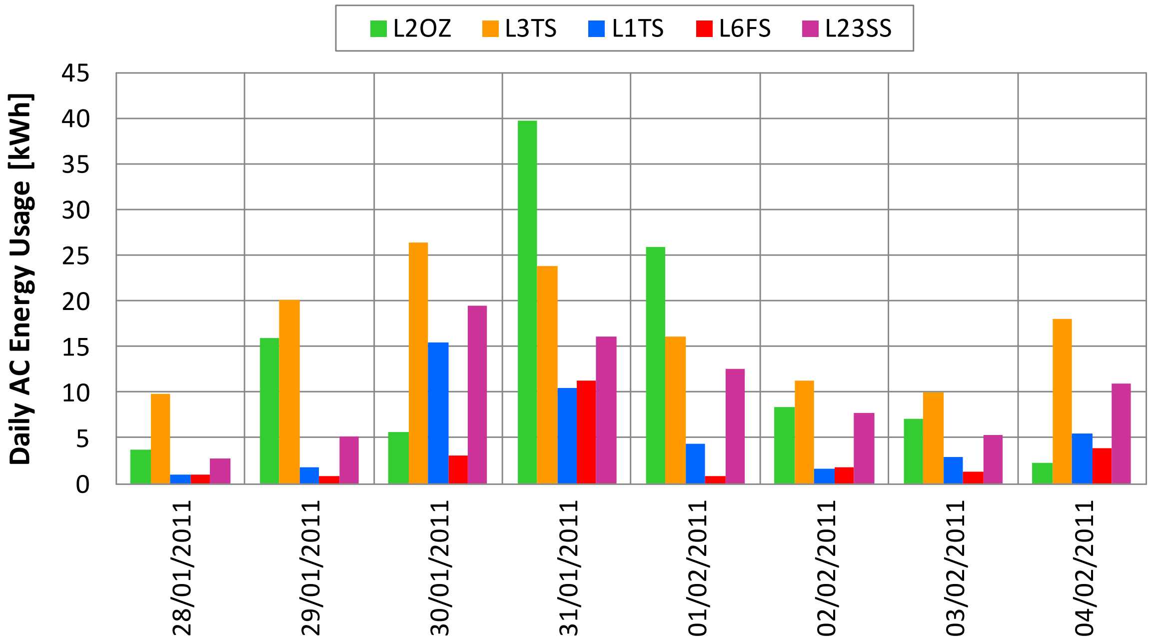


Figure 4.27 above shows the large variation in daily reverse cycle cooling energy consumption between the detailed monitored households. The largest variations seen were between house L6FS, which used the least cooling energy at all times, and various households on different days. It should be noted that although the cooling energy consumption of house L2OZ on the hottest day (31/01/2011) is relatively high, on average the cooling energy consumption for the houses on this day was only 20.3kWh (almost half). This is a relatively modest value for cooling energy use in comparison with typical Adelaide homes. The fact that house L2OZ contains an infant is most likely the contributing factor to the high cooling energy consumption for this household.

Figure 4.28 Measured daily proportion of air conditioner (AC) to total electrical energy consumption, during Adelaide's hottest period throughout the monitoring period.

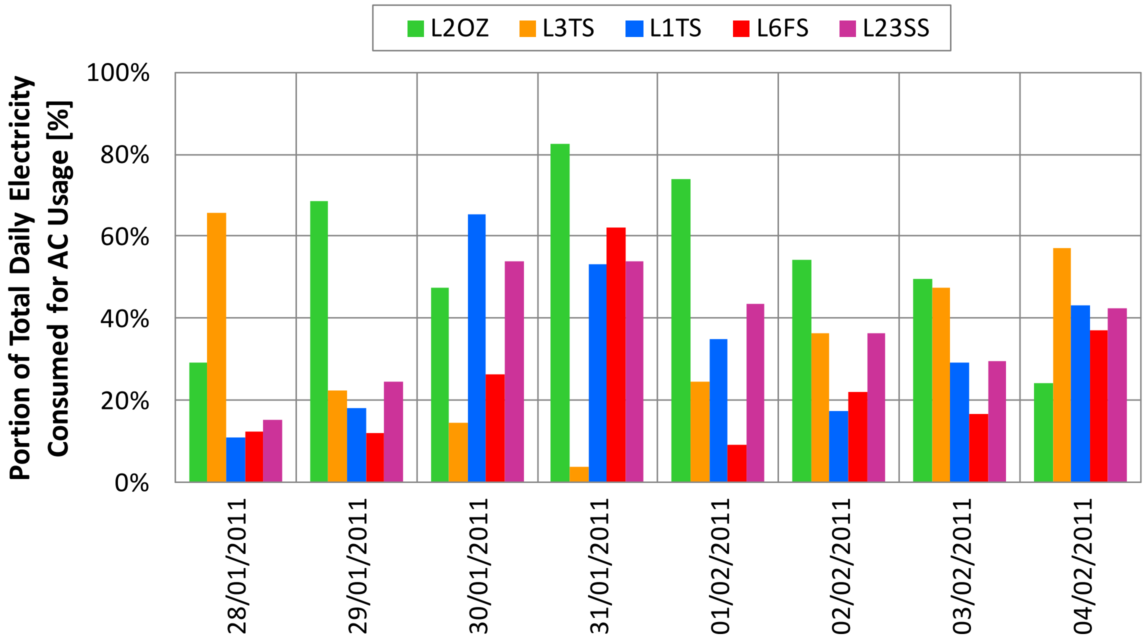


Figure 4.28 above shows that air conditioning does not dominate the energy consumption of all houses in the detailed monitored group during the hottest part of the monitoring period. While it amounts to up to 82% in several of the households on some days, however this is not the case for any individual household for the entire hottest period.

Winter AC usage

Analysis in this section will focus on air conditioning usage of the aforementioned households over a one week period during the coldest part of the monitoring period. Table 4.5 below shows the variations in daily minima and maxima throughout the period of interest. This figure shows the relatively constant range of minima and maxima over this period and the fact that the lowest minimum occurred on the 7/08/2010, therefore this would be where the highest energy consumption is expected, especially given the duration of the period of colder weather preceding this day.

Table 4.5: Daily minimum and maximum ambient air temperatures (Ta), obtained from the Bureau of Meteorology (BOM), during Adelaide's coldest period throughout the monitoring period.

Date	3/08/2010	4/08/2010	5/08/2010	6/08/2010	7/08/2010	8/08/2010	9/08/2010
Min. Ta (°C)	7.1	8.5	3.7	4.8	3.6	7.4	7.1
Max. Ta (°C)	12.4	12.5	13.4	12.3	14.2	13.4	14

Figure 4.29 Measured indoor temperatures, during Adelaide's coldest period during the monitoring period.

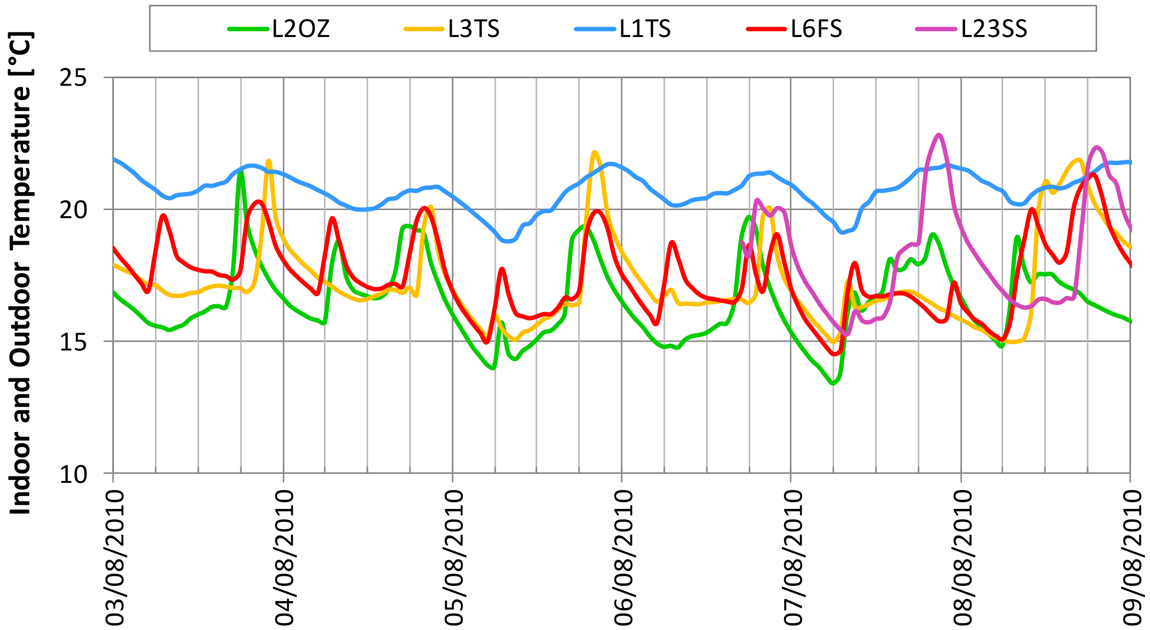


Figure 4.29 above shows the indoor temperature response of Lochiel Park households during an extended period of relatively cold weather. This figure highlights similarities in the way that the buildings respond to low temperatures, but also in the way that residents condition their houses in response to this, given reference to Figure 4.30, which shows the air conditioner load for the same period. A very different average indoor temperature profile is seen for house L1TS, based on the fact that this house also has a solar-gas underfloor heating system, which was the primary source of heating during the period of analysis, therefore this will not be considered in this analysis, based on the fact that a valid comparison cannot be made with electrical heating.

Figure 4.30 Measured hourly average air conditioner (AC) power consumption, during Adelaide's coldest period throughout the monitoring period.

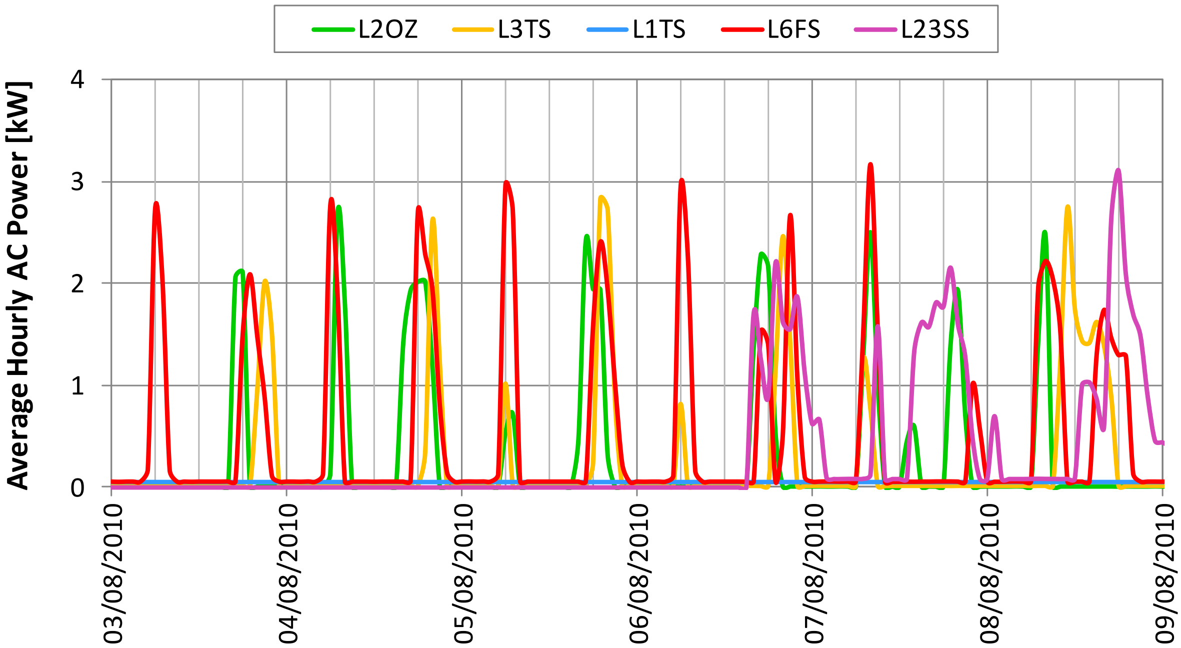


Figure 4.30 above shows a relatively constant pattern of daily power demand across the monitored households and, as with the summer peak period, the maximum demand in this winter period is only slightly higher than 3kW and, on average, it is lower. Once again, this demonstrates the impact of both limiting the size and efficiency of air conditioners and improved thermal design of houses at Lochiel Park. Figure 4.30 also shows that the duration of demand for most of the monitored households is relatively short, with most heating being limited to mornings and evenings and not continuing day and night. Specific attention should be paid to house L6FS, which has the highest heating energy over both this coldest period and the entire heating season. The uncharacteristically high energy consumption for air-conditioning in house L6FS appears to relate primarily to a behavioural based propensity toward sustained, relatively high indoor air temperatures (refer to figure 4.29 noting that more detailed analysis of data revealed that the resident did not appear to be absent for extended times during this period. This observation appears to support earlier suggestions that this household is inclined toward higher indoor air temperatures, based on analysis of summer AC usage data. As previously discussed, the very low load of house L1TS is based on the use of a solar-gas underfloor heating system as the primary heating source, therefore this house will be ignored in the analysis.

Figure 4.31 Measured daily air conditioner energy usage, during Adelaide's coldest period throughout the monitoring period.

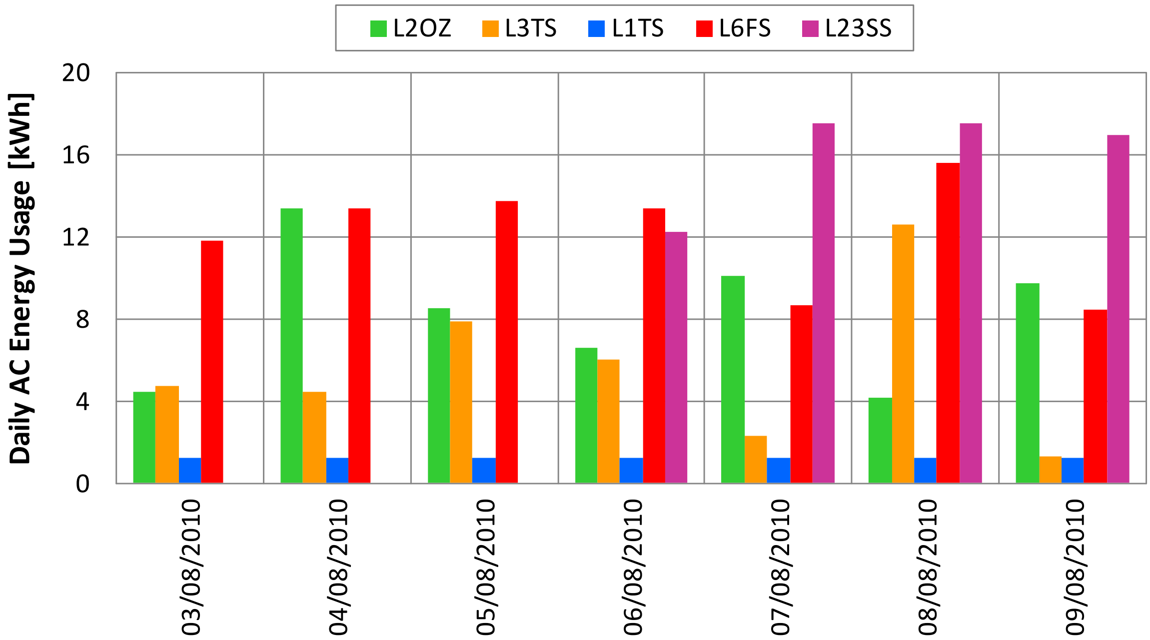


Figure 4.31 above shows the variation in daily reverse cycle heating energy consumption between the detailed monitored households. The largest variations seen were between house L3TS, which used the least heating energy at all times, and various households on different days. The highest heating energy consumption on the day with the coldest minimum (07/08/2010) occurred at house L23SS, though the actual amount of energy is less than one quarter that of the summer peak. It should also be noted that, on average, the heating energy consumption for the houses on this day was only 7.9kWh (less than half the maximum). The relatively small heating energy requirements during the coldest days highlights the influence of passive solar design in reducing the heating load at Lochiel Park.

Figure 4.32 Measured daily proportion of air conditioner (AC) to total electrical energy consumption, during Adelaide's hottest period throughout the monitoring period.

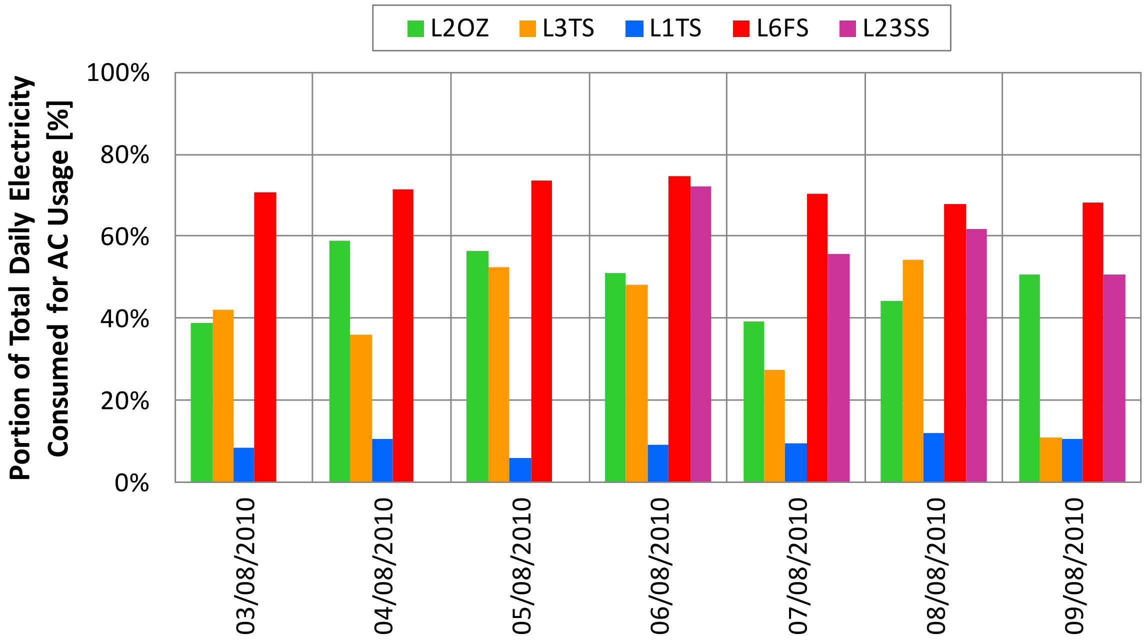


Figure 4.32 above shows that heating dominates the energy consumption of most houses in the detailed monitored group during the coldest part of the monitoring period, as one would expect in Adelaide. As previously discussed however, the total daily heating energy was quite low, therefore this high percentage must be put into the context of overall very low total electrical energy consumption. When viewed from this perspective, the importance of heating being the dominant end use is dramatically reduced.

5. COMPARISON WITH AVAILABLE DATA

This section compares the measured Lochiel Park data with other detailed monitored housing developments, such as Mawson Lakes (SA), in which UniSA monitored 6 houses for a period of 12 months, and other relevant literature. Note that section 5.1 provides data that allow comparisons between the detailed monitored Lochiel Park houses with similarly detailed monitored Mawson Lakes houses, whilst section 5.2 compares both the average of all (and in some cases, only detailed monitored) Lochiel Park houses, with other state / national figures.

5.1. Comparison with Mawson Lakes Monitored Houses

The Mawson Lakes development is major housing development in an outer suburb of Adelaide. The development was established with specific energy and water reduction targets. The energy reduction target was facilitated by using an energy rating scoresheet for every home built to ensure compliance with the minimum energy efficiency standards. The scoresheet awarded a number of positive and negative points for design features, building materials and major fixed appliances. A total minimum score was required. On average, each point represents a 1% saving in primary energy consumption, compared with a typical South Australian home. The scoresheet was devised on the basis of mathematical modelling of heating, cooling, hot water, lighting and other energy consuming appliances (Saman et al, 2003)

Energy monitoring was undertaken in the housing development to validate the effectiveness of this tool in reducing household energy consumption. Detailed monitoring of six individual houses was conducted in which all electricity circuits and major gas appliances were individually monitored in each of these houses, with values recorded at 15 minute intervals. .The group of six houses that were monitored are located within larger networks, in which gas and electricity consumption was also monitored. Total electricity and gas consumption, in networks of approximately 50 and 150 houses respectively, was continuously monitored over the same period. These various monitoring regimes were carried out in 2002-2003 for a period of twelve months.

Comparisons between energy consumption of the energy use in Adelaide at the time with the average Mawson Lakes house, obtained through network monitoring, showed an average of 26% reduction achieved in household primary energy consumption per unit floor area.

It should be noted that there are some significant differences between houses that were monitored in detail at Mawson Lakes and Lochiel Park, however awareness of these differences will help to place the comparisons that follow into a more appropriate context. Several fundamental differences between average characteristics of the monitored households are listed below in Table 5.1. It should also be noted that the Mawson Lakes data were collected approximately eight years before monitoring at Lochiel Park, when there were significant differences in the availability and market penetration of certain technologies, such as ‘plasma’ and ‘LCD’ televisions with considerably larger screens and computers. It could also be argued that the residents’ energy use patterns and their level of awareness of environmental sustainability issues also make a direct comparison difficult. Never the less, a comparison was considered useful to demonstrate a number of key differences in energy use patterns and quantum and in view of the unavailability of detailed monitoring data of similar households.

Table 5.1: Average conditioned floor area, occupancy and star rating of detailed monitored households

Parameter	Mawson Lakes	Lochiel Park
Avg. Conditioned Floor Area (m^2)	125.9	147.8
Avg. No. of Occupants	3.0	2.4
Avg. House Star Rating	4.1	7.6

A graphical comparison between monthly average air-conditioner energy for Mawson Lakes and Lochiel Park households is provided below in Figure 5.1. This is based on complete monitoring data for 5 homes in Mawson lakes and 5 in Lochiel Park. In both cases, reverse cycle air conditioning was used throughout the year. Noticeable differences between monthly energy consumption values during heating and cooling seasons stand out, with Mawson Lakes values almost four times higher during the peak cooling month of January and almost double during the peak heating months of June and July. The average total annual air-conditioning energy for Lochiel Park households (1208 kWh) is less than half that for Mawson Lakes households (2451 kWh). It must be noted that these data are for quite different households (see Table 5.1) from different years with correspondingly different climatic fluctuations. Any conclusions about the impact of these differences would be speculative, however it is safe to say that any increase in the Mawson Lakes average heating and cooling requirement associated with a higher average number of occupants would be, at least partially, offset by the decreased requirement relating to lower conditioned floor area at Lochiel Park. The large drop of the air conditioning requirements is due to the improved thermal design as reflected by the star rating as well as the energy efficiency improvement of the air conditioning systems.

Figure 5.1: Comparison of monthly average air conditioning energy for Lochiel Park (2010/11) and Mawson Lakes (2002/03).

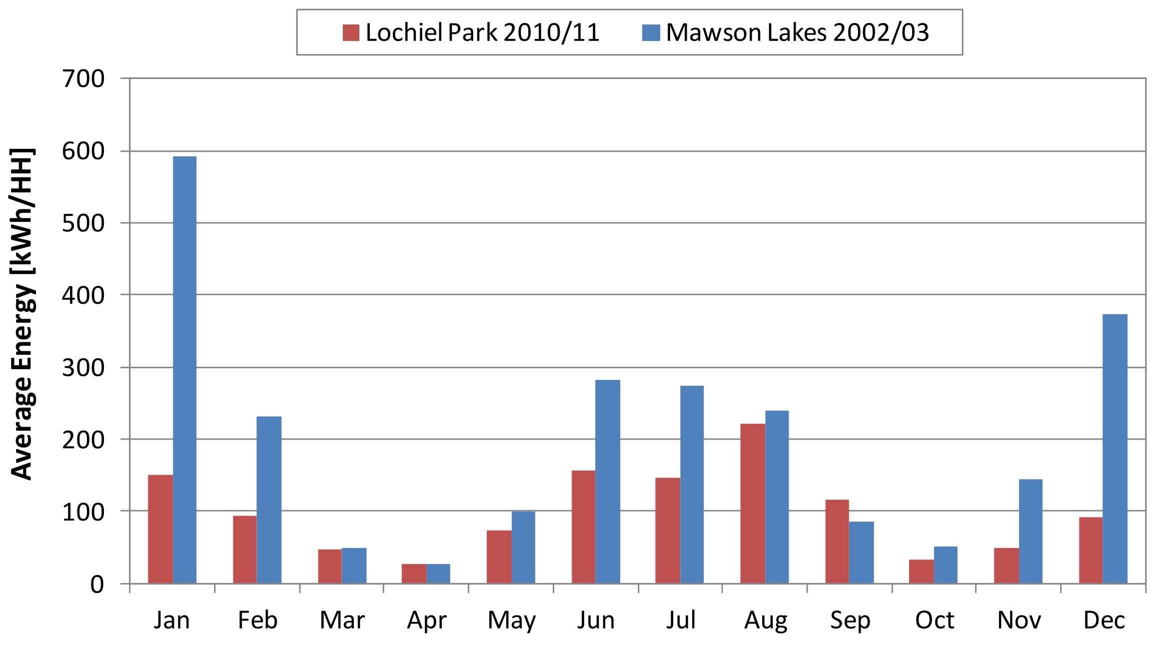


Figure 5.2 below provides a comparison between the monthly total electrical energy for lighting at Lochiel Park and Mawson Lakes for the respective monitoring periods. As previously discussed, the reduction is likely to relate to higher efficiency fixtures at Lochiel Park. The lower seasonal fluctuation seen supports the earlier suggestion that enhanced access to daylight is a significant factor. As well as better building envelope design to optimise access to daylight, the use of double-glazing and highly insulated building shells is likely to have encouraged the use of daylight, rather than artificial light, on hotter days, given that the need for using curtains to block out heat is likely to have been decreased, in comparison to Mawson Lakes households.

Figure 5.2: Comparison of monthly average lighting energy for Lochiel Park (2010/11) and Mawson Lakes (2002/03).

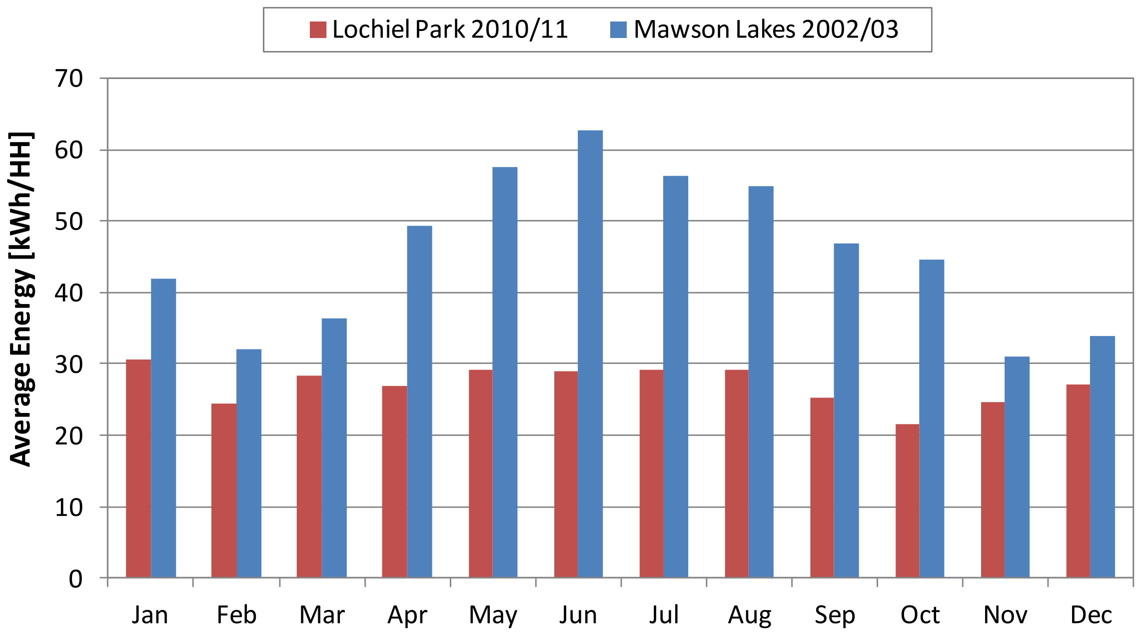
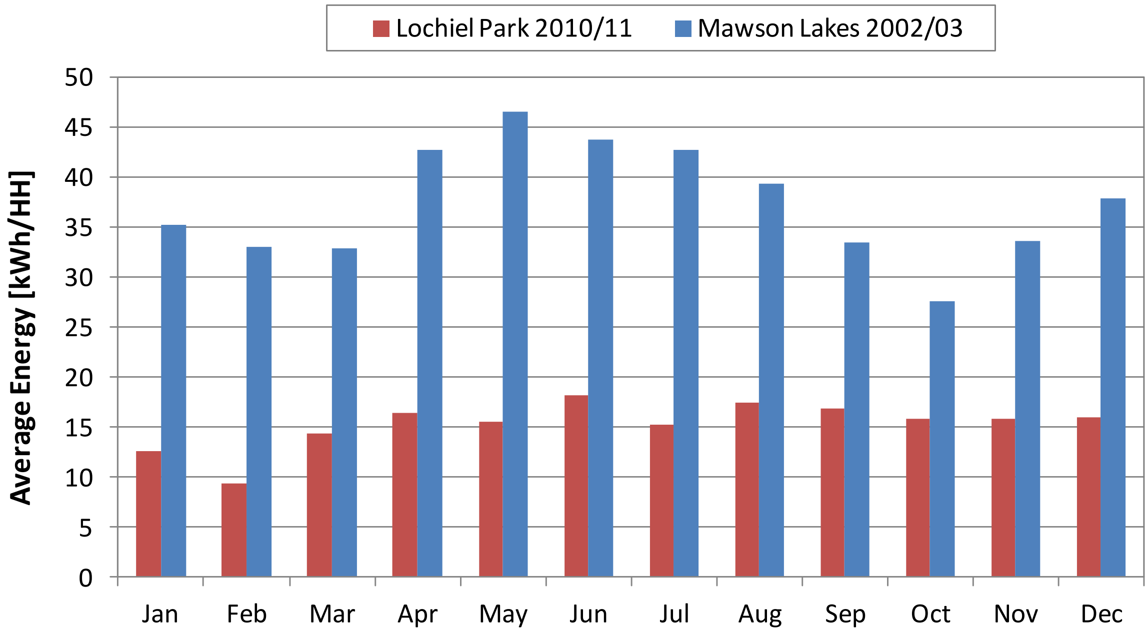


Figure 5.3 below provides a comparison between the monthly total electrical energy for dishwashers at Lochiel Park and Mawson Lakes for the respective monitoring periods. The reduction is likely to relate primarily to higher efficiency fixtures at Lochiel Park. The seasonal fluctuations seen are likely to relate, in part, to associated fluctuations in cold water temperature and water heating requirements.

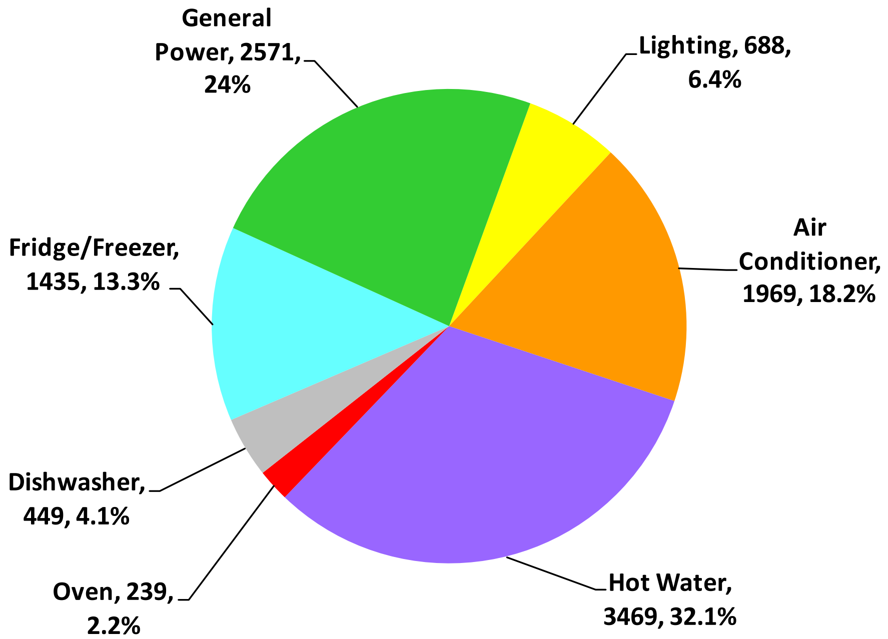
Figure 5.3: Comparison of monthly average dishwasher energy for Lochiel Park (2010) and Mawson Lakes (2002/03).



A breakdown of annual electrical energy consumption by appliance type at detailed monitored Mawson Lakes households is shown below in Figure 5.4. Comparisons between this figure and Figure 1.1 are problematic. Before making comparisons to Lochiel Park data however, it must be noted that Figure 5.4 includes electrical energy for water heating, unlike Figure 4.13, and these data relate to a different period of time, where the uptake of certain electronic appliances was, on average, either much lower or non-existent in relation to technologies that have only recently penetrated the domestic market. This is likely to have heavily influenced the fact that the end-use termed general power for Mawson Lakes data is, in total, lower (2571 kWh) than that for the Lochiel Park equivalent (2836 kWh), which included both general power outlets and laundry appliances. This could also relate to a greater proportion of Lochiel Park appliances using stand-by power at all times in comparison to appliances used at Mawson Lakes houses.

Electric ovens (not including microwave ovens) were responsible for a similar percentage of annual electrical energy consumption at both developments, however in total, this end-use was responsible for less than half the comparable energy use at Lochiel Park. This factor could partially reflect the use of more energy efficient ovens at Lochiel Park, however it is more likely to relate to behaviour, given the technical limitations of making resistance-type ovens more energy efficient and is most likely behavioural, relating to a tendency towards the use of microwaves and gas cooking appliances at Lochiel Park.

Figure 5.4: Breakdown of electrical energy by end-use, Mawson Lakes (2002/03).



Annual lighting energy consumption (325 kWh), as previously mentioned, is significantly lower, in comparison to both national figures and Mawson Lakes (688 kWh), which was more than double and is likely the result of energy efficient fixtures, enhanced day lighting and behavioural factors, as discussed earlier.

The energy consumption of dishwashers at Lochiel Park (184 kWh) was less than half that for Mawson Lakes (449 kWh). It is highly likely that this was primarily the result of better appliance performance at Lochiel Park, given the requirements set out in the Urban Design Guidelines, but also relating to advances in technology and reductions in the price of higher efficiency appliances, in comparison to when Mawson Lakes householders installed such appliances. The influence of behaviour of Lochiel Park residents should also not be overlooked in the explanation of this large difference.

The most striking outcome of the comparison is the dramatic reduction of the total (gas and electrical) annual household energy use in Lochiel Park (8.39MWh) in comparison with Mawson Lakes (14.4MWh). Note that this Lochiel Park value ignores the contributions made by the solar systems.

5.2. Comparison with State and National Data

In this section a comparison is made of the energy usage and greenhouse gas emissions of the Lochiel Park households with residents in South Australia (SA) and available national averages.

Table 5.2 lists the sources and methods used to compare the monitored Lochiel Park data with. Note that the colour code shown within the table is maintained for all remaining charts in this section.

Table 5.2: Summary of sources and methods used to compare Lochiel Park data

Label	Method	Reference
LP-D(10/11)*	Calculated from LP monitored data, for detailed houses only, not incorporating the effects of the PV systems.	-
LP-DPV(10/11)*	Calculated from LP data, for detailed houses only, incorporating the generation of the PV systems.	-
LP-A(10/11)*	Calculated from LP data, for all houses only, not incorporating the effects of the PV systems.	-
LP-APV(10/11)*	Calculated from LP data, for all houses only, incorporating the generation of the PV systems.	-
ML(02/03)*	Calculated from Mawson Lakes monitored data.	-
SA AVG, ESCOSA(10)	Taken from Appendix 3 of the ESCOSA 2009/10 report.	ESCOSA (2010)
SA AVG, SAGovt(09)	Average calculated from values shown on the SA Govt website, for houses with both gas and electricity connections.	SAGovt (2009)
SA AVG, DEWHA(08)	Average of projected 2010 and 2011 figures, for South Australia.	DEWHA (2008)
AUS AVG, DEWHA(08)	Average of projected 2010 and 2011 figures, for Australia.	DEWHA (2008)
AUS AVG, ABS(10)	Projected national average value, i.e. Australia wide.	ABS (2010)

* indicates that values used in charts are calculated from monitored / measured data.

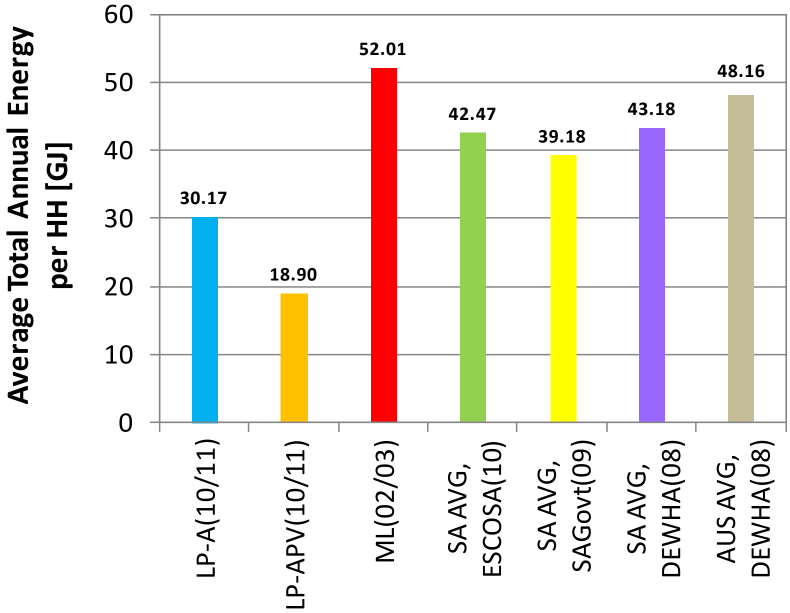
5.2.1. Energy Consumption

Per Household

Figure 5.5 shows the total energy (electricity and natural gas) per household, for both the measured Lochiel Park and Mawson Lakes developments, together with the SA state averages from three sources and the national average. Note that two of the three SA state averages agree, i.e. those calculated from ESCOSA10 and DEWHA08 data. The Lochiel Park data is shown twice, i.e. once with and once without the impact of the local electricity generation of the PV systems, to exemplify its influence on the average energy values. Considering the average LP household without PV systems, i.e. the first (blue) column. The figure clearly shows that these households uses significantly less total energy than each of the SA state and national averages and than that for the Mawson Lakes development. This average energy consumption is further reduced when the energy generated by the LP PV systems is added, as shown by the second (orange) column.

Figure 5.5: Comparison of average total annual energy consumption per household (HH) of all Lochiel Park houses (both with and without PV systems), with various SA state averages (SA AVG), and the national average (AUS AVG).

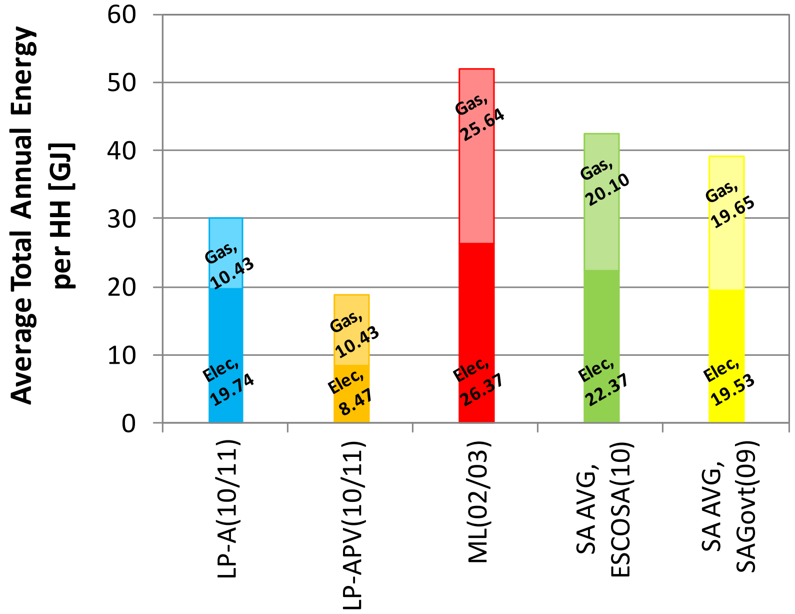
Note that the total energy is shown for each data set and has units of GJ.



The above data is further examined in Figure 5.6, which breaks down the total energy consumption by fuel type. It should be noted that the Mason Lakes data was measured in 2002/03, whilst the Lochiel Park data was measured in 2010/11, and that all state and national averages are calculated for 2010/11. As such the Mawson Lakes data should be used as a guide for comparisons, as the state and national average would have been higher in 2002/03, than the current averages.

Figure 5.6: Comparison of average total annual energy consumption per household (HH) by fuel type, of all Lochiel Park houses (both with and without PV systems), with Mawson Lakes and various SA state averages (SA AVG).

Note that each column indicates the fuel type and amount of energy consumed (GJ).



Consider the gas data of the above figure. This indicates that the average Lochiel Park house consumes about half of that of the SA state average, and about 41% of that of the Mawson Lakes households. This is attributable to the use of gas-boosted solar hot water heater systems. Note that this average gas consumption could be further reduced if all LP households used instantaneous gas-boosted solar hot water heaters. Currently about one third of all LP households use storage water heater systems, which consume approximately twice as much gas as their instantaneous counterparts, for similar volumes of hot water consumption (Saman, et al, 2011). It is estimated that of all solar storage water heaters were replaced with instantaneous units, the average LP household gas consumption could be reduced by an additional 16%.

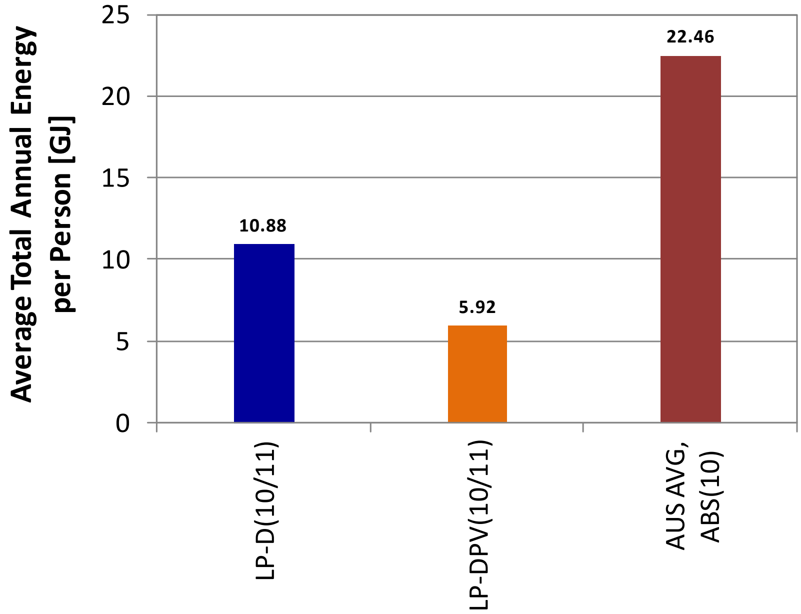
Now considering the average LP household electrical energy consumption of Figure 5.6; firstly without the aid of PV systems (blue column). It is seen that the average LP households consume only marginally less energy than the South Australian average (SAGovt09), whilst it consumes about 25% less than that of the similar sized Mawson Lakes households. This is despite the average Lochiel Park houses having approximately 50% larger conditioner floor areas than the SA average; calculated from DEWHA08 data. This indicates that the LP households are using less electrical energy per square meter of conditioned floor area, due to the use of less energy for air conditioning and more energy efficient appliances.

Now consider the average LP household electrical energy consumption of Figure 5.6, with the aid of PV systems (orange column). This shows the PV systems to be providing 57% of their total electrical energy consumption. As such only 43% of the average LP electrical consumption is relied upon from the grid (recall Figure 4.9). As such, the average LP householders consume only 38-43% of the SA state average (based on data obtained from ESCOSA10 and SAGovt09), and only 32% of the measured Mawson Lakes average electrical energy.

Per person

Figure 5.7 below, compares the average energy consumption per Lochiel Park resident, both with and with PV systems, with the national average. Note that the LP data is now concentrated on the detailed monitored households, which on average is comparable to the development average. This was required due to the uncertainty of the number of residents living in all houses, whilst the numbers of residents living in the detailed monitored households were constantly monitored. Consider the LP average excluding the influence of the PV systems, i.e. the first (navy blue) column. The figure indicates that the average LP resident consumed significantly less energy, i.e. about 50% of the national average. This is further reduced, by including the influence of PV systems, i.e. the second (dark orange) column, which shows that the average LP resident consumes about 26% of that of the national average. Note that SA state average values per user could not be obtained.

Figure 5.7: Average total annual energy consumption per person, for the detailed monitored Lochiel Park houses (both with and without PV system), and the projected 2010-11 national average (AUS AVG).



Per Habitable Floor Area

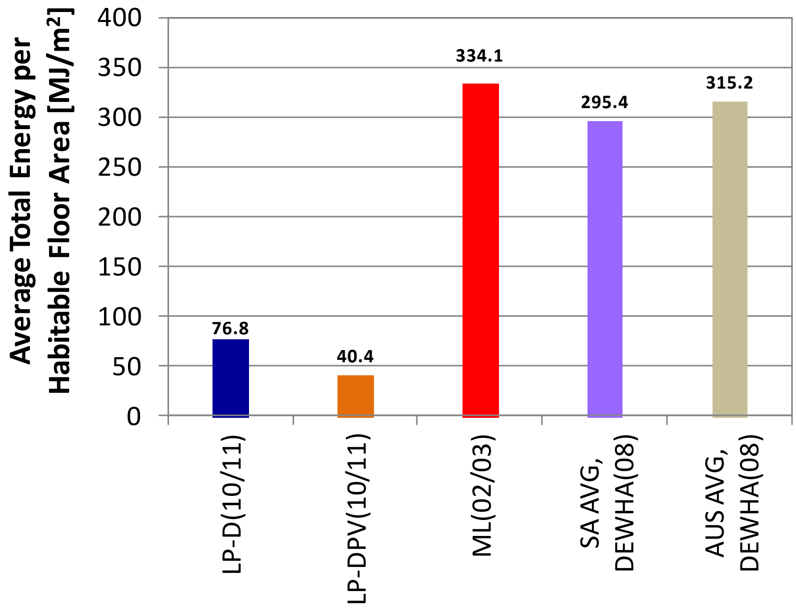
Table 5.3 below summarises the average habitable (residential) floor area of the detailed monitored Lochiel Park households, the Mawson Lakes households and the available South Australian state and national averages. These values are then used to calculate the average total energy per habitable floor area (energy consumption density) for the detailed LP and ML households, as well as the state and national averages; this is shown below in Figure 5.8.

Table 5.3: Average habitable (residential) floor area of the detailed Lochiel Park, Mawson Lakes and SA state and national averages.

	Mawson Lakes	Lochiel Park	SA AVG (DEWHA08)	AUS AVG (DEWHA08)
Avg. Habitable Floor Area (m^2)	155.7	196.6	145.2	151.8

Consider the first (navy blue) column of the figure below, which corresponds to the energy consumption density of the average detailed monitored Lochiel Park house. This is shown to be significantly less than the Mawson Lakes and both the South Australian state and national averages. The LP energy consumption density is about 24% and 26% of the national and state's average, respectively. These LP values are further reduced when taking the effect of the PV system generation into account, as shown by the second (dark orange) column. The resulting LP household energy consumption densities are now approximately equal to 12.8% and 13.7% of the national and state's average, respectively. This is a significant reduction in energy density, and is largely due to the above average habitable floor area and below average total energy consumption.

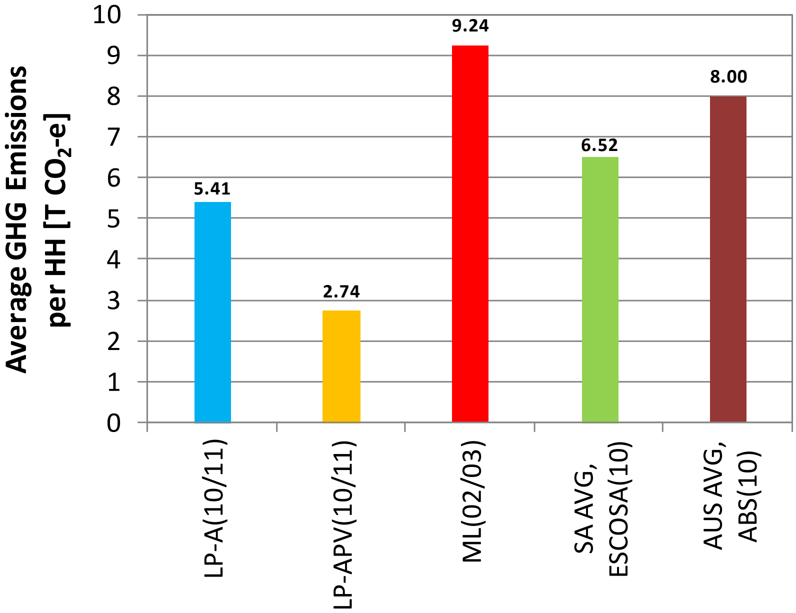
Figure 5.8: Average total annual energy per habitable floor area for the detailed monitored Lochiel Park houses (both with and without PV systems), the monitored Mawson Lakes houses, and the projected SA and national averages for 2010-11.



5.2.2. Greenhouse Gas Emission Comparison

Figure 5.9 below, compares the greenhouse gas emissions per household of the Lochiel Park and Mawson Lakes households, with the calculated state and national averages. Consider the LP average without the aid of PV systems, this shows greenhouse gas reductions of 17%, 32% and 41% of the state, national and Mawson Lakes averages, respectively. When the PV system generation is included in the LP houses, i.e. the second (orange) column, a further significant reduction in greenhouse gas emissions per household is seen. In fact the average LP household emissions are now reduced by 58%, 66% and 70% when compared with the state, national and Mawson Lakes averages, respectively.

Figure 5.9: Average greenhouse gas (GHG) emissions per household (HH), for all Lochiel Park house (both with and without PV Systems), the monitored Mawson Lakes houses, the SA average, and the national 2003-04 average.



5.3. Summary of Comparisons

This section has shown that the Lochiel Park households use significantly less electrical and gas energy than the average South Australian, national or Mawson Lakes households. The significant energy and hence greenhouse gas emission reductions are caused by i) the high star rating of each house, ii) the use of highly efficient reverse-cycle air conditioners and other general electrical appliances, iii) the use of gas-boosted solar hot water heater systems. Note that whilst energy is reduced, the average habitable floor area has increased, which has significantly reduced the energy consumption density.

The results have also shown that the use of photovoltaic systems significantly reduces the amount of energy purchased from the grid, which drastically reduces the households' total energy consumption and the consequent greenhouse gas emissions.

6. IMPACT ON THE GRID

The Lochiel Park Green Village represents an exemplar of new Australian housing developments in the next decade where more attention is paid to minimising energy consumption through house design, energy efficient appliances and smart technologies with local generation of solar electricity being common practice. While grid connection to tomorrow's smart grid is anticipated to continue, the impact of housing developments on the grid is currently attracting much attention. This chapter examines the impact of the completed homes on Lochiel Park on the grid, particularly during peak demand periods.

6.1. Impact of Solar Systems – Net Electrical Power Profiles

This section examines the impact of the solar systems on the net power drawn from or exported to the grid, by showing the average solar and subsequent net electrical power profile per household, during the coldest and hottest period throughout the monitoring year, as well as these profiles during a typical Spring day where neither heating nor cooling is required.

6.1.1. Winter Period

Figure 6.1 shows the 15 minute instantaneous solar and net electrical powers per house as an average of 21 houses, during the coldest period of 2010. The figure shows that the average solar power is low, as expected for the winter months, and when combined with a high electrical demand for heating (common in SA), this increases the net electrical power that is drawn from the grid. The figure shows that throughout this four-day period, only a very small portion of the solar generated power is in excess of demand, i.e. fed to the grid with this taking place around noon. However, the peak power taken from the grid seldom exceed 2.5kW and takes place in the evening (6.00 to 9.00pm). A summary of the maximum and minimum ambient air temperatures, as well as the peak instantaneous solar and both peak and minimum subsequent net electrical power demand, during the coldest period of 2010, is shown in Table 6.1.

Figure 6.1: House average measured solar and net electricity power profile, of 21 houses, for the coldest period of the year (3-6/08/2010).

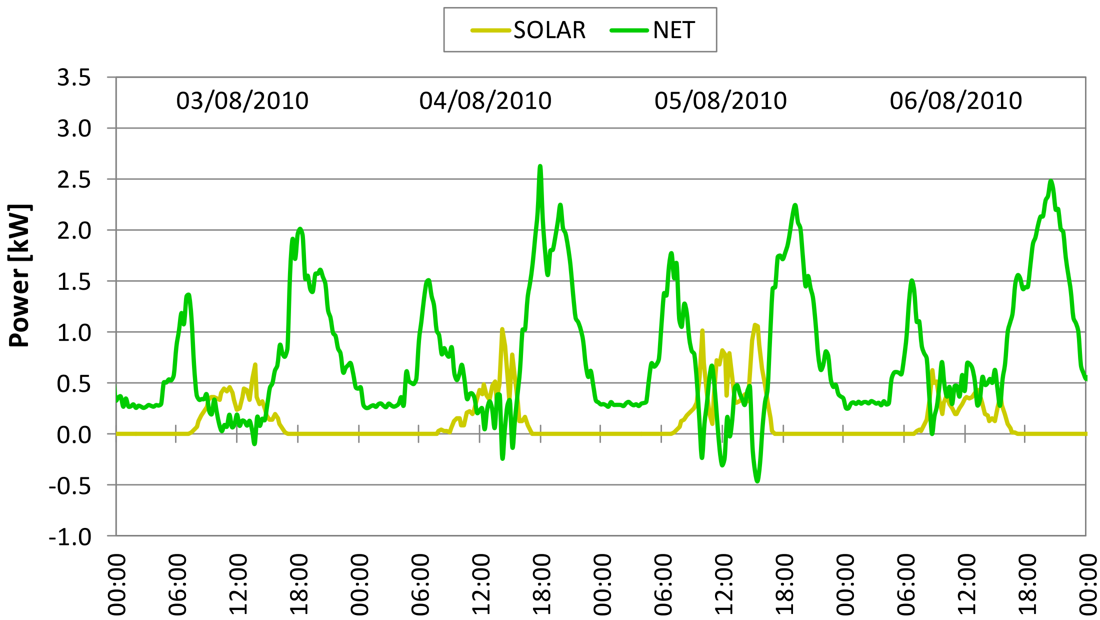


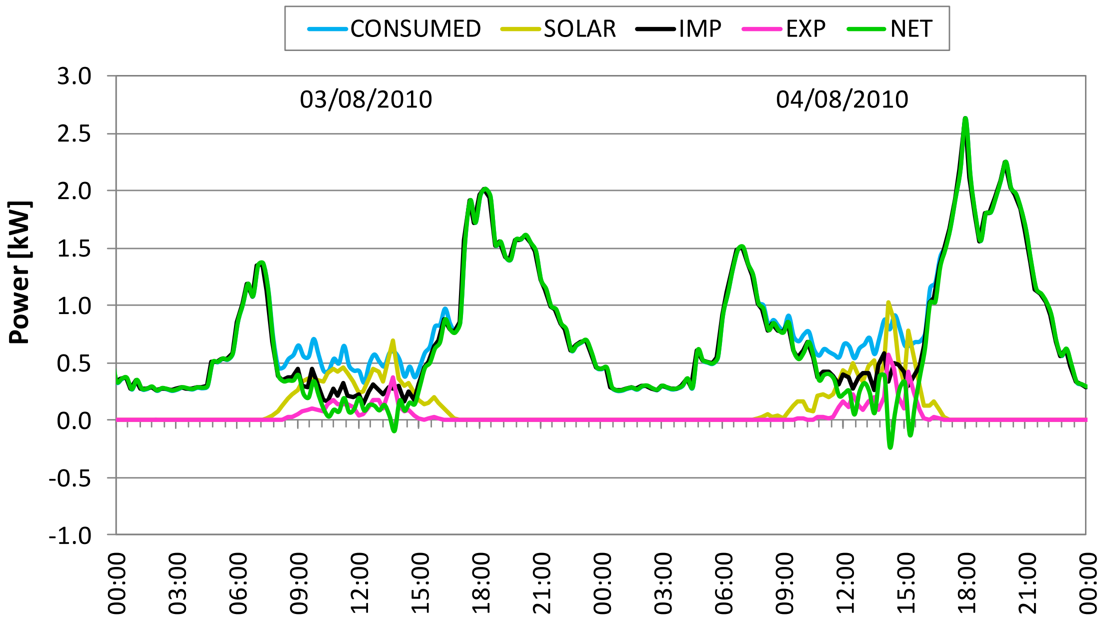
Table 6.1: Summary of daily minimum and maximum ambient temperatures (T_a), and average peak solar and net electrical power demands, during the coldest 2010 period.

Date	03/08/2010	04/08/2010	05/08/2010	06/08/2010
Min. T_a (°C)	7.1	8.5	3.7	4.8
Max. T_a (°C)	12.4	12.5	13.4	12.3
Peak Solar (kW)	0.69	1.03	1.08	0.63
Peak Net (kW)	2.01	2.63	2.25	2.48
Minimum Net (kW)*	-0.09	-0.23	-0.46	-0.01

* Note that a negative net power indicates that excess solar power is provided to the grid.

Figure 6.2 further examines the average electrical power profile of the 21 houses during two days of this cold period, by adding the consumed, imported and exported electrical powers. Note that the figure indicates that the average house was importing and exporting energy simultaneously, which reflects the fact that some of the houses were importing energy, whilst others were exporting at the same time. Despite this, the average net power is equal to the difference between the average imported and exported energy. This shows the net impact of aggregating a number of houses in an estate on the local grid which is to be expected due to the different patterns of energy use/generation in individual homes.

Figure 6.2: Average measured i) consumed, ii) solar, iii) imported, iv) exported, and v) net electricity power profile, of 21 houses, for a two-day period surrounding the coldest day of the year (03/08/10).



The figure shows that both days have morning and larger evening electrical peak demands, whilst during the day, a steady load of about 500-700W is consumed. This steady day-time electrical load is fairly well matched by the solar output, and hence does not draw a significant amount of power from the grid. In contrast, both the morning and evening peak electrical demands occur pre and post daylight hours, and as such the demanded power is purchased from the grid. Despite this, the average peak electrical demand during the coldest period of 2010 is 2.6kW, which is most likely dominated by reverse-cycle air conditioner heating, but also includes power used for cooking, lighting and other appliances. This Lochiel Park peak winter power demand is hence somewhat lower than the typical SA house operating a reverse-cycle air conditioner for heating, and also highlights the impact of good thermal design and installing highly efficient reverse-cycle air conditioners.

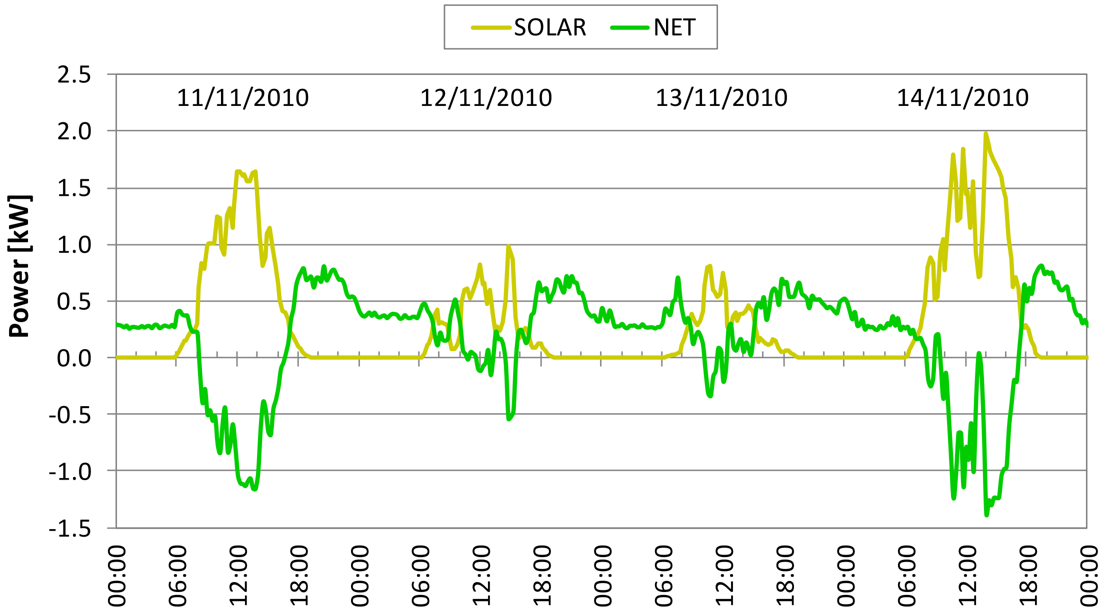
6.1.2. Spring Period

Table 6.2 below summarises the daily minimum and maximum daily temperatures, and the average solar and net electrical power demand during a typical Spring day, for 26 houses. Compared to the corresponding data for the coldest 2010 period (Table 6.1), the peak net electrical power demand is lower. This is due to the increased average peak solar power generation (higher solar intensities and longer sunlight hour etc.), and the reduction in average electrical power demand. The 15 minute average solar and net electrical power demand for the same four-day period is shown in figure 6.3. The figure also shows that on average, the photovoltaic systems are producing a maximum power amounting to 86% of the peak power installed capacity during this period.

Table 6.2: Summary of daily minimum and maximum ambient temperatures (T_a), and average peak solar and net electrical power demands, during a typical 2010 Spring four-day period.

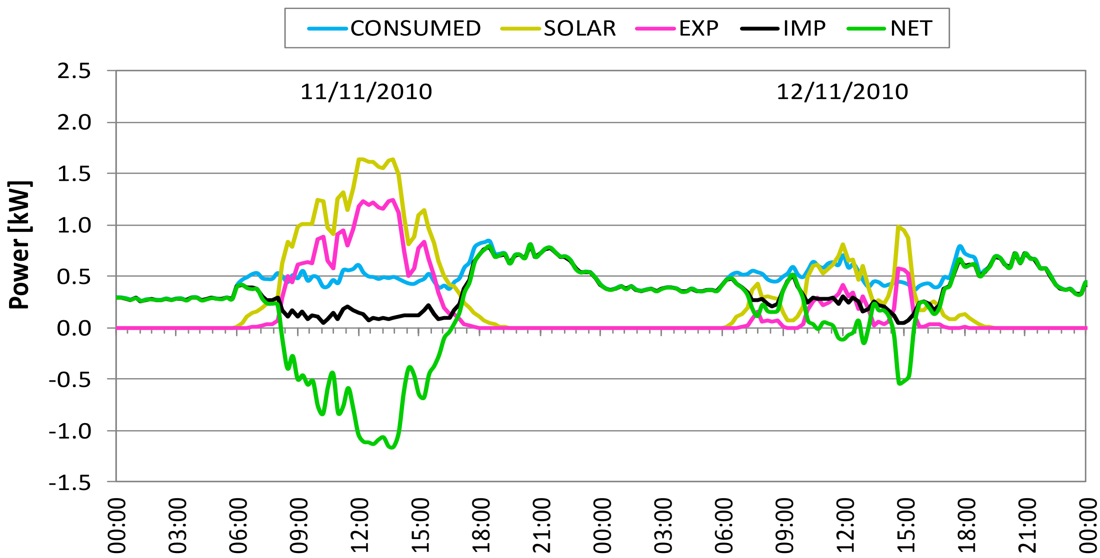
Date	11/11/2010	12/11/2010	13/11/2010	14/11/2010
Min. T_a (°C)	15.2	21.6	14.7	12.5
Max. T_a (°C)	32.1	22.2	17.6	22.6
Peak Solar (kW)	1.64	0.98	0.81	1.98
Peak Net (kW)	0.81	0.72	0.71	0.81
Minimum Net (kW)	-1.15	-0.54	-0.33	-1.37

Figure 6.3: Average measured solar and net electricity power profile, of 26 houses, for a four-day period surrounding a typical Spring day.



The above figure is further examined in Figure 6.4, which in addition, shows the consumed and the imported and exported electrical power. The consumed power is shown to be steady in comparison with winter (Figure 6.2), as there is no need for heating and or cooling during this period. This reduction in consumed energy, together with increased solar power generation, increases the average net energy; as seen below for a sunny day (11th). This however, seldom exceeds 1.0kW per home after aggregation. In contrast, the solar power for a partially cloudy day (12th) is lower. Despite this, the solar power approximately matches the average electrical demand.

Figure 6.4: Average measured i) consumed, ii) solar, iii) imported, iv) exported, and v) net electricity power profile, of 26 houses, for a two-day period surrounding a typical Spring day.



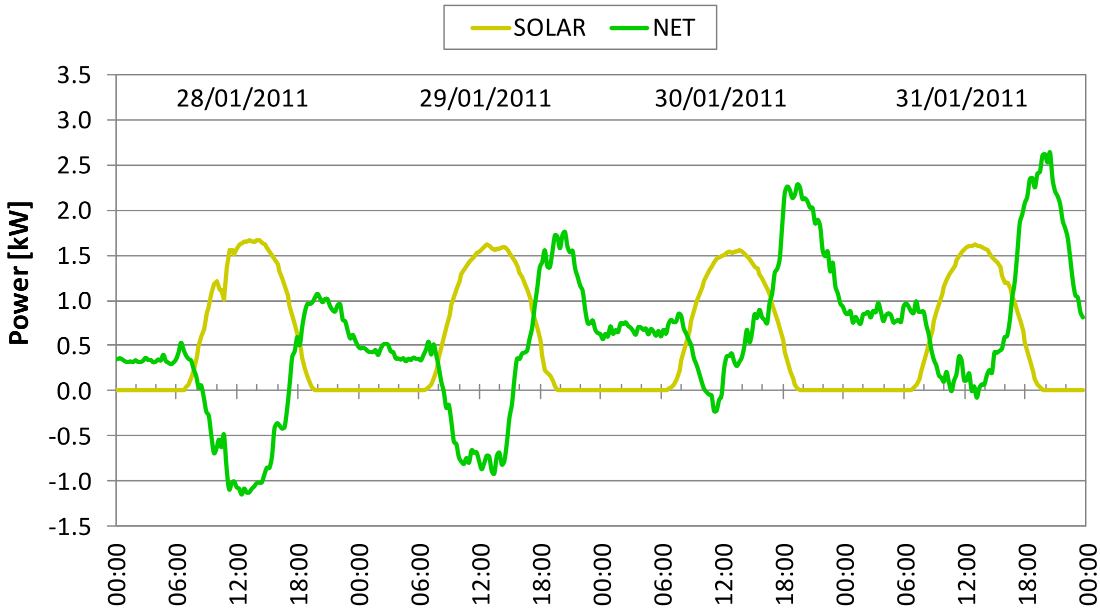
6.1.3. Summer Period

the daily minimum and maximum temperatures and peak solar and net powers are listed in Table 6.3, whilst the average 15 minute solar and net electrical power, of 27 houses, during the four hottest days of 2011, are shown in Figure 6.5.

Table 6.3: Summary of daily minimum and maximum ambient temperatures (T_a), and average peak solar and net electrical power demands, surrounding the hottest 2011 day.

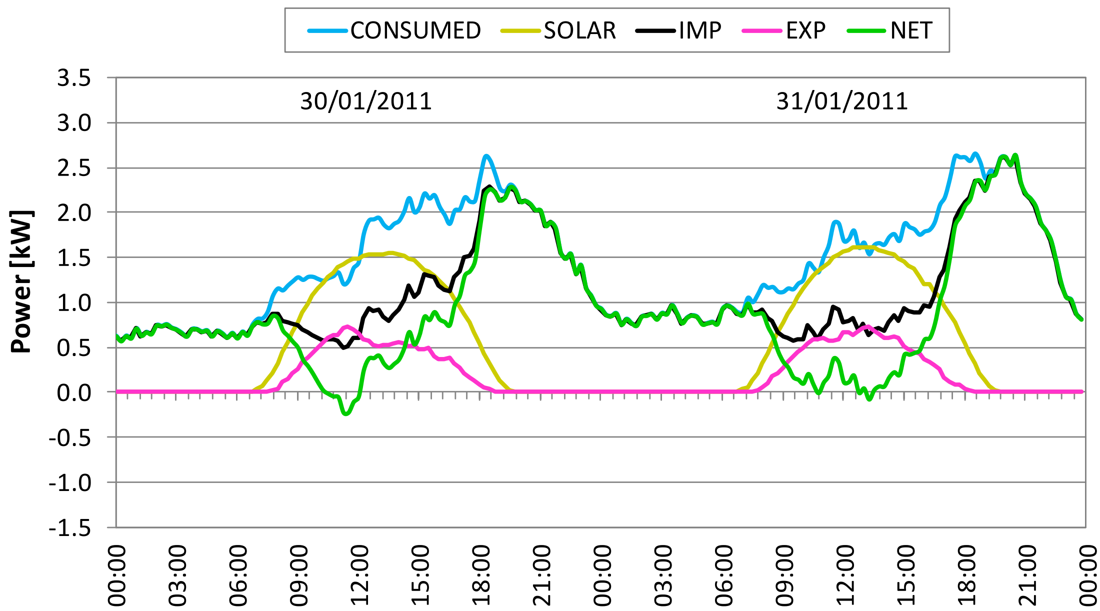
Date	28/01/2011	29/01/2011	30/01/2011	31/01/2011
Min. T_a (°C)	15.8	18.5	25.8	28.2
Max. T_a (°C)	31.8	37.7	42.5	42.9
Peak Solar (kW)	1.67	1.62	1.55	1.62
Peak Net (kW)	1.07	1.75	2.28	2.63
Minimum Net (kW)	-1.15	-0.92	-0.23	-0.08

Figure 6.5: Average measured solar and net electricity power profile, of 27 houses, for the hottest four-day period of the monitoring year (28-31/01/11).



The above figure shows that the net power sharply increases at about 18:00, each day, and that the net peak demand increases in subsequent days. The overnight base load power is also shown to increase each day (with maximum daily ambient temperature). This indicates increased use of reverse-cycle air conditioning for cooling, which can be more easily seen in Figure 6.6, which also shows the consumed and the imported and exported electrical power. Note that during the daytime period some houses exported power whilst others imported it (as shown by the averages in the figure). The net impact reduces the net demand on the grid during daytime hours.

Figure 6.6: Average measured i) consumed, ii) solar, iii) imported, iv) exported, and v) net electricity power profile, of 27 houses, for a two-day period surrounding the hottest day of the year (31/01/11).



The solar systems, seen in the above figure, are shown to provide a significant portion of the consumed power, between the hours of 9:00 and 16:00. The figure also shows that the local generation continues contributing during the house peak demand which takes place around 6.00pm which will reduce and delay the peak demand impact on the grid. Despite this, the peak aggregated consumed power demand is 2.6kW, which takes place after 8.00pm. This is similar to the winter peak, and is considered very low in comparison to a typical SA house operating a reverse-cycle air conditioner during a similarly hot period.

6.1.4. Summary

The daily solar and net electrical power profiles, corresponding to hot and cold spells, as well as a typical non-heating or cool period, have shown the impact of low energy housing and solar system installation on the grid. The figures showed that for Lochiel Park houses, the solar systems generally offset heating and cooling load during winter and summer months, during the day, however, they generally do not significantly reduce peak demands for heating or cooling after sunset. In contrast, the Lochiel Park houses generally export power to the grid during the milder months, where neither heating nor cooling are required. The aggregated values of both net power imported from the grid and exported to it is less than anticipated in other Adelaide houses with the net peak power demand not exceeding 2.6kW per home and having similar values in both summer and winter. The aggregate peak springtime power export did not exceed 1.4kW per house given the average installed system capacity was 2.3kW$_p$.

6.2. Impact of Air Conditioners on the Peak Electrical Demand

6.2.1. South Australia Peak Event Days

Details of South Australia's summer peak power demand for the last three years, i.e. 2009-11, are listed below in Table 6.4 (ESIPC09, AEMO09, AEMO10). The table shows that peak events have taken place in January for these years and the last two events occurred at early-mid afternoon. Each peak event has occurred on a weekday, as expected, where commercial and industrial demands contribute to the peak electrical demand. It is worth noting that the 2010/2011 summer period did not witness a prolonged heat wave period unlike the previous two summers. In contrast with section 6.1, this section focuses on the data from the detailed monitored houses where the air conditioning systems and indoor temperatures were monitored.

Table 6.4: Summary of South Australia peak electricity events, 2009-11.

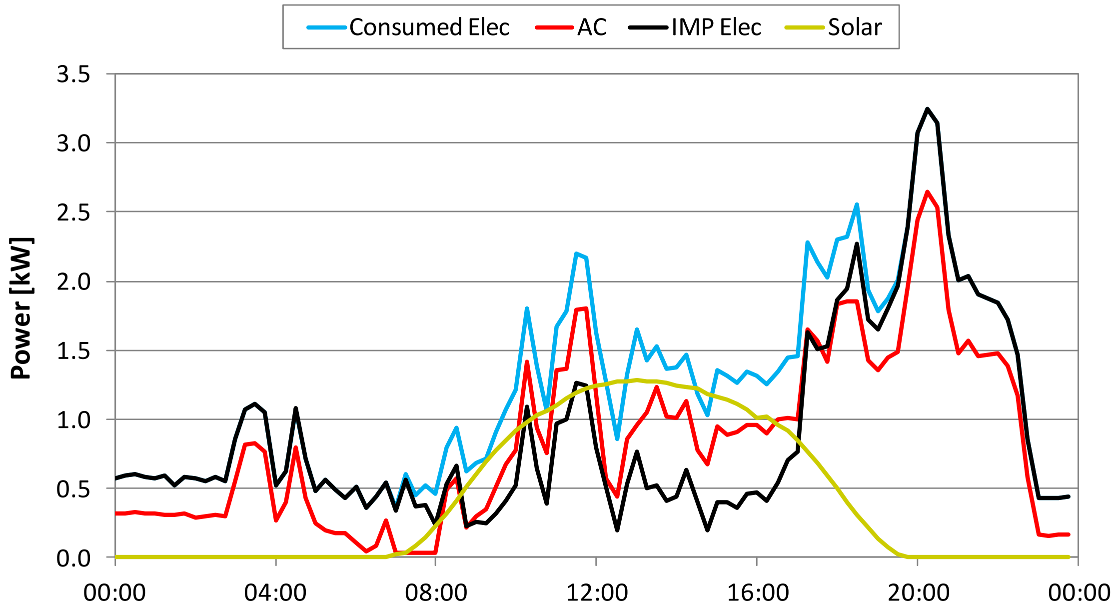
Year	Date	Time	Reference
2008/09	January 29	-	ESIPC09
2009/10	January 11	12:30	AEMO09
2010/11	January 31	16:30	AEMO10

6.2.2. Performance of Lochiel Park Houses during Peak Demand Events

2011 Peak Demand

Figure 6.7 shows the average instantaneous power consumption of the air conditioner, the house total load, the solar system generation and the resulting electricity imported from the grid during South Australia's peak demand day for 2011. Note that the data shown is averaged for periods of 15 minutes, and for each of the five houses that use reverse-cycle air conditioners for cooling (as shown in section 0). The figure indicates that the average peak Lochiel Park air conditioner power usage occurs between 17:15 and 22:30, which is after the state's peak demand, which occurred at 16:30. At the time of the state peak, the figure also shows that the houses aggregated average air conditioner load is matched by the power generated by four of their PV systems, i.e. the air conditioning load has not placed a burden on the electrical grid infrastructure during the state peak period.

Figure 6.7 Measured 15 minute average instantaneous i) consumed electrical (Consumed Elec), ii) air conditioner (AC), iii) imported (IMP Elec) and iv) solar powers, of five houses, during the 2011 South Australian peak electrical demand.



The above figure also shows that on average, the houses are only demanding an additional power of about 500W during the peak event, which is imported from the grid. This demand on the grid power is very low in comparison with typical demand of SA houses when operating a reverse-cycle air conditioner and do not have a solar system installed. The average air conditioner power is shown to increase after 17:30, as this is when the Lochiel Park residents, who were not home at the peak time, arrived home. The average AC power increases with time, as the solar contribution decreases, hence increasing the imported power. The average LP AC power peaks at 20:15, a time which the solar systems could not contribute to reducing the demand.

Note that

Figure 6.7 shows the effects of aggregating, and for reference, the minute by minute individual electrical power profiles of each of the five houses can be found in Appendix A. For comparison, the electrical and air conditioner power demand, shown in

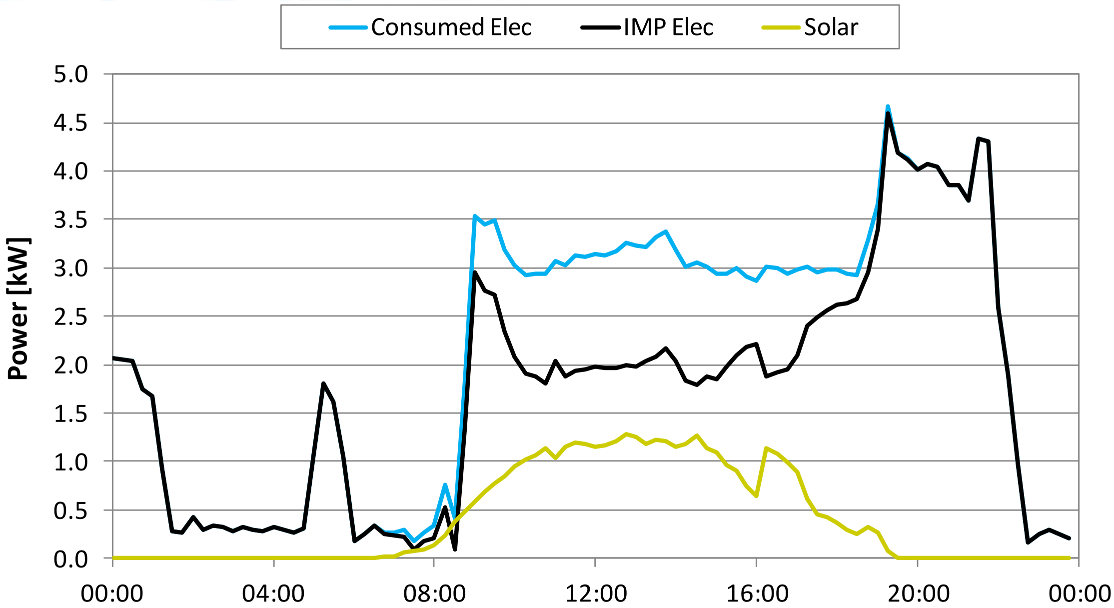
Figure 6.7, are compared with those of five similarly monitored Mawson Lakes houses; this is further discussed in section 6.2.3.

2010 Peak Demand

The 2010 peak electrical demand occurred in January 2010 (Table 6.4), which is the first month of collecting monitoring data. As such, the electrical, solar and hence imported power, corresponding to this peak day, is shown for a single house in

Figure 6.8. Note that this was the only house monitored during this month, and this house is only generally monitored. As such, an exact air conditioner power profile cannot be determined, although the figure suggests that this was used between 08:30 and 22:30. The results show the positive impact of the PV system on peak demand reduction in the early afternoon. However, as the house peak demand takes place between 19.30 and 22.30, the PV system does not make a contribution during this period.

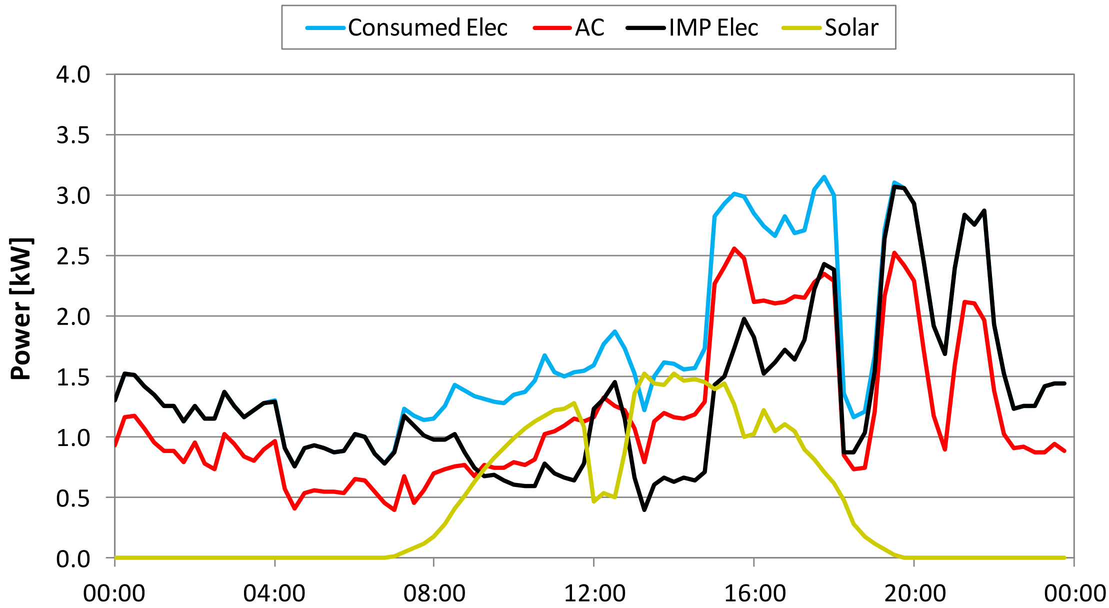
Figure 6.8 Measured 15 minute average instantaneous i) consumed electrical (Consumed Elec), ii) imported (IMP Elec) and iii) solar powers of the only monitored house during the 2010 South Australian peak electrical demand.



Due to the lack of detailed monitored January data, Figure 6.9 shows the average consumed electrical, solar, air conditioner and hence imported power profiles, of two detailed monitored houses for the hottest February day, i.e. the 9th. The state peak demand on that day was close to the maximum of the year which took place on 31st January.

The figure below shows that on average, the two houses used air conditioning for the entire 24 hour period corresponding to the hottest February day. This occurred as the previous day experienced a similar maximum ambient temperature, and air conditioners were left operating from the previous night. Note that the air conditioner power sharply increases at 14:45 and then fluctuates between 18:00 and 22:00. This shows the effects of averaging, as one of these households maintains a steady air conditioner power profile, whilst the other household switched their AC on at 14:45 and then it cycled on and off on an hourly basis between 18:00 and 22:00. The actual load profiles of each individual house can be found in Appendix A. The figure demonstrates the significant contribution of the PV system during the first peak demand period. However, the PV output power is nonexistent during the later peak demand period.

Figure 6.9 Measured 15 minute average instantaneous i) consumed electrical (Consumed Elec), ii) air conditioner (AC), iii) imported (IMP Elec) and iv) solar powers, of two houses, during the hottest February day in 2010.



6.2.3. Comparison of Lochiel Park and Mawson Lakes Peak Demands

The total electrical and air conditioner power consumption profiles of the five Mawson Lakes and the five Lochiel Park monitored houses, for each respective peak electrical demand day, are shown in Figure 6.10 and Figure 6.11, respectively. Note that the solid black line of Figure 6.11 represents the imported electrical power, which should be compared to the blue line of Figure 6.10. The imported power shows the effects of the PV systems, i.e. less power is drawn from the grid.

Figure 6.10 Measured 15 minute average instantaneous i) consumed electrical (Consumed Elec), and ii) air conditioner (AC) powers, of the five Mawson Lakes houses, during the 2003 peak electrical demand day.

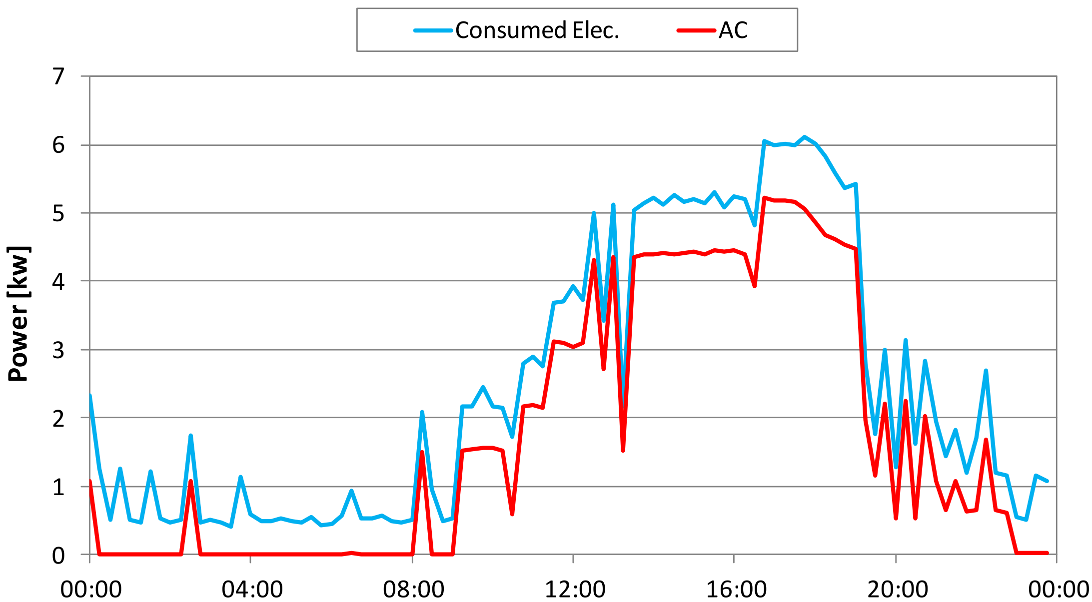
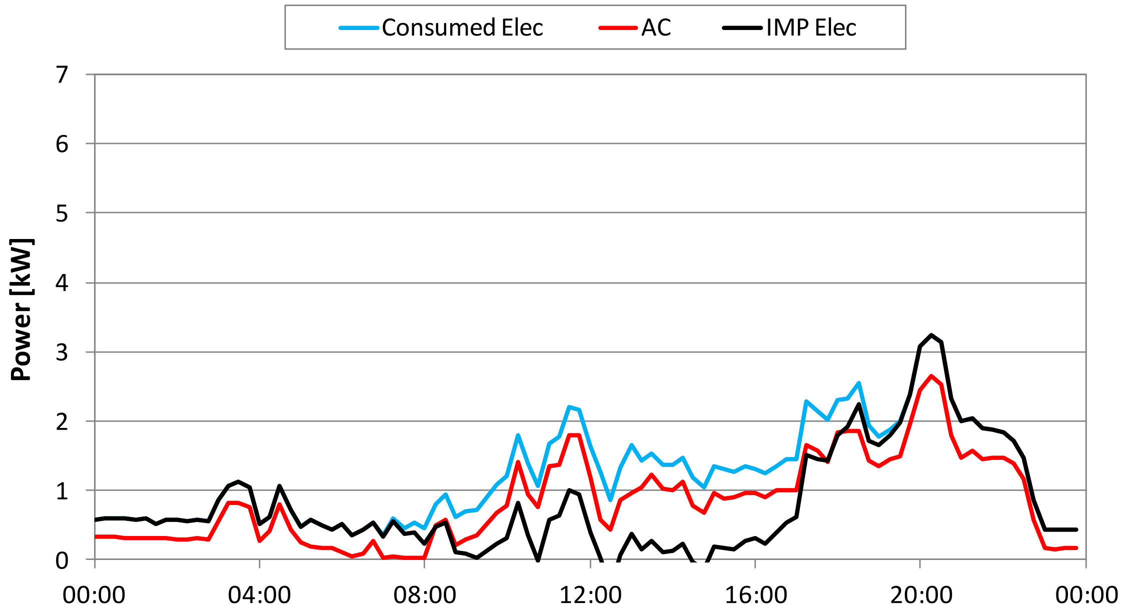


Figure 6.11 Measured 15 minute average instantaneous i) consumed electrical (Consumed Elec), and ii) air conditioner (AC) powers, of the five Lochiel Park houses, during the 2011 peak electrical demand day.



Both figures show that on average, air conditioners are responsible for about 70% of the household's power demand, during a peak demand day. The important difference between the figures is the significant reduction in air conditioner power demand for the Lochiel Park houses, despite the increase in Lochiel Park household conditioned floor area (recall Table 5.1). This reduction in AC demand is caused by the higher average house star ratings and the installation of highly efficient reverse-cycle air conditioners (limited to 4kVA input). This shows an average peak power demand reduction at Lochiel Park to about half the average power at Mawson Lakes.

While these initial findings need considerable more data gathering and analysis, the technical and economic implications of reducing the peak power demands of Australian housing to around 3kW are enormous.

7. HOUSEHOLD ATTITUDE SURVEY METHODOLOGY AND RESULTS

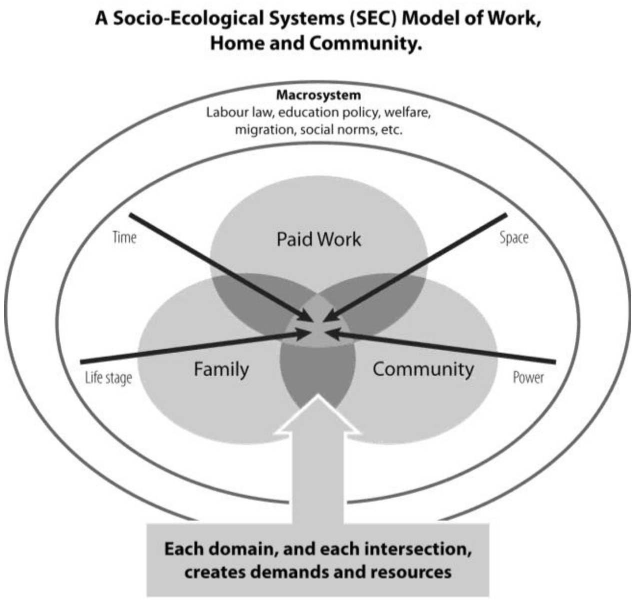
7.1. Introduction

Lochiel Park is a master planned community that seeks to demonstrate that urban, medium-density housing developments can have sustainable living as their core principle. All houses are serviced by solar PV cells, recycled water systems, gas-boosted solar hot water systems and have a minimum 7.5 star thermal performance rating. Houses are, or will be, equipped with EcoVision monitors that allow external monitoring of household energy and water consumption. The monitors also facilitate householders to monitor their own energy and water use, with the intention that this will allow them to reduce their consumption. However, if the innovative features of the homes in Lochiel Park are to reduce household energy consumption effectively and sustainably, there needs to be an understanding of the social factors that shape household energy consumption.

Prior research on household behaviours relevant to domestic energy and water use has been dominated by disciplines that are individualistic in orientation, notably psychology and economics. Critics of this perspective point out the mistaken assumption of rationality as the primary driver of behaviour (Eiser, 1994) and the conception of the individual as an autonomous free-acting agent (Kaiser et al, 1999). By contrast, sociological analysis of household energy consumption is underdeveloped, despite evidence that such behaviour is mediated by social variables such as gender, income, education and place of residence. One compelling indicator of the need for a sociological framework is the ‘green attitudes, brown behaviour’ paradox, relating to the fact that higher greenhouse gas emissions per capita are often generated by those expressing higher levels of environmental concern (Sandu and Petchey 2009). This would suggest that a households’ ability to effectively change habits, practices and behaviour is affected and influenced by a number of complex and interacting factors that may be overlooked without consideration of the broader social perspective.

Encompassing these ideas is Bronfenbrenner’s (1979) ecological systems theory, as applied by Voydanoff (2007) in relation to work, home and community. This approach distinguishes the microdomains of work, home and community (in which face-to-face relations occur); the meso-systems where these domains intersect (e.g. where work affects home life and vice versa); the ecosystems that represent the external environment in which a person does not participate but is affected (like the school system affecting a working parent), and the larger macrosystem (the over-arching law, culture, institutions and broad belief settings). Together, these make up an ‘ecological system’ of work, home and community. Voydanoff (2007) melds a demand-resource model (Demerouti, Bakker, Nachreiner & Schaufeli, 2001) with this ecological system, to identify the characteristics of work, home and community that create either resources or demands. Demand-resource models consider the degree to which structural, social and psychological characteristics of key domains place demands on an individual or group or alternatively create resources for an individual or group. This is a useful model to apply to analysis of the demands and resources created by a work, home and community ecosystem and the way they affect and influence ‘adaptive capacity’ in relation to environmental outcomes, and is in accord with the use of the household (rather than individual) as the most common unit of analysis in ecological footprint research (Hertwich, 2005).

Figure 7.1: A socio-ecological systems model of work, home and community



The present chapter presents the methodology and results from an investigation by the Centre for Work + Life, UniSA, into the social influences on 'green' attitudes and household practices amongst a small group of residents who have moved – or plan to move – to Lochiel Park. The socio-ecological model provides a framework for considering factors affecting the behaviour of residents as they take up new homes amid their existing and changing employment, family and community relations in a unique 'green village' context. Specifically, the research aimed to explore people's motivation for moving to Lochiel Park; the expected or actual difference the move made to energy use; influences on the 'green' practices of householders, and how people interacted with the design features of their homes. In doing so, further insight can be gained into potential changes in household organisation that are necessary to use the technology effectively, along with an in-depth analysis of the factors that help or hinder households in optimally reducing their carbon footprint.

7.2. Methodology

The study adopted a qualitative, in-depth, semi-structured interview method. As this research was conducted early in the development's life when only 25% of the intended 106 dwellings were occupied, it was necessary to include prospective as well as existing residents. As such, ten interviews were conducted with 16 people (six couples and four individuals) who were resident or soon-to-be resident in Lochiel Park.

Interview times ranged from 31 to 85 minutes with an average of 53 minutes. Eight interviews were conducted face-to-face and two were conducted via telephone. All interviews were recorded and transcribed verbatim and transcripts were thematically coded.

The semi-structured interviews were guided by the following topics:

- What were people's attitudes and practices related to 'green' household behaviours prior to living in Lochiel Park?
- What factors helped and hindered household 'green' practices?

- What difference has, or will, living in Lochiel Park make to these practices?
- What is people's experience of their homes in Lochiel Park?
- What prompted people's decision to purchase properties in Lochiel Park?

These topics sought to illuminate the observations, perceptions, practices and values of the research participants to gain a finely textured understanding of the practices employed by households and why they were undertaken. The qualitative data presented here can complement the objective data presented elsewhere in this report by offering insight into why people undertake certain practices and what facilitates and hinders 'green' household behaviours. The characteristics of the research sample are presented below in Table 7.1.

Table 7.1: Characteristics of interviewees.

Identifying term	Description	Residency status
Couple One	Married; adult children living elsewhere; both work FT	Resident
Couple Two	Married; retired; adult children living elsewhere	Resident
Couple Three	Married; man works FT; woman PT	Intending resident
Couple Four	Married; two children at primary school; man FT work; woman PT work	Resident
Couple Five	Married; retired; adult children living elsewhere	Intending Resident
Couple Six	Married; retired; adult children living elsewhere	Resident
Individual One	Married; retired; adult children living elsewhere	Intending resident
Individual Two	Married; retired; adult children living elsewhere	Intending resident
Individual Three	Married; both partners work FT; adult children living elsewhere	Resident
Individual Four	Married; 3 young children; man works FT; woman not currently in labour force	Resident

In addition to the qualitative phase, a survey was undertaken of Lochiel Park residents. Eighteen functional email addresses were supplied to the research team. All eighteen were contacted. However, only six surveys were completed, despite reminders being issued. Due to this, very little weight should be attached to the survey findings which are included only to add weight to the qualitative findings. The following section summarises the findings in relation to the main themes emerging from the data.

7.3. Results

7.3.1. Consumption and comfort

Household consumption has a preponderant role in explaining domestic energy and water use, generally leading to a call for reduced consumption on the part of individuals (Hamilton and Denniss 2005). However, such perspectives often treat consumption as an individual choice, failing to recognise the way it is built into the fabric of daily lives. In relation to consumption, interviewees most frequently talked of their strategies and preferences for keeping their homes cool. The word ‘comfort’ was ubiquitous in discussion of household temperature. All interviewees wanted their houses maintained at a temperature that avoided extremes of heat or cold; that is, that made them comfortable. Couple Five articulated the position of all interviewees: *‘Look, being warm in the winter and being cool in the summer, they are important to us’.*

Interviewees were clear that ‘artificial’ heating and cooling were still required in their Lochiel Park homes:

[when] we were building, people were talking about the style of the house, ‘You might not need heating and cooling’. I totally disagree. Totally. I don’t think the double glazing is in any way enough. (Individual Four)

Most people who were resident in Lochiel Park considered that the upper storeys of their homes were uncomfortably hot during spells of warm weather. The survey conducted among Lochiel Park residents revealed that no respondent considered that the upstairs sections of their homes were comfortable in hot weather in the absence of air-conditioning. Indeed, 83 per cent considered that in hot weather upstairs rooms were moderately or very uncomfortable without air-conditioning. Couple Four pointed out that ‘*if you let it go the temperature difference between downstairs and upstairs on a warm day could get to be five degrees easily’.* Individual Four told of how upstairs rooms with a western orientation can be particularly uncomfortable in summer:

we’ve got two small west windows which were a problem in the summer. The study up there [upstairs] is one room that isn’t cooled. It was like an oven. So that is a problem ... it gets very hot up there if you haven’t got it [air-conditioning] on as a maintenance thing. So we probably would potentially leave it [air-conditioning] on if we’re generally in and around.

Couple Four suggested that even downstairs areas need some cooling, but not to the extent that upstairs ones do, ‘*You’d only need half as much coolness down here as what you need upstairs to keep [the temperature] even’.* However, most people considered that air-conditioning in hot weather was more important than heating in their home. Those participants who had spent a winter in their homes considered that they retained heat quite well and that they needed less heating than they had required in their pre-Lochiel Park homes. Couple Six articulated this sentiment: ‘*we need less heating in the winter than we probably need cooling in the summer, because of the incredibly hot days’.* Two-thirds of the survey respondents considered that the upstairs and downstairs sections of their home were moderately or very comfortable in the absence of artificial heating.

Factors precipitating use of air-conditioners

While interviewees regarded thermal comfort as very important to them, they are not passive consumers of air-conditioning in response to hot weather. The decision to switch on an air-conditioner is often the end of a process of evaluation and action, rather than an automatic response. Factors such as the style of the house, the outside temperature, the time of day, the duration of hot weather and the ability to use other measures such as fans or blinds influences whether an air-conditioner is switched on. It also influences when it is activated and the length of time it is used. Further, most interviewees did not appear to believe that their houses should maintain a more-or-less uniform temperature, regardless of season. Some were prepared to accept some degree of discomfort, particularly in relation to hotter weather. Individual One, for instance, said the house he occupied prior to living in Lochiel Park was poorly designed and was *'stinking hot in summer and we tend to just use fans and we've got a couple of evaporative coolers that just stand in suitable places. The rest of the time we just put up with it.'* Couple One, who were living in Lochiel Park at the time of interview, try not to put their air-conditioning on at the first sign of hot weather: '*We tend to persevere quite a bit.'*

While many of the research participants regarded comfort highly, they did not expect to 'switch it on' passively. Some of the respondents remarked on how they will wear particular forms of clothing to stay warm. Couple Five changed their clothing to keep warm: '*I mean I will wear an overcoat around the house sometimes ... sit in there with a rug over my lap.'* Couple Two said they do not put on a heater as their first response to cold weather: *'put on a pullover on in the house rather than put the heating on. Why walk around in your shirtsleeves when you can put a pullover on?'* Wearing appropriate clothing was only mentioned in relation to keeping warm in hot weather. No interviewee discussed clothing styles as a strategy for promoting comfort in hot weather, however. Nevertheless, in the survey of residents, 100 per cent of respondents indicated that adjusting their style of clothing was a strategy they employed in promoting thermal comfort.

Research participants also indicated that they take quite elaborate steps to use other features of their home to regulate its temperature; they are prepared to take active steps to promote thermal comfort. Many respondents spoke about how effective they found ceiling fans as an alternative or adjunct to air-conditioning. Many people also undertook considerable research to identify the most effective form of internal blinds. Couple Four, for instance, did quite extensive investigation before deciding on double blinds: *'we've got double blinds up there ... in summer in the afternoon we'd actually pull [one] down and if it's really hot we could pull the other one down'.* Couple One also use purpose-built blinds to mitigate the effects of summer sun: '*We've got a solar one up in the [name] room ... that reflects the sun, because we get a fair bit of sun from this side going up into the bathroom.'* Individual Three demonstrates the way in which people track the direction of the sun and take steps to protect the thermal comfort of their home in ways other than through use of air-conditioning:

Well, in the morning these [solar blinds] would be down from the word go, 'cause you get eastern sun in here in the morning. On a hot day I would always draw them down before I go to work ... and leave them down all day.

While many people had installed blinds of various kinds and considered them useful in regulating temperature, they do reduce the level of natural light coming into the house: *'this morning, like when I was organising making lunches and stuff and quarter to eight this morning, I had the light on'* (Couple Four).

Others made use of features such as verandas, pergolas and other external fixtures to cool the house. Couple One built a pergola to adjust the temperature of their house, '*to increase the shade into the house ... to stop all the sun coming in*'. These structures, however, require considerable assessment and planning and as such require a high level of knowledge and motivation. Individual Three pointed out:

we're waiting, we're still deciding what to do out the back here as far as shade structure for the outdoor living area. We're waiting a whole two seasons to make the decision whether we want a blind that's retractable, whether we want some kind of permanent pergola, whether we want a vergola.

Some people use natural breezes to maintain a comfortable temperature range: '*more often than not, we'll open up everything. We try to use the natural breezes this house is supposed to generate'* (Couple One). Individual Three also uses fans as the first-order response to hot weather. Air-conditioning is used as a kind of last resort: '*I use the fans a lot too ... 'cause you can have 30 with a fan quite comfortable during daylight hours, but not at night*'.

The survey of Lochiel Park residents reveals the popularity of means other than air-conditioning to cool their homes as demonstrated below in Table 7.2:

Table 7.2: Preferred means of cooling other than air-conditioning.

Means of cooling	% Using this means
Ceiling fans	100
Inside blinds	83
Double glazing	67
Opening doors and windows to promote air flow	67
Outside awnings	50
Inside curtains	33
Outside blinds	17

Respondents could nominate multiple responses, (*n* = 6), 33% response rate

Air-conditioning and tipping points

Many of the Lochiel Park residents, or intending residents, were knowledgeable about ways of keeping their homes cool in hot conditions and exercised considerable initiative in using these methods before resorting to air-conditioning. However, unanimously, research participants indicated that they had a 'tipping point' that would lead them to switch on air-conditioners. Comfort was the word most frequently used to identify this tipping point. While comfort is clearly related to temperature, it was not the only tipping point that prompted the use of air-conditioning. Comfort, therefore, needs to be understood as a multi-faceted phenomenon.

For all research participants, heatwaves are a tipping point because of the discomfort they produce. Couple One expressed this clearly: '*We tend to persevere quite a bit, especially after you have those few days [of extreme heat], then enough is enough, we need a bit of relief. Then we'll put it on.'* Couple Six agreed and indicated how thermal comfort has become a routine part of household life. They identified it as a right:

when we get these extreme periods of weather we have the right to have a choice to be comfortable. But at the same time we would not switch it on until at the point you say, '... it's just too hot inside the house now'. In that heatwave last week we ran our air-conditioner for about five days and didn't turn it off. However, the air-conditioner was turning off because the house was at a cool thermostatic temperature.

One dimension of comfort that a few interviewees identified was that hot temperatures felt uncomfortable because it robbed them of energy, which interfered with the routine of their lives. Couple Two explained this: '*I don't like the hot weather ... I don't like the fact that the hot weather depletes my energy. So when it gets to that level I have to do something about it.'* For many interviewees, the needs of young children were a catalyst for putting on air-conditioning. Couple Four explained: '*I guess when the kids start sort of mentioning that they're getting a bit [hot] ... The kids need it on.'*

Another very commonly nominated tipping point was trying to sleep in hot weather. Individual Four told how disruptive hot weather can be for sleeping and normal family functioning. The house they lived in prior to Lochiel Park only had air-conditioning in one room. '*The bedrooms at night were like 35 degrees, so it was really difficult. We all slept in the kitchen-dining room. Yeah, it wasn't good. ... it was really difficult.'* Comfort is especially important in relation to sleep. Individual Three told of how she uses air-conditioning to aid sleeping in her Lochiel Park home:

we've a timer ... we just turn [it] on just before we go to bed. It stays on for maybe two hours and then it turns off ... Because you don't need it all night, you just need it to get to sleep and be comfortable.

Some people put the air-conditioning on for a few hours in the evening and then switch it off before going to bed and they may leave fans on during the night in order to maintain a desired temperature. However, heatwaves are seen as particularly problematic for children; their need for cooling is regarded as more compelling:

it [air-conditioning] would be off say maybe seven o'clock or eight o'clock at night. We don't have air-conditioning going at night time at all. We just have occasional ceiling fans going ... but the kids just have the fan on. They sleep with it. (Couple Four)

Another important tipping point that precipitates the use of air-conditioning is health status. Couple Six told how being sick increases their use of air-conditioning:

last week we both had the 'flu and we ran it more, almost constantly, because we were just debilitated. Whereas if we had been well we probably wouldn't have used it anywhere near as much.

This couple also use air-conditioning as a preventive strategy: *'if it's going to be 43 degrees ... we've also got to look after ourselves'* (Couple Six). This is in line with government warnings that people in vulnerable groups should use artificial cooling if it is available to them during heatwaves (South Australian Department of Health 2010). A few respondents indicated that if a family member had a medical condition that was affected by temperature extremes they would use as much heating and cooling as they felt necessary. Couple Four keep the air-conditioning on more than they otherwise would because their children are allergic to dust.

You're more likely to keep the air-conditioning on then because these guys do get allergies, so the air-conditioning also helps with that because it reduces the amount of dust in the house.

Likewise, Individual Three has a son whose medical condition made it harder for him to control his body temperature, so there was no question about putting on the air-conditioning if he needed it: '*I wouldn't stop them if comfort-wise [son's name] needed to be cooler ... it would never be questioned, if he needed air-conditioning to sleep all night, he would have it.'*

In a similar vein, many respondents indicated that they are much more likely to switch on air conditioning when they have visitors. Couple Two encapsulated this:

when we had that week of very intense, 40 odd [temperatures] ... we had overseas visitors. So while we can put up with a short period of [hot] time on your own [that is, without air-conditioning], it's not very comfortable and it's not very pleasant, but when you get visitors it's unbearable. If you're going to get visitors that are only here for a few days and these are the days that you've got, it makes a really big difference.

Heating and cooling are also important in the context of particular practices. Heating, for instance, becomes imperative when people need to sit for long periods. As Couple Five says, *'as long as I'm moving about I can put up with coolness. But [partner's name] tends to be sitting much more than I am, so he can't'.* About half the study sample indicated that children had individual heating in their rooms in order to complete their homework. Couple Two were typical in explaining '*if they [the children] were studying in their bedrooms in winter they would have a small fan heater'.*

Our survey of residents asked them to nominate the factors that influenced their decision to use air-conditioning. The reasons nominated in decreasing order of frequency are set out below in Table 7.3.

Table 7.3: Reasons for using air-conditioning.

Help with sleeping
Get house to comfortable temperature
For the welfare of visitors
For the welfare of children
Allow usual activities to be undertaken

Respondents could nominate multiple responses. n=6, 33% response rate.

This reveals that there are many tipping points and that comfort is a multi-dimensional concept and any attempt to understand patterns of energy use in households needs to understand the many meanings that people attach to 'comfort' and to comprehend its place in routine household practice. We also need to understand those practices in light of wider social structures and processes. The notion that air-conditioning is a right, for instance, reflects a wider social expectation that air-conditioning is increasingly a normal feature of household life.

Effective use of air-conditioning

Many respondents indicated that, while they used air-conditioning to promote their comfort and well-being, they tried to use it in particular ways that were efficient and parsimonious. Couple One also indicated that they use the air-conditioner only sparingly and episodically to bring down temperature spikes and get particular parts of the house to a comfortable temperature: *'It still gets fairly hot in the rooms upstairs ... it it's too hot, we might turn on the air conditioner for about an hour, just to cool the place down.'* About half of the interviewees exhibited high levels of knowledge about the most efficient ways to use their air-conditioning. Couple Two said:

We leave our air conditioner set at 26, not 19. I don't like walking into houses that are freezing in the hot weather. That's ridiculous. Plus it takes a lot more energy to get from an outside temperature of 39 down to 19 ... No air-conditioning system can lower it more than 14, 15 degrees from the ambient outside temperature.

Couple Six also try to use their air-conditioning efficiently to maintain a comfortable household temperature in heatwaves:

I think you can make it [air-conditioning] work for you ... if you know it's going to be 43 degrees for the next seven days ... you're going to manage your air-conditioning so that your house ... doesn't overheat because if you let it get too hot then put air-conditioning on it's going to work like crazy to get it cold ... put your air-conditioning on so that it can actually sustain the thermostatic temperature that enables it go on and off ... and therefore I think more efficient.

The research participants, for the most part, indicated a high degree of awareness of the temperature ranges that felt comfortable for the routine running of their households. Couple Four, by way of example, run their air-conditioner in summer at 23.5, *'that's just what we're comfortable with'.* Individual four nominated *'probably 18 or 19, sort of thing, I'd say'*. Individual Three suggested that her 'comfortable temperature' depends on the weather conditions:

On a 40 degree day, it [house] will get to 30. So it's certainly not unbearable, but after a few days then you think, probably if it's over 30 when you get home from [work], it's nice to reduce the temperature to ... about 26, so I'm quite comfortable with that. That's only a few degrees but it makes a difference.

While people unanimously indicated that they needed to use air-conditioning at certain times and in particular situations, many believed that some of the features of their Lochiel Park houses did mean that they used them less than they otherwise would have, as Couple Six explained:

Apart from that [heat-wave] we haven't [used the air-conditioner], it hasn't been too bad here. It's more comfortable in here for longer periods of time without heating and cooling ... Because of the qualities of the house it knocks the peaks and troughs off the temperature extremes ... it just reduces the amount of time you need to use it [air-conditioning].

Clearly comfort is a major factor in shaping use of air conditioners and energy use. Comfort drives energy use even amongst these residents in houses specifically designed for energy-efficient thermal comfort, who have exceptional levels of knowledge and who have a firm commitment to reduce their negative environmental impacts. Our data illustrates 'thresholds' of comfort and these are shaped by *the kind of effects* (for example health consequences) and *who is affected*, that is, whether effects fall upon vulnerable or dependent residents such as children, or on visitors. In the next section we turn from comfort to convenience, which also emerged in our data as a significant factor affecting behaviours.

7.3.2. Consumption and convenience

As noted by Hobson (2003), consumption is built into the routine practice of daily life; it is part of the infrastructure that underpins routine activity for many households. Indeed, much of the household consumption of energy is used in the interests of convenience. Dishwashers, microwave ovens, refrigerators, freezers and washing machines, for example, are valued because of the way they allow many of the routine aspects of household life – the storage and preparation of food, together with personal and household cleanliness – to be more easily and quickly undertaken. Likewise many appliances such as computers allow adults to work or run businesses from home, children to complete homework and permit otherwise time-consuming activities, such as paying bills, to be conveniently undertaken at home.

The largely unexamined importance of convenience in contemporary domestic life has two important implications for understanding patterns of energy and water consumption. The first is that convenience will promote particular forms of consumption, notably by electrical appliances. The patterns of consumption for appliances in the past few decades are evidence of this. However, it also means that householders may be less likely to practice environmentally friendly behaviour if it does not promote, or hinders, convenience. Individual One, for instance, had a long-standing commitment to sustainable living, but revealed that if household routine demanded it he would use convenient forms of heating, even if they were not particularly environmentally friendly. His house (prior to Lochiel Park) was 'permanently' heated by slow combustion stove, but at particular times instant heat was needed, '*having a radiator on first thing in the morning to have breakfast ... some nights when you come home and you do have to put the radiator on'.*

Couple Five also pointed to the way heating and cooling is interwoven with the need to get adults to work and children to school on cold mornings: *'you know ... when you're working and you get up in the morning, you want the house warm ... you've got to get yourself ready and the kids and so on. You want instant heat*.' This couple were extremely knowledgeable about sustainable ways of living, but their comments highlight the importance of understanding wider influences on behaviour. Behaviour that supports the effective functioning of complex and busy household routines is more likely to be practised than behaviour that does not support domestic schedules. Individual Two also pointed to the way less environmentally friendly choices may be made in the interests of heating a space quickly and for short periods, *'we do use radiators kind of like, now there's only the two of us, sometimes we're not here for long. We will heat with the radiator.'*

Couple Three both had demanding jobs and teenage children living at home. Despite being committed to reducing their energy and water use, they revealed that maintaining a household routine that suited all its members meant they used energy that they would not otherwise have used. For instance, it was necessary for a smoothly running household that dishes were done in the evening. However this required electrically boosting the solar hot water supply: '*it's just that sometimes, particularly during winter, you run out of hot water in the evenings when you are trying to wash up or something and there is no hot water'* (Couple Three). This is not so much a choice to consume energy, but an action to keep a busy household functioning effectively. Ample evidence indicates that for many contemporary households, especially those with children living at home, lives are intricately organised and timetabled (Williams et al. 2009: 41). The attempt to juggle a number of demands in the context of limited time meant that environmental concerns can be accorded less priority than the emphasis placed on convenience even when levels of knowledge and commitment to reduce energy use are high. One member of Couple Three revealed how when she is busy she will make convenience a priority even though it contravenes her long-held environmental concerns: '*Putting clothes on the line instead of putting them in the dryer and stuff like that. It is like, "I haven't got time to fiddle with the clothesline when it's wet and raining" and I* *stick them in the dryer.'*

Convenience and household dynamics

It is important to recognise that some behaviour may be perceived as more necessity than choice in the face of complex household schedules and the various demands of household members. Several people told us, for example, of how the needs and preferences of teenagers could compromise 'green' behaviour. This is consistent with ABS (2009) findings that people aged 18–24 were less concerned with environmental issues than other age groups. Couple Three, for instance, outlined how their teenage son's habits required them to use energy they would not have otherwise used: *'the classic thing, when it was a cold day and it [water] didn't heat up during the day and [child's name] had his long shower in the morning and drained [all the hot water]'.* Couple Two also pointed to the way that young people have a set of practices that can undercut attempts to have an environmentally friendly household: *'they had longer showers than we did and I don't know how clean 'clean' is, but sometimes you wonder, "how much longer do you have to be in the shower?"'.*

Couple One told how children in particular were 'heavy' users of household appliances: *'they're light leaver on-ers, love the computer and really into all the gadgets'.* Survey respondent three agreed that young people's habits and practices made limiting energy use in their home *'difficult to achieve with two young adults in the house'*. Individual Three also revealed that her children, while they lived at home, were less frugal with energy use than she or her partner were:

they don't think about the cost ... just how comfortable they are and they would turn things on and off a lot more … lights on and off that would just bug me and I tend to just turn them off.

While parents commented frequently on the way in which children's habits, preferences and practices could thwart running an optimally environmentally friendly house, they rarely indicated that they took issue with them. They said that they tried to educate their children about the benefits of frugality and consider that in many instances this has paid off in the long-term; children who are now adults are perceived to exhibit greater frugality than they exercised during adolescence. However, very few interviewees reported clashes with their teenagers over their energy-related behaviour. This suggests that parents will accommodate particular practices, even if somewhat unwelcome, because they respect their children's needs and because it may be preferable to domestic disharmony.

Convenience and working life

Couple Six are instructive in that they exemplify increasing environmental awareness among the Australian population. Like many people, they are now much more aware of the need to reduce energy consumption and greenhouse gas emissions. However, they are also honest about the way busy working lives push environmental concerns to the periphery of their consciousness. They do not think about environmental issues in relation to their behaviour at home. Their previous lack of attention to environmental issues, in part, reflects the low profile of the issue among the population until recently. But their remarks are a revealing commentary on the way busy lives mean that people focus narrowly on doing what needs to be done simply to keep their daily routine operational. Their observations of their life since retirement probably still hold true for many contemporary Australian households. Their remarks also illustrate the benefits for pro-environmental behaviour of having time to think about the implications of their actions and to change their practice accordingly:

We were busy working people ... I don't think we thought about it [the environment] ... just an old habit that you'd go and buy an appliance that looks like it is going to do the job ... we were probably working 50 hours per week [each] ... You do things, you've got housework, got washing and whatever to do on the weekend ... and all of that just occupies your mind. Whereas now, we don't have to go to work so that makes a lot of difference ... not having to think about work or prepare to go to work or come home from work or not to have to rush or program other things ... now we can go 'OK, we need a new electric kettle. Will we buy one? No we won't. We'll go and buy that thing ... which only heats the amount of water you need for a cup of coffee' ... Yeah, well I think we were indicative back then of most people – their environment is not the top of your tick list.

Another couple, who are unusually well-educated about, and highly committed to, environmental issues, also revealed how the schedule of working and domestic lives crowds out the possibility of thinking and acting in other ways, even when those ways are desired:

one of the things about working and having to file out early-ish in the morning and get kids off to school or getting off to work or whatever ... your time is more limited ... you don't get the same pleasure out of growing food slowly, or cooking slowly or living slowly ... As much as I would like always to do the environmentally [friendly] thing, it doesn't happen. (Couple Five)

In this account, time is not available to change behaviour; busy lives pre-empt it. Couple Three also have a long-standing and deeply held commitment to living more sustainably, but testify to the way that some behaviours have to mesh with individual and household routines. Behaviours or practices that thwart the easy maintenance of routine are less likely to be practised:

we basically do everything that we can think of that is reasonable and coming back to this convenience factor I suppose. We don't sit the bucket under the shower to catch the water ... It is like, I haven't got time to fiddle around ... there are a few things like that and you think, 'Well it's just too much like hard work'.

Couple Five also reveal that a commitment to living more sustainably requires a kind of constant consciousness about the implications of even mundane domestic tasks. They reveal that habits of thought and practice often take precedence over more considered behaviour:

I think all the time, you're weighing up all those these things. It's often more convenient to take the car or turn a heater on or ... say some cooking things where you might think about how much power you're using when you cook. But you just do it.

These accounts illustrate how changes to habits take time: it takes time to think about change and then adopt new systems. In these experiences, time is a resource that makes change possible and without it new ways of living are crowded out.

Even something as apparently innocuous as turning off appliances at the wall is not a simple attitudinal or behavioural issue and demonstrates how pervasive and multi-faceted the notion of convenience is. Apparently simple actions have a number of potentially unwelcome consequences and many people are therefore reluctant to switch them off. In the survey of Lochiel Park residents, not a single respondent indicated that they always turned off computers when not in use. While 60% said that they mostly turned them off, 20% indicated that they sometimes turned them off and a further 20% responded that they never turned off computers when not in use. One respondent said that they did not turn off their computer so as *'not to lose information stored'* (survey respondent one). Another indicated that they did not turn off their computer '*just for the ease of starting up'* (survey respondent two). Sixty per cent of those surveyed said they never switched off TVs and other home entertainment equipment when not in use. One respondent illustrates the primacy of convenience in shaping behaviour. They do not turn off TVs and related equipment because it is *'Too difficult to access the switch and the number of appliances plugged into the sockets makes it difficult to determine the correct switch'* (survey respondent two). Only 20 per cent of those surveyed said they always switched off TVs and other equipment when not in use.

These accounts illustrate how pro-environmental behaviours often take more time in themselves. Further, the processes and decisions to reassess behaviour and do things differently also take an investment of time and thought. Even amongst these householders with firm commitments to reduce energy use, the issue of convenience frequently outranks changed behaviours, especially where lives are made time poor by work arrangements, long hours or intensive care responsibilities. Strong values and high levels of knowledge are trumped by convenience in this social context, as many interviewees acknowledged. In the next section we turn to the issue of cost and the contribution it makes to behaviour.

7.3.3. Cost

It is evident that the research population in Lochiel Park weigh their behaviour related to energy consumption by reference to notions of comfort and convenience. This demonstrates that knowledge levels and environmental attitudes are of themselves inadequate predictors of behaviour. This research population has a strong commitment to pro-environmental behaviour and high levels of knowledge, yet environmentally related behaviour is weighed against – and often overtaken by – the potential cost of reduced comfort and inconvenience, which are particularly shaped by changing paid work patterns, household demands and social norms. If the consequences of household practices are impaired comfort and convenience, environmental values may not be given the highest priority. Environmentally friendly behaviour may have unacceptable non-economic costs. However, the financial dimensions of pro-environmental behaviour are also important to the residents and future residents of Lochiel Park.

While people clearly have a concern with their economic well-being, they also exhibit altruistic attitudes and their behaviour may not always be driven by material self-interest. Berglund and Matti (2006) argue that in relation to pro-environmental behaviour people may act as citizens or consumers. Citizens act on ethical and altruistic concerns and they are collective in orientation rather than being motivated by individual self-interest. By contrast, consumers act as self-interested individuals, seeking to maximise their well-being. The interview data from Lochiel Park suggest that people exhibit the concerns and behaviours of both consumers and citizens. At times they emphasised costs and their economic well-being; at other times they revealed altruistic behaviour that may even have adverse economic consequences for them.

Citizens and consumers in Lochiel Park

Couple Two, revealed that their major motivation for having PV cells is to reduce energy consumption and to help generate energy for the collective: '*if we can help to cut down [energy use] or contribute toward the grid, all the better and cut our usage as well. So, it's a small part to play.'* Couple Six, likewise, exemplify the ethos of the citizen by saying that their primary motivation for moving to Lochiel Park was for the pro-environmental features of their home and for their behavioural practices:

[our] main focus on what we do here is not to be rewarded ... I mean if the environment benefits, then as far as I am concerned that should be reward enough for all of us, and that's what we should be aiming for.

Couple Five demonstrated that their environmental concerns will sometimes lead them to behave in ways that contradict the 'economic' principle of self-interest. They put PV cells on the house they lived in prior to Lochiel Park:

Just to do the right thing environmentally ... we didn't think the payback period was enough for it to be financially sensible really. Yeah, the payback when we put them on was at least 10 years, possible 12 years. So you don't do it for the payback ... and economists will tell you it's stupid, but ...

People's concern over the environment makes them want to behave as citizens; however they cannot if they face insurmountable economic barriers. Several interviewees wanted to install energy- and water-saving features in the houses they lived in prior to Lochiel Park but felt financially constrained from doing so. Couple Three, who were aware of the features of sustainable housing considerably earlier than most of the populace, testified to the fact that they were only able to install some equipment when they unexpectedly received some money: '*We did the solar hot water ... when we got some money from a dead relative.'* They would like to have added other things to their home or made modifications that reduced their energy and water consumption but *'we didn't have the money to do it'.* Individual One also tells of how he wanted to have a home that was very sustainable but '*We had kids then at high school and the costs of that sort of thing, I thought, "Well, it's just a dream."'* Individual One also wanted to install PV cells on the home in which he lived prior to living in Lochiel Park, but reveals how the decision was tempered by an economic calculus. They do entail a significant up-front cost, which people are reluctant to make if they will not recoup their investment:

I would have put PV cells on here, but when it became clear that we were going to retire ... I got some real estate people through the place and they said, 'You're mad to spend any money on it, you won't recover much of it.'

Couple Two pointed to the dilemma that many householders face. They would benefit financially by being able to install features that reduce energy and water consumption soon after buying a house. The earlier they install these features in their home, the greater the economic advantage to them and the greater the benefit to the environment. However, early in the stage of buying a house, and – for some – family formation, they do not have the money to undertake significant additional investment in their homes. Ironically these are probably the most energy- and water-intensive phases of their lives because of the presence of children. So at the time that people are likely to gain most from installing 'green' features, they are least able to afford to do so*. 'I regret that if we could have afforded it [PV cells] earlier, because usually if you buy a house you're mortgaged up to the hilt and it gets easier years on'* (Couple Two).

Individuals exhibited the concerns of consumers in relation to their homes in Lochiel Park. For some respondents this meant that they did not provide any features on their house, beyond those required by the Land Management Corporation. In some cases this was because they felt their house was sufficiently sustainable without additions, as well as because of economic considerations. As Individual Three explained, '*we haven't done anything in excess to what was required because all of those things cost a lot of money anyway'.* Couple Four also acknowledged financial barriers to making their home at Lochiel Park as sustainable as they would like: *'Do we think we are doing everything possible? Probably no. But ... within our financial realm, we've done* *everything possible*.' Couple Five could accurately be described as environmental activists, having a long history of pro-environmental behaviour. While they have installed features beyond those required by the Land Management Corporation (for example in relation to water and energy consumption), they too acknowledge the compromises occasioned by economic considerations in discussing their old home and their new one at Lochiel Park:

Money is another thing. I mean, the whole house business; we had this house built but we couldn't afford to do it as nicely and as environmentally well as we would have liked. The same with Lochiel. It's very much not really what we would really love to have ... it is a compromise. It's largely because of money. (Couple Five)

Individual Three points to a combination of awareness and incentives for the decisions she and her partner made about not installing green-friendly features to her house, such as PV cells and solar hot water:

back then, they weren't so much around, there wasn't the push on it, the government rebates weren't there, there wasn't that general [awareness]. So we just went with what we were required to do, but didn't actually install anything.

Couple Four illustrate that the economic concerns of the citizen extend beyond the cost of sustainable houses to buying appliances that are energy- and water-efficient. While they buy the energy-efficient appliances required at Lochiel Park, their commitment to this is tempered by cost considerations:

We bought the most energy-efficient ones [appliances] we could find, same as I bought a new telly and obviously went to the [brand], the eco one, so it was the most efficient one I could find without spending $5000 and I wasn't going to do that.

The calculus of energy-saving technology

While some participants judged that they could not do all that they wished, they also considered that some of the costly features of their homes were an investment. In this context, the needs of the consumer and the citizen meet. Couple Four considered that, having spent the money to make their house in Lochiel Park more sustainable than the average suburban home, they have made something of an investment that will save them in the longer term. They considered that these features will eventually pay for themselves, either in reducing energy costs or because of the re-sale value they build into the home:

Quite happily I could say I can retire here and stay here because the house has got the efficiencies ... Even if you don't stay here, the house has got them and it's a feature. You won't get as much return on them instantly, but because of the rebates ... you wouldn't lose out on what you have outlaid on all those things.

Individual Three also revealed the influence of life stage on whether investment in things like PV cells will 'pay off'. She considered that the PV cells they have installed will be recouped in *'the lifetime of the house, maybe not for our lifetime in the house ... we're in our late 50s, we hope to stay here for hopefully 20 years'.* This kind of economic calculation is likely to be particularly powerful in the case of less advantaged populations, who may well consider that they are unlikely to recoup the cost of installing features such as PV cells. Less well-off populations, like those in rental properties, may therefore simply decide against taking such action. Renters, in particular, have no incentive to install such features in their homes. Given that almost 30 per cent of Australians were living in rental properties in 2005–06, this is a significant obstacle to making Australian homes sustainable (ABS 2008). Research amongst low-paid workers in Australia illustrates that their capacity for substantive capital investment (for example in energy- or water-saving devices) is likely to be severely restricted by low household incomes and many competing, more pressing demands (Masterman-Smith and Pocock 2008).

Of the householders surveyed in Lochiel Park, 60 per cent indicated that they tried to save energy primarily to save money. This finding has important policy implications, suggesting that to induce people to behave as 'citizens' in relation to the environment there must be due recognition of the needs of 'consumers'. Even those people who had installed solar or PV features in their homes prior to Lochiel Park monitored their electricity and water bills. Couple Three, for instance, closely monitored their water use and bills after installing a solar water heating system '*[for] five years or something ... we would go out and read the meter every morning to see how much hot water we had used and graphed it all'.* While Lochiel Park residents have been willing to pay to have green technology installed in their home, they are still carefully monitoring it for the long-term savings they might accrue. Couple Four are paying close attention to their electricity bills to monitor the impact of the PV cells on their homes: '*Like the electrical bill ... that was $53 ... we were in front ... we were generating more power than what we were using'.* Even those who installed features such as PV cells for primarily altruistic reasons concede they can also be regarded as an investment. Couple Six discovered that they are now paying about $130 in electricity, in contrast to their previous bills of approximately $400 and consider, *'being in retirement, you know, cost savings into the future are important. Though it [PV cells] was a one-off cost to some extent, but ...'* Couple Five consider that being able to sell excess electricity to the grid will

be an income earner and since we've put these on, in this house, the government – they've come and introduced the feed-in tariff. So that we get 50 cents a kilowatt hour for every kilowatt hour we generate over and above what we use. So that means that, at least two of the quarters of the year, Origin Energy pay us money.

Couple Four consider that those people with features such as PV cells will reap greater benefits in the future as electricity prices rise. Like many interviewees, their judgement was that current price signals did little to encourage significant reductions in energy use. When prices are increased, those with PV cells will reap the greatest gains:

it's not going to be long for the authorities to wake up and say that our energy is under-charged. They're not charging what they should be charging to make us use less ... when they do wake up to that ... and charge more for electricity ... we're going to be the beneficiaries because we're not paying much now.

Many of the research population are behaving like consumers and calculating the economic benefits of living in Lochiel Park. Couple Two, for instance, reveal, *'We've got our first quarter bill and we're $50 ahead.'* However, this couple also illustrate how the impulses of the citizen can sometimes override the imperatives of the consumer. They bought very expensive blinds to minimise the impact of hot weather. While this could be construed as economically self-serving, other considerations clearly influenced their decision making:

they are not cheap, but I think in the long run they'll serve a good purpose ... You don't always choose window dressings thinking 'Are they going to pay back?' I never really considered that ... so yeah, in terms of cost, I don't know. (Couple Two)

Subsidies

Couple Four are grateful for the subsidies they received towards their PV cells. They consider that they would have installed them anyway, but that without the subsidy '*it would have made it much more difficult definitely. It would have made it too much or uncomfortable to us, put it that way.'*

Individual Three also testified to the way subsidies have shaped her choices. In the home she lived in prior to moving to Lochiel Park, she and her partner did not have features such as solar hot water. *'I guess we didn't think of spending that extra money ... back then [there] wasn't the push on it, the government rebates weren't there. So we just replaced the gas, that's what we had before.'* However, the cost of buying such items can be a barrier and incentives are a good mechanism to encourage people:

> *The things the government have done, like if you have to replace your fridge, if you have to replace your washing machine, there are financial incentives to replace it with a water conservation [appliance].* (Couple Two)

Couple Six pointed out that the subsidies they received for the various features associated with their home were significant. They have a commitment to the sustainability principles under-girding Lochiel Park, but there is some doubt in their mind about whether they would have bought into the area without the financial support that was provided. In their words:

> *We built a house that required photovoltaic cells and hot water systems and double glazing and all of the insulation and all of these encumbrances, and as a result of that we got a rebate of $43,500 back, plus the $8000 back for the PV cells. So we got a $50,000 rebate ... it is significant. So, if you didn't get that you'd probably, you know, instead of spending $600,000 here, you might go and spend $550,000 somewhere else. Even if we didn't get the rebate we would have wanted to be here, but whether we would have done it I don't know.*

This is a population that are motivated very strongly by the concerns of the citizen in that most of them want to be at Lochiel Park for environmental reasons. However, the evidence in this report suggests that, even for a highly motivated population, there need to be carefully targeted incentives. While the land and houses in Lochiel Park are mid-range in price ($5–600,000), they are nevertheless not at the bottom end of the housing market, suggesting a population that is financially comfortable, if not affluent in some cases. Given that financial incentives are important for this relatively well-off population, they are likely to be even more influential in promoting energy- and water-efficient homes among the less advantaged segments of the wider population.

7.3.4. Self-sustainability rating pre- and post-Lochiel Park

The interviewees were asked to rate the sustainability of their lives prior to living in Lochiel Park and what they considered it was, or would be, once they were residents. The rating ranged from 0 to 10, with zero being the lowest possible score. Table 7.4 reveals that most people rated their sustainability at five or under prior to Lochiel Park. As the table demonstrates, most people consider that living in Lochiel Park will have a beneficial impact on the sustainability of their lives.

Table 7.4: Self-rating of sustainability.

Name	Prior to living in Lochiel park	Actual or expected impact of living in Lochiel Park
Individual One	1 – 2	> 5
Individual Two	4	*
Individual Three	< 5	8 – 9
Individual Four	3	6
Couple One	7.5	9.75
Couple Two	< 5	9 – 10
Couple Three	5	*
Couple Four	3.5	7 – 8
Couple Five	5.6	7 – 8
Couple Six	5	6

* Unwilling to speculate; either had not yet moved in, or moved in very recently

Sustainability and housing design

Most participants spontaneously linked sustainability with energy and water use. For the majority who gave themselves scores of five or under prior to living in Lochiel Park, most attributed this to the poor design, or other structural features, of their homes. Some mentioned behavioural practices, such as recycling or growing vegetables, but for the most part sustainability was linked to the features of their houses. This suggests that, for the research population, the gains in sustainability lie in infrastructure, not in behavioural change. Individuals One and Two gave their pre-Lochiel Park houses a low score, for instance, because they were not correctly situated on the block and had minimal insulation, making efficient heating and cooling difficult. As Individual One said, at the time the house was built in the 1960s, there was not the awareness of orienting houses to maximise winter sun and minimise the impact of summer heat: *'it was built totally back to front on the block meaning you just had a blank wall to the north so you spent the winter heating it'.* Couple Two said of their old home, *'it just wasn't an energy-efficient home. It was a 60s home and that's what they built.'* Couple Six also said their previous house was energy inefficient because it *'didn't take advantage of any breezes or orientation; cost a fortune to cool'.*

Some people tried to undertake pro-environmental behaviour by fitting their old homes with insulation and solar hot water, for instance. However, the structure of these houses meant that in some cases people could not install the features they wanted to. Couple Three, for instance, wanted to have rainwater tanks and make use of grey water, but the design of their house did not make it possible. Couple Two pointed to the lack of insulation in their walls and the way this made heating and cooling their home difficult. They attempted to reduce the impact of hot weather by installing outside awnings and installing swirlies in the roof.

Couple Six, however, attributed their low sustainability score prior to moving to Lochiel Park to lack of awareness of environmental issues:

in general our focus on the environmental aspects of life were very low because we were just ... middle-aged types that progressed the appliances we all bought.

Sustainability was not a concept that was associated with housing design in earlier decades, for either builders or buyers. For many of the interviewees in this study, the home they lived in prior to Lochiel Park was chosen because it met the needs of a family. Individual Two pointed out that bigger houses are needed by people in certain life stages: *'the children were growing up and [we] needed space'.* Individual Three considered that her home prior to Lochiel Park met family needs, but suggested that its size and some of its features were significant deficits in terms of sustainability:

it was a big home, over 36 squares over two levels. So there was air-conditioning upstairs, air-conditioning downstairs in two different areas. We had a pool, we used water, we used power to keep it clean.

Given the steady increase in Australian house sizes, it would appear that 'lifestyle' factors continue to dominate people's choice of housing. The survey of residents found that no respondent considered their home in Lochiel Park too big. Approximately 17% considered their dwelling too small, while about 83% judged its size as just about right.

While many of the research population may have felt that the design and/or orientation of their homes were sub-optimal in terms of their sustainability, many of them undertook behavioural practices to increase the sustainability of their lifestyles. Recycling and composting were nominated by most interviewees as longstanding practices that were directed towards sustainable lives. Couple Three said, '*We have composted all our food scraps ... We fill up the recycle bin every two weeks. Everything we can reasonably do, we do.'* Hence, even while they consider the structural features of their homes the most relevant factor in sustainable living, they make it clear that they practice pro-environmental behaviour. Most interviewees had been active in recycling. It had become a routine aspect of their household's life. In contrast to some of the available literature (Judkins and Presser 2008), the practice was not gendered among these research participants. Both men and women were active in recycling and it was seen as a general household task, not as a job belonging to a particular member of the household. Interviewees also ubiquitously spoke about how council support made recycling an easy household task, by providing separate bins and having kerbside collection, for example. This suggests that these householders wish to undertake certain practices that are perceived as having benefits for the environment, but that they are more likely to become routine if there is a supportive policy in place. In the words of Couple Five:

I mean these days everybody [should be able to recycle] because the councils give a green bin, yellow bin, a blue bin ... Unless you're totally cranky and bolshie, I mean you do like the council suggests you do. It's no big deal.

Jensen (2008) suggests that much of the behaviour undertaken by people is symbolic; they want to help the environment, but only by taking action that has minimal impacts on their lifestyle. The 'accusation' of merely symbolic action cannot fairly be levelled at most of the participants in this research. Many of them had taken significant steps to limit their energy and water use. Most people had bought properties in Lochiel Park so that they could make a more significant impact on environment well-being. While they attributed most of the anticipated benefit of living in Lochiel Park to the structural features of their homes, it is clear that people still place emphasis on behaviours that they consider helpful to the environment, even if their impact is relatively small.

EcoVision monitors

EcoVision monitors are one of the ways that it is envisaged that living in Lochiel Park will lead to more sustainable use of energy and water. The premise of the monitors is that householders will be able to gauge their energy use by seeing how much they use with particular appliances. This tailored feedback is presumed to influence behaviour (Darby 2006). Unfortunately, few households had EcoVision monitors operating effectively at the time of data collection, therefore most people could not comment about their experience of them.

No interviewee who had a system installed indicated that they found it difficult to use. The survey results offer some confirmation of this: 80 per cent of respondents said they found them easy to use. Couple Four revealed how user-friendly they found EcoVision monitors:

it's very simple. I mean tonight we came home and who looked at that screen first and switched it on? [name], my son. He switches it on and has a look, sees what's going on with the power.

Some people predicted that smart meters would change behaviour by making people more aware: 'The perception is that EcoVision will help modify people's behaviour because it will make people constantly aware of their power and water consumption' (Couple Two). However, in some instances, they were relying on second-hand information rather than on behaviour they had witnessed. Survey respondent five, however, offered an account of how EcoVision had changed their behaviour, explaining how it made them 'more aware of energy consumption of household appliances and less wasteful, e.g. [we now] turn stuff off when not using it'.

However, in the opinion of some residents, those who are not living in Lochiel Park because of environmental considerations are unlikely to make much use of the EcoVision system: '*I think a lot of people in this estate who have built have gone, "oh, okay, yeah put the [EcoVision] system in, but I'm not really interested"*' (Couple Six). They consider that such residents will not use the meters as a way of monitoring energy and water use and, therefore, as a guide to changing behaviour: '*I get the feeling that some others will probably never touch the screen [at their house]*' (Couple Six). One couple exemplified this attitude. They do not use their meter very frequently because they feel they are already sufficiently responsible and prudent in their use of energy. It is clear that they do not use the meter to gauge the impact of particular appliances. When asked if the meter had changed their behaviour, they replied:

Not really. I suppose we are fairly ... we're just conscious of it all the time ... Like if you go around the house you'll find that most of the power points are turned off. I suppose we use our computers a bit, I don't know how much energy they draw. Hopefully not a great deal. (Couple One)

The survey of household residents revealed that 80% of respondents checked their monitors daily or several times in a day, while 20% indicated that they looked at their monitors less than daily. While most respondents indicated a high degree of interaction with this technology, they were less united in their assessment of its impact on their behaviour. Forty per cent of respondents indicated that the EcoVision monitors had changed their behaviour, while an equal percentage indicated it had not. No survey respondent indicated that they used EcoVision monitors to set the time that air-conditioning switched on. Survey respondents were equally divided about whether they would like consumption data provided to their computer in preference to their EcoVision monitor: 50% indicated that they would, while 50% indicated that they would not.

Some respondents with a functioning EcoVision system used it to monitor their energy and water use, as well as to monitor the temperature of certain rooms. Knowing about patterns of use, particularly how much energy individual appliances used, made them more conscious of their use and many felt they modified their behaviour because of this awareness. Residents who are often home make much more frequent use of their monitors than people who work:

We use ours all the time. There wouldn't be a day go by that we wouldn't look at our monitoring system and see what's being used and what's going where – several times a day as we walk past it even. (Couple Six)

Another couple felt that EcoVision could be used by people as an educational tool that allowed them to show visitors the way particular appliances use energy; this might persuade them to use appliances differently:

Their friends and rellies will be visiting them and will, you know, start to hear about these things and we've all got this green thing with technology ... on the wall so that their friends and rellies can be all fascinated by that. You know, put the kettle on and the electricity spike goes up. (Couple Five)

The limitations of individual behaviour

In the survey of Lochiel Park residents, 80% expressed a belief that there was something that they could do as an individual about the environment. However, 20% disagreed. During the interviews, some participants pointed out that they could not overturn many of the wider structural factors shaping social life. Specifically, they indicated a well-developed awareness of the forces that shaped their consumption patterns. One couple who could accurately be described as environmental activists pointed to what they regarded as the limits of individual action. While they had significantly modified their previous home and installed green features beyond those required by the LMC in their residence, they commented:

we do participate in a capitalist economy ... Everything we do has an impact ... We just bought a new TV ... we've got one of those super-dooper flat lines, HD and all that stuff ... I still feel guilty about it. We don't need a table this big ... we don't need a barbie [barbecue] that big ... we buy books. (Couple Five)

Couple One also hinted at how consumption is such a routine practice that much of the time it goes almost unnoticed, *'at times you can't help it ... you look at your computers and what goes into them ... at all your electrical appliances'.* Couple Six also confessed to feeling a bit guilty about some of their consumption patterns: '*OK, we've got a big place and a TV which is probably a bit naughty, but we've had that for quite a while.*'

Couple Five pointed out that relatively affluent populations can consume things that are positive or negative for the environment: *'when you're working, it's both easier to spend it on less sustainable things ... But it's also easier to spend it on things that will benefit the environment more'.* Couple Five also consider that it is all but impossible for them to live as sustainably as they would wish:

we should not live in cities ... the best you can do is about eight out of ten ... nine and a half would be living in a small village, with your own vegetable patch and you'd go out hunting food ... Most people could grow a great deal more than they currently do, but it's much more convenient for somebody 50 kilometres away to grow the lettuces, put them on a truck, bring them into the supermarket, the *supermarket keeps them cool for us, we go there at eight o'clock at night and all the lights are on. More convenient, especially if you work.*

Jensen (2008) points out that people are willing to make changes to their behaviour and to their way of life, but they are less willing to practise behaviours that might be considered 'fringe' or 'extremist'. That is, environmentally related behaviour must conform with their lifestyle. Lifestyle is a complex concept, but one of its important dimensions is that it relates to social norms and promotes social inclusion. People are therefore unlikely to undertake behaviours that break the social norms relevant to them and that might lead to them being seen as extremist or fanatical.

Individual Three practises pro-environmental behaviour in her household and has a well-developed understanding of how to live sustainably. However, she too suggested that her behaviour must fall within certain socially acceptable limits: *'I'm not going to march in a floppy hat. I won't necessarily do that.'* Despite a lifetime of committed environmental action, one interviewee also acknowledged limits to the kinds of behaviour he is willing to practice: *'there's a lot of talk about, we should all become vegetarians. Well, I'm not going to become a vegetarian'* (Couple Five). One member of Couple Five told of how being very committed to environmental action can require that people be somewhat at odds with the mainstream:

I realised that, it doesn't matter what I do really, it's not going to make any difference and that the only way to make a difference ... was to be an activist ... I'm not really an activist type. So I think that was quite depressing.

Couple Three have made significant changes to their house to reduce its energy and water consumption and practise behaviour that would make their lifestyle more sustainable than the average, but they also underscore how their action fits within accepted social norms. They self-deprecatingly suggested that, despite their long history of significant pro-environmental behaviour, they cannot be identified as outside the mainstream. Their comments implicitly suggest that in their attempts to consume less and avoid waste they do not veer into the fanatical:

Well we are not ... moralistic to the [extent] that we stint ourselves. It doesn't mean to say we don't waste things. We are not kind of Scrooge you know or anything ... We use a disproportionate amount of resources. We still do.

This suggests that people will only undertake routine practices that are regarded as congruent with the norms of their social environment. Many of the environmentally friendly features of Lochiel Park are common to all residents and fit with the residents' values, hence they are likely to be appropriately used and will not result in social exclusion. However, this may not be the case in other contexts.

Couple One provided an illustration of the way consumption is also undertaken to facilitate belonging and social inclusion. In this sense, consumption is not primarily about the purchase of goods, but is a means of reinforcing identity and membership. This couple try to reduce their carbon footprint; they are keen recyclers and they try to avoid using artificial heating or cooling unless it is essential. However, they tacitly point to the way that consumption of some appliances, and the energy they use, allows them to interact with their family and peers in desirable ways:

In saying that, we've still got a few mod cons in the house ... we're in the twentieth century ... like the appliances, the dishwasher – we never had that before. The idea was to entertain more here ... be in a lovely home environment ... and have a nice home for both our families to come and visit and entertain.

Couple Five likewise pointed to the compromise that is needed to stay within the confines of normality and the wish to live sustainably: *'if you want to be totally sustainable, don't live in a city. Don't ever go to the cinema.'*

7.3.5. Appeal of Lochiel Park

In this final section we consider what residents think about Lochiel Park as a residential facility, drawing out their reasons for being there, and their experience of community in this location.

Reasons for living in Lochiel Park

Residents or intending residents in Lochiel Park can be divided into two groups. The first group – a majority of 67% – have chosen to live there because of its environmental features. In the survey, 75 per cent of respondents reported living in Lochiel Park because they wanted to live more sustainably. Many people in this group have had a longstanding commitment to living more sustainably and have practised various kinds of pro-environmental behaviour prior to living there. Some have only more recently become interested in environmentally friendly ways of living. But, within this first camp, the sustainability of Lochiel Park is its major drawcard.

A second group live in Lochiel Park because of 'neighbourhood' factors. That is, they live there because they want to live in the area because of family or other ties, or having always lived in the area. Others are drawn by Lochiel Park's proximity to the city, while others emphasised its aesthetic appeal. When Individual Three, for instance, was asked why she and her partner had chosen to live in Lochiel Park she explained:

You probably want me to say the green aspect, but I have to be absolutely honest and say locality because we've been in this area ... I wanted to get a smaller house, wanted to stay in the same area.

However, even for those whose primary motivation in moving, or planning to move, to Lochiel Park is to improve the sustainability of their lives, its location and aesthetic qualities were also pivotal in their decision to move there. As Couple Three explained, *'being near the city [8 kilometres from the centre] is part of it as well. We don't want to retire out in Woop Woop.'* Couple Six wanted to be in Lochiel Park because of its environmental qualities, but its location was also crucial to their decision to move there: *'I mean if this [Lochiel Park] had been 25 kilometres out of the city, we wouldn't have done it'.* Individual Two liked its proximity to the city and the fact that it might reduce car use: '*You could hopefully ride into the city and market and things like that.'* For others, the local environment had appeal because it would allow them to exercise, as Couple Two explained: '*just to be able to step out the front door and go for these wonderful walks at Linear Park ... I love walking in a natural environment, not along the street.'* Couple Three also considered they would benefit financially because of its location, '*Near to the city in terms of its investment value ... it will pay for our nursing home bonds one day.'* Some were attracted by Lochiel Park's affordability, as Individual One outlined: *'[we] got a copy of the [building] guidelines ... and thinking if they adopt these guidelines it could be pretty good. The prices that were being touted ... seemed within our grasp.'*

These motivations for living in Lochiel Park suggest that even people who have a commitment to living more sustainably will not move to localities that are not close to desired facilities and venues, that are not aesthetically pleasing, that do not support people's desired lifestyles and do not represent a sound economic investment. Ecologically sustainable housing needs to address the range of people's housing and lifestyle needs: sustainability alone is not a sufficient drawcard.

Community in Lochiel Park

The Land Management Corporation has placed considerable emphasis on the existence of a close-knit community within Lochiel Park and have undertaken a range of initiatives to help it develop. The sense of community was not a factor prompting most research participants to live, or intend to live, there. However, for most interviewees, the development of community has become something they value about living, or intending to live, in Lochiel Park. One reason for this is that people feel that Lochiel Park is unique and is a testing ground for the development of more sustainable ways of living; this promotes a sense of common identity and shared values. Couple Two explained that most people in Lochiel Park feel like *'Pioneers, if you like, in testing where urban design guidelines have not gone before and actually we got a bit of excitement about building a more environmentally sustainable house'.* Individual Two outlined how she expected that shared values will help her feel enmeshed in the community: '*I think it's good to know the people around you and probably they've got similar ideas to us.'*

Couple Six illustrated how the community is beginning to develop:

We go for a walk at night – just a short 15 minute walk – and we get home an hour and a half later, because you end up in these congregations as you go – and that was one of the advantages as well is that there is 100 new blocks so there's 100 new houses and 100 new families moving all in, so we're all in the same boat ... And even last night one of the people over here had a party, and the main reason she had the party was to, again, just that community feeling ... we didn't have to ask each other anything because ... we're all here for the same reason.

For some residents, the sense of being part of a new enterprise is important. For others, however, more 'conventional' aspects of community are important. Couple Three pointed out: '*we don't have any relations in South Australia. So ... the communities that we belong to are kind of really important.'* Other residents who are retired also reveal that the existence of a community is important to them because it gives them a sense of belonging and they know they have someone to call on if help is needed. As one couple explained:

neither of us has parents alive or brothers or sisters here, or any family basically. So we are basically on our own ... we have friends and so on but we like the idea of having people around more, just like closer neighbours ... rather than just be neighbours and be nice to each other. (Couple Five)

Given that most people felt a sense of community was desirable, they were very appreciative of the steps initiated by the LMC to help develop it. The community garden in particular was nominated as a valued way of building community, as one couple explained:

that gives you something to do which helps you to get to know people ... It's a bit like cooking for one or two. Not the easiest of things to do efficiently. Gardening is much the same. I mean, you end up – we've got miles of silver beet and what not at the moment. Well there's only a limited amount of silver beet if it's your favourite food. But if you've got people on the next door plot, you say to them, well you grow the tomatoes, we'll grow the silver beet and they can grow the lettuces. (Couple Five)

The community website and the existence of other community-based groups were also regarded as important steps in building community. People also felt that the regular community meetings held by the LMC were important parts of community life. However, it is possible that this sense of community could be dissipated once people settle in and develop household routines. One couple observed:

Well it's an interesting thing ... that you see more of people as the houses are being built because they're out there each day, and you know, you get talking and so forth, once they're built and people move into the houses and close the front door you don't see as much of them. (Couple Six)

One way in which people think that the community dimension of Lochiel Park could help them maintain sustainable lifestyles is by promoting the sharing of information. Not only can information be shared by having a sense of community; it can generate norms about sustainability. Having a party, for instance, became a way of sharing knowledge and, implicitly, setting community standards:

So, even at the ... party last night, and we were looking around the lady's house that we went to, I hadn't been in there before and she was showing us around the house, and things that she was pointing out were, you know, 'oh look at this, and we've got this and the windows are orientated this way', and that was all because, for environmental components of the building. (Couple Six)

Another couple commented much more explicitly on how communities generate norms, which can then 'police' other community members:

you'll see people ... who put us to shame ... I know people who are already living sustainable eight out of ten. Now if they are living next door to you ... you wouldn't dare go up to the shops in the car when they go up there on their bike. (Couple Five)

Half of the survey respondents considered that interacting with other people in Lochiel Park made them more active in reducing their carbon footprint.

7.4. Conclusion

Lochiel Park residents are financially comfortable and some are affluent. They have a strong commitment to sustainable living. However, as this research demonstrates, despite pro-environmental attitudes, comfort, convenience and cost are the factors that most strongly influence behaviour related to domestic energy and water consumption. This chapter concludes that the most effective way to explain household behaviour lies in understanding the importance of comfort and convenience for householders and the way that these concerns structure routine practices that consume energy and water.

Cost is a significant factor in explaining householder behaviour, but it is not a simple cause–effect relationship. It is clear that carefully targeted subsidies and rebates play a key role in people's capacity to install energy efficient features generally and in the choice to move to Lochiel Park.

7.4.1. A socio-ecological system in Lochiel Park and its implications for action

To return to the model we set out in the introduction, how is environmental behaviour in Lochiel Park shaped by a range of factors that create demands and provide resources to residents? In the following table we propose some factors that arise from our analysis which might be further investigated in a larger future study.

We find that householders act as well as they can in their specific contexts; these contexts are affected by the ways in which their households, family life, community and working arrangements create resources for pro-environmental behaviours – or make demands that inhibit new or better behaviours.

In this context, particular actions – by governments, developers and others – will help, including those that:

- minimise the time demands on residents;
- understand that residents who are short on time will act 'conveniently';
- make it as convenient as possible to reduce energy or water use;
- improve knowledge about pro-environmental behaviours, and initiate simple accessible feedback loops to support changed behaviour;
- help build community fabric in support of pro-environmental behaviours, supporting the development of new social norms in its favour;
- provide efficient transport that reduces time, money and environmental effects arising from travel;
- ensure accessible local services (health, education, retail) that help reduce time demands;
- assist with the large early investments in pro-environmental appliances, housing and transport, especially for low income earners;
- recognise that energy use relates to the life cycle, household size and income; and
- provide safe, shared spaces and places that can be used as thermal refuges during periods of hot weather.

Table 7.5: The demands and resources shaping environmental behaviours in a socio-ecological system of work, home and community life: early experience at Lochiel Park

DOMAIN	Demands	Resources
Home		
	Low income crowds out capacity to adapt Larger household group, more children, older workers create bigger energy/water needs.	Higher income creates capacity to adapt
	Life stage matters: family formation, child raising: higher energy/water use	
	Care responsibilities create higher energy/water use	
	Sick or young children's needs stimulate energy use and raise comfort thresholds	
Community	Housing design requirements and recommendations can increase cost	High level of community knowledge about pro-environmental behaviours encourage energy/water saving
	Having visitors raises the comfort threshold	Strong community values in favour of pro-environmental behaviours encourage energy/water saving: new social norms affect action
	Poor transport options add to time and money demands	Good transport options save time and money
	Distant services (retail, health, care options, etc.) take time, increasing 'convenience use' of energy	Community garden adds quality food and builds social relations
	Not being embedded in community leads to less knowledge about ways to reduce energy and water use	Common green space increases opportunity for sharing knowledge and consolidating pro-environmental social norms
	Lack of shared open and safe space leads to people seeking individual, in-house thermal comfort	Shared, open and safe space provides a communal thermal refuge
Work	Takes time, increasing 'convenience use' of energy	
	Dual income earners more likely to have higher levels of 'locked-in' consumption	Generates income, financing investment in pro-environmental technologies

	Dual earners means two commutes	Dual earners means two incomes and more resources to finance pro-environmental technologies
	Working a long distance from home takes time	Working close to home creates time
	Working from home increases energy use at home (phone, IT, heating, cooling)	Working from home reduces commute, saves time: good IT and net speed increase likelihood of working from home

The residents of Lochiel Park are enjoying many aspects of an experimental ‘green village’ that exhibits many positive features. Its high standard of building design, close proximity to jobs, its investment in community, its frameworks guiding appliance installation, and its overall design are all viewed positively by residents. The experience already offers – at this early stage of its life – some important lessons about how residents can reduce their use of energy and water, and still enjoy the amenity of a good home and community.

This study shows that those who wish to see residential communities reduce their energy and water need to take account of social factors that affect behaviour, including comfort, convenience and cost. Simple appeals to individuals and households to change behaviour are likely to be less than optimally effective. There needs to be a systematic investigation of the social forces that make comfort and convenience a premium for contemporary households. A more detailed and comprehensive understanding of the way households’ need for convenience shapes energy and water consumption is then required. This understanding is a prerequisite for behavioural change programs that promote energy- and water-efficient behaviour as well as the convenient running of households. Similarly, a more detailed understanding of what comfort means to households and the way it shapes household routine will facilitate the development of strategies that dovetail with household practices, rather than strategies that run counter to the way households function. The study shows that pro-environmental behaviour is not just about cost: comfort and convenience jostle vigorously with the question of cost and override it on many occasions. However, more insight is needed into the way these factors – comfort, convenience and cost – are mediated by socioeconomic status. Approximately one quarter of the houses in Lochiel Park are social housing and this therefore provides an ideal opportunity to understand the way low-income households conceptualise and respond to issues of comfort, convenience and cost and compare this with that of higher income households. At the time the research was undertaken, the social housing component of the development was not complete and it was not possible to include this segment of the population in the project.

Our findings also show that pro-environmental behaviour is not just about provision of the most energy- and water-efficient appliances and house design – not even in the hands of a group of self-selected citizens with very pro-environmental values. Evidence suggests that, even in technically similar homes, there is wide variation in the amount of energy and water consumed. While comfort, convenience and cost appear to be factors that shape patterns of energy and water consumption generally, it is clear that they do not operate uniformly in all households. Further investigation at Lochiel Park may provide an ideal opportunity to identify the causes of this variation. We find that householders act as well as they can in their specific contexts; these contexts are affected by the ways in which their households, family life, community and working arrangements create resources for pro-environmental behaviours – or make demands that inhibit new or better behaviours.

In this context, particular actions – by governments, developers and others – will help, including those that:

- minimise the time demands on residents
- understand that residents who are short on time will act ‘conveniently’
- make it as convenient as possible to reduce energy or water use
- improve knowledge about pro-environmental behaviours, and initiate simple accessible feedback loops to support changed behaviour
- help build community fabric in support of pro-environmental behaviours, supporting the development of new social norms in its favour
- provide efficient transport that reduces time, money and environmental effects arising from travel
- ensure accessible local services (health, education, retail) that help reduce time demands
- assist with the large early investments in pro-environmental appliances, housing and transport, especially for low income earners
- recognise that energy use relates to the life cycle, household size and income.

Based on this very early and modest-sized study, Lochiel Park goes a long way towards implementing many of these suggested actions, with its close proximity to jobs, its investment in community, its frameworks guiding building and appliance installation, and its overall design. Future research of this maturing ‘green village’ will build on our early assessments and provide a longer term view of outcomes and their underpinning drivers.

8. MAIN OUTCOMES AND CONCLUSIONS

8.1. Main Outcomes

The project describes the process and outcomes of planning and implementing a world leading low carbon housing development; the Lochiel Park Green Village. Due to its novelty, the project has taken longer to implement than planned and at the time of writing, half of the dwellings are complete. The report outlines the process followed for planning and executing the development and for setting and validating the ambitious targets in reduced energy consumption and greenhouse gas emissions. It also describes the lessons learnt during the implementation process. As the Lochiel Park Green Village is seen as the forerunner of new Australian low carbon housing suburbs, many of the outcomes should serve to make new similar developments less time consuming and less costly to implement. The project demonstrates that zero and negative emission housing is possible with current technology and building practices. It also highlighted the need to develop the necessary regulatory framework and educational programs for all involved in the implementation process. It has also demonstrated that regardless of the technology used, it is the residents and their behaviour patterns that determine the energy and emission levels. Without the provision of necessary information to users and making their use convenient, many of the new features and appliances cannot operate according to the designers' perceived use pattern.

One of the features that sets this development apart is the level of rigour implemented in monitoring the energy use in total and in detail. Minute by minute data was recorded and analysed to monitor overall as well as detailed performance of individual houses, specific appliances and features. The monitoring of electrical systems, natural gas and water use provides unique details of patterns of use of appliances and their energy use as well as the house solar system performance under real conditions. The aggregated 18 month results for some 30 households provide reliable data on the overall impact of low energy housing generating solar power on the electrical grid.

The data analysis should provide real world evidence to support the development of energy regulatory frameworks and future energy policy directions in the housing sector. This includes the validation of the NatHERS and other house energy rating systems, policy instruments including evaluation of small scale technology certificates for subsidising solar electricity and solar hot water systems and star rating of domestic appliances.

8.1.1. Energy and emissions reductions

On the basis of data for some 30 houses, monthly average electricity and gas consumption results are evaluated. In addition, the average monthly solar electricity generation is provided. The average Lochiel Park home consumes 5520kWh of electricity per annum (15.1kWh per day) of which 57% is locally generated and only 2340 kWh per year (6.4kWh/day) is supplied by the grid.

Operating under the Adelaide climate, the study has shown that on average, the solar electrical systems installed at Lochiel Park generated ranges from 2.4kWh/kW_p in June to 5.5kWh/kW_p in January with an annual average of around 4.0kWh/kW_p. As more distributed photovoltaic systems are being installed in dwellings, this result provides direct evidence in estimating the impact of rooftop solar electrical systems on the grid and anticipated emissions reduction. With this in mind, further monitoring evidence is necessary to allow for annual variation of climatic conditions.

The gathered data demonstrates the impact of the number of occupants in a household and their behaviour on the electrical grid. In winter (June-August) the range per household varied from feeding the grid 100kWh/month to drawing 1 200kWh/month from it with the average winter demand on the grid being 400kWh/month. The summer period (January-February) shows a maximum input to the grid above 400kWh/month and a maximum demand on the grid of 950kWh/month with the summer demand of all houses averaging around 150kWh/month.

Considering the breakdown of energy consumption in houses, having reduced the air conditioning, hot water and lighting demands, other appliances including laundry (10.4%) and fridge/freezer (12.8%) assume more significance and require more attention in seeking deeper cuts in consumption. The plug energy, mainly used for computers and entertainment (43%) becomes the most significant contributor to the overall energy consumption. These results demonstrate the need to pay particular attention to the energy consumption of appliances associated with current lifestyle such as televisions, audiovisual appliances, computing facilities and home office equipment.

Turning to the impact on the greenhouse gas emissions, it is evident that they are dominated by the electrical consumption. The emissions associated with natural gas could be further reduced with better selection, commissioning and use of the solar hot water systems. The highest emitting homes were responsible for 1.2 tonne of CO_2 in winter and 0.4 tonne of CO_2 in autumn. The corresponding lowest emitters produced zero emissions in winter and a negative net emission (-0.4 tonne per month) in summer. The average emissions of the monitored Lochiel Park homes ranged between 0.1 tonne in May and 0.5 tonne in the winter months. This is substantially lower than the South Australian and Australian averages.

While only one house consistently produced more energy than it consumed and negative emissions, 50% of the monitored dwellings produced more electricity than they consumed and 40% of them produced negative net emissions during the period October to April due to the high performance of the photovoltaic systems during that period.

8.1.2. Hot Water Systems

27 gas boosted solar hot water systems were monitored which complied with the Development environmental guidelines; 11 were storage systems and 16 had instantaneous gas auxiliary heaters. The analysis shows that on average, the daily hot water consumption rate varied from 60 litres during summer and 100 litres in winter. The number of occupants had considerable influence on the total household consumption. The hourly consumption pattern showed more consumption during the early morning and late evening than assumed in the evaluation methodology. While solar heat accounted for most of the hot water requirements, the results showed considerable potential for reducing the auxiliary gas consumption through better commissioning and operation information to households.

8.1.3. Heating and cooling/ peak demand reduction

The significant feature of the use of air conditioning system usage is the relatively low hours when air conditioning was needed even during hot spells in comparison with similar Adelaide homes. With peak power demand being a key limiting feature, the worst of the houses investigated needed a maximum of 3 kW of electrical power with some systems needing below 1kW. This is well below typical air conditioning systems (about half the previously measured values) and has a significant impact on peak demand during heat waves and the cost of associated transmission/distribution infrastructure. Never the less, the energy consumption of the worst dwelling approached 40kWh during the peak day. This constituted 80% of the total consumption. However, in better designed houses and appropriately selected and used systems, this percentage did not exceed 20%. During the peak heating period, the maximum daily heating demand varied between 1kWh and 17.5kWh (70% of the total).

8.1.4. Potential national impact

To illustrate the impact of the combination of having a thermally comfortable home design and using a medium size photovoltaic system on the peak power demand, the average demand of the monitored homes at Lochiel Park was only around 0.5kW during the January 2011 SA peak demand event which took place at 4.30pm. For the limited number of monitored homes, the air conditioning load was matched by the solar generation during this period. This contrasts with the monitoring data previously obtained in 2003 which shows the average home peak demand exceeding 6 kW with the air conditioner requiring 5.2kW during the peak event. For the limited number of monitored systems, the comparison shows the maximum power demand for air conditioning to be halved in comparison with previous monitoring results.

The overall impact of the Lochiel Park Green Village research is demonstrated through making a comparison with available data for Australian and South Australian homes. The total annual monitored energy use of Lochiel Park homes amounts to 18.9GJ. This is a reduction of 53% in comparison with the Australian average. The corresponding reduction of greenhouse gas emissions is 66%. In addition to the significant environmental benefits, the outcome is a significant reduction of energy bills to households at a time of escalating energy costs.

While a direct comparison should be made with dwellings of the same age, it is still useful to compare the impact on energy use and greenhouse gas emissions if more houses were built or refurbished using specifications similar to those of Lochiel Park. Assuming the replacement of a million existing Australian homes by new homes having the Lochiel Park energy use characteristics will lead to an electrical consumption reduction of 3,000 GWh, which is equivalent to two thirds of the current electricity supply to residential customers in South Australia. The corresponding overall reduction of greenhouse gas emission is over 5 mega tonnes.

8.1.5. Behaviour

The report presents results of a primarily qualitative investigation of the social influences on green attitudes and household practices of residents, or intending residents, in Lochiel Park.

The study has been conducted very early in the development life. However, our findings can help inform the Lochiel Park development and illuminate the social factors that shape environmental behaviours in this exemplary settlement, and beyond.

Existing research is dominated by disciplines that are individualistic in orientation, such as psychology, engineering and economics. This report confirms that knowledge levels and attitudes are in themselves inadequate predictors of household energy consumption. Moreover, the role of economic factors in household energy consumption is more complex than a model of self-interest, or response to price signals, might suggest. Comfort, convenience and cost emerge as the biggest influences on the behaviour of residents of Lochiel Park, and these are in turn affected by a range of factors that arise in the domains of work, home and community life, and the ways in which these domains intersect. The project has also demonstrated the need for providing better information for households to enable them to interact better with the new technologies installed in their dwellings.

8.2. Recommendations

The Lochiel Park represents a step change in housing energy consumption and consequent emissions reduction. Unlike many previous demonstration projects, it has gone beyond a single building to the level of a new suburb being developed, constructed and lived in by typical Australians. Many of the lessons learnt in this project point the way to sustainable energy use in future Australian housing in the move to zero energy and zero carbon housing developments and carbon neutral communities.

While the project demonstrated that through using existing design and building practices, energy efficient appliances and smart technologies, it also provided valuable lessons on areas for improvement in future developments. Work will continue not only in constructing the remainder of dwellings including 26 smaller units but also in monitoring current and new homes. As more technical and social data is urgently needed to ensure quicker and more affordable transition to zero carbon housing in Australia.

On the basis of the Lochiel Park experience during the last 3 years, the following recommendations are put forward:

- While cost wasn't monitored, an estimated additional cost of 8-10% of the property values has been incurred in achieving the low energy outcomes. The novelty aspects and monitoring framework of the development have no doubt been responsible for some additional costs. However, no attempt was made to optimise performance at minimum cost. A design tool is necessary for reducing life cycle energy use at the lowest economic cost. The tool needs to model the building fabric and appliance use and evaluate the most economic integrated design and appliance selection including the size of the necessary solar system. The proposed tool needs to consider the main climatic regions of Australia, as local climate will influence the optimum design and appliance selection.
- While demonstrating the ability to design and build low and zero energy dwellings, the project has demonstrated the need for an integrated implementation approach between the architects/ builders and engineers to produce an integrated low energy design. Further integration is necessary for achieving improved aesthetics, comfort, cost and carbon reductions.
- The project has demonstrated the need to develop and provide information/educational material to all involved in the design, construction and commissioning of the dwellings. Builders, electricians, plumbers and other trades are highlighted as the groups who need most urgent attention.
- The project has also highlighted the need to provide further detailed information to residents on how to get the best use out of their house features and appliances to achieve comfort at minimum cost. There are a number of examples where seemingly similar families residing in similar size and design dwellings produce a variation of over 100% energy consumption. While convenience and cost have been demonstrated to influence behaviour, providing information in a suitable format to enable residents to get the most out of their house is a significant priority area.
- The project has demonstrated the enormous potential of the combination of passive solar design, energy efficiency, smart technologies and local solar energy generation in both reducing the overall energy consumption and peak demand. This provides large cost

reduction opportunities for electrical transmission and generation. The use of distributed generation has been demonstrated as a viable alternative to infrastructure augmentation. Further evaluation of this opportunity is necessary.

- The limited monitoring results of the rooftop solar systems have shown their positive contribution to peak demand. Further evaluation of this opportunity is necessary particularly during heat waves. In addition, the introduction of local electrical and thermal storage systems and their cost and impact on demand reduction during peak demand days requires investigation.
- While large scale demand control trials have been carried out by South Australian and other utilities, further investigation of the impact of demand control at the local household level where the residents can chose the order of priority of peak demand reduction options as demonstrated in some Lochiel Park homes is worthy of further investigation.

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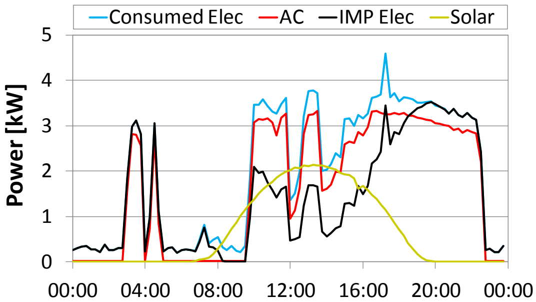
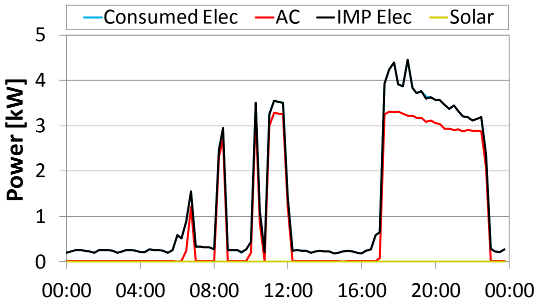
APPENDIX A – ELECTRICAL POWER PROFILES DURING PEAK DEMAND

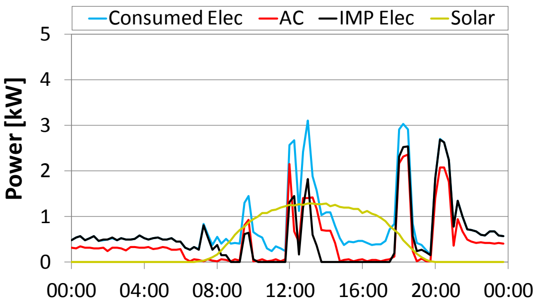
2011 Peak Demand Day



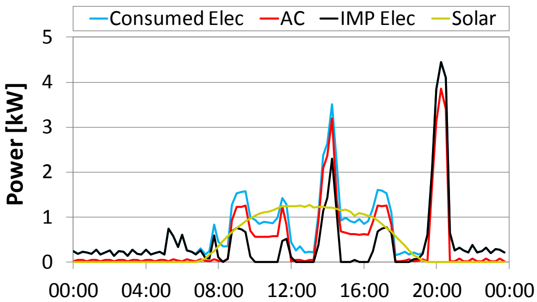
(L2OZ)



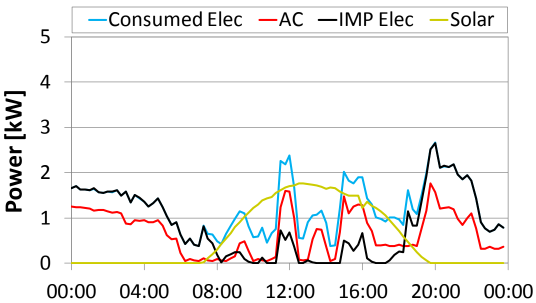
(L3TS)



(L1TS)

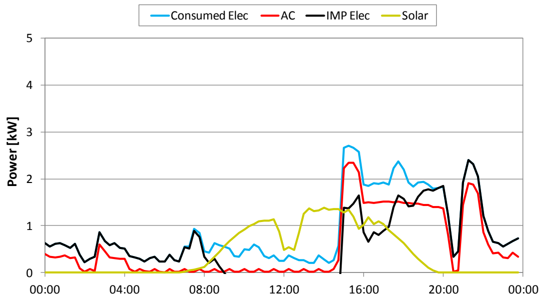


(L6FS)

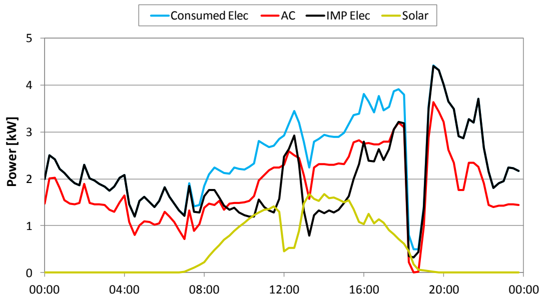


(L23SS)

2010 Hottest February Day



(L1TS)



(L4FO)

APPENDIX B - PUBLICATIONS

Saman, W. Y., Mudge, L., Whaley, D. and Halawa, E., "*Sustainable Housing in Australia: Monitored Trends in Energy Consumption*" International Conference on Sustainability in Energy and Buildings, Marseille, Franc, June 2011.

Saman, W., "*Towards Zero Energy Homes Down Under*", Invited paper - Presented at the World Renewable Energy Congress IX, Abu Dhabi, UAE, September 2010.

Whaley, D., Saman, W., Halawa, E., Mudge, L., "*Lessons learnt from implementing intelligent metering and energy monitoring devices in a new housing development*" - Presented at the Australia Solar Energy Society (AuSES) Solar2010 Conference, Brisbane, 1st -3rd *December 2010.*

Saman, W. & Halawa, E., "The impact of passive design and solar energy use in a housing development on the electrical grid", presented and published in Proceedings ISES Solar Word Congress, October, 2009, Johannesburg, South Africa.

Alam, F., Rasul, M.G., Saman, W. Y., Theos, T. Khan, M.M.K. and Akbarzadeh, A., "Residential House Energy Rating in Australia", Central Region Engineering Conference (CREC), CQ University, Rockhampton, ISBN 1-921047-62-3, pp 1-6, 2009, Queensland, Australia.

APPENDIX C – MEETINGS / CONFERENCES / TRAINING

- Wasim Saman attended IGrid meeting in Brisbane 4 Feb 09.
- IGrid Project members meeting 23th March 09 Adelaide to discuss the project progress and implementation details.
- Wasim Saman, Edward Halawa and David Whaley participated in the Intelligent Grid-Cluster Researchers teleconference held on 12 March 2010.
- P6 Project Team Members meeting was held on 16th March 2010 at the Sustainable Energy Centre - UniSA, Mawson Lakes, to discuss the handling of the monitoring data.
- P6 Project – LMC monitoring meeting on 30th March 2010 at Lochiel Park Sustainability Centre to discuss the project progress and implementation details.
- David Whaley attended Smart Grid Energy Efficiency TechClinic held in Adelaide on the 8th June 2010 and with Phil Donaldson (LMC) gave a presentation titled: “Lochiel Park CEIC Smart Grid Energy Efficiency Technology Clinic”.
- David Whaley and Lachlan Mudge attended a Resident Training session at the Sustainability Centre on 10th August 2010, with staff members from LMC and EcoVision.
- Lachlan Mudge attended the Database Training program for the period 20th to 30th September 2010. The custom training package was delivered by Jeff Headley from Academy IT.
- Wasim Saman was invited to and attended the Smart Grid/Smart Home Australia and New Zealand Conference which was held in Melbourne 3rd-5th November. Wasim made a presentation entitled “The Lochiel Park Green Village: How can smart homes reduce energy and water consumption and reduce peak demand?”
- David Whaley and Lachlan Mudge attended the project meeting held on 16th November 2010 at Lochiel Park Sustainability Centre to discuss the project progress and implementation details.
- David Whaley and Lachlan Mudge analysed and reported preliminary confidential Lochiel Park data for LMC, November 2010.
- David Whaley, Wasim Saman and Edward Halawa attended the AuSES Solar 2010 Conference held in the Australian National University, Canberra 1st – 3rd December 2010. David Whaley presented a paper (see Publication Section - Appendix A).
- David Whaley attended a Resident Training session at the Sustainability Centre on 9th August 2010, with staff members from LMC.
- David Whaley analysed and reported confidential Sustainability Centre 12 month energy / water usage data for LMC, September 2011.
- UniSA, LMC and Campbelltown Council staff demonstrated the energy/water monitoring and display systems and the features of the houses and development in the Lochiel Park sustainability centre demonstration home to international researchers, many thousands of specialist visitors and the general public. The home was also used as a venue for training courses on aspects of environmental sustainability.
- Three final year undergraduate students, 1 Master student and 1 PhD student have used Lochiel Park data and features in their research.

APPENDIX D – COMMISSIONING ISSUES IDENTIFIED AND RESOLVED

Tradespeople

Builders

There has been one case of builders severing a 4-core wire between the Programmable Logic Controller (PLC) and the temperature / relative humidity sensor of an upstairs bedroom, when installing plasterboard walls. This has caused the EcoVision to incorrectly record a constant temperature and relative humidity of -12.5°C and -25%, respectively. The severed wire should be replaced, however, this would require the wall panels to be removed and replaced; further action is required to correct this.

Electricians / Data Cables

Insufficient cables have been wired to and from the PLC to the digital sensors, for a number of early built properties. This has been corrected by using common cables from the PLC to digital sensors located near each other, e.g. ETSA import and export and gas sensor meters.

The following issues have been found following the required EcoVision firmware upgrade; these were mainly discovered in early installations and have since been corrected:

24V power supply has not been replaced with 12V power supply, which does not allow the import / export meter to operate correctly (2 houses).

12V power supply terminals (polarity) have not been reversed, which also renders the import / export meter non operational (lots 16, 19).

PLC inputs, from digital sensors, have not been adjusted. This mainly affects the early EcoVision systems. This resulted in all utility readings being invalid.

The solar Wattmeter terminals have not been reversed (several lots), leaving the solar input of the PLC constantly high. During this state, the Wattmeter does not give a solar reading.

Some of the wiring from digital sensors to the PLC have been insufficiently sized / cut prematurely. Such wires have been extended to reach the required PLC inputs.

The Solar Wattmeter has not been wired to the PLC nor the inverter output in 2 houses.

The Wattmeters, which breakdown electricity usage of a detailed home, are incorrectly labelled in one property, e.g. the PLC and hence EcoVision screen display electricity usage in the laundry when an appliance is used in the kitchen. It similarly reports lounge room power usage when an appliance is used in the bedroom. This requires further investigation as either the Wattmeter labels or the power circuits in the distribution board are incorrectly labelled; the latter may cause undesired effects in the event of the load management system tripping the incorrectly labelled power circuit.

The temperature / relative humidity sensors were incorrectly connected to the PLC and incorrectly configured. These sensor configurations have been corrected.

Often the import / export wires are swapped at the PLC, implying that the import, export, total and net electricity usage are recorded and displayed incorrectly.

The Ethernet cable connecting the EcoVision screen and ‘port 4’ of the ONT has been incorrectly terminated at one end (2 houses). This is required for the EcoVision to be commissioned, and to communicate (for data storage) with the Lochiel Park Server. These have since been corrected.

Plumbers

Only one water billing meter has been installed near the rain water tank of one house. This is connected to the mains, which feeds the rain bank (supplementary mains hot water usage). Without another billing meter, the resident will not be able to monitor hot water usage, and subsequently rain water usage.

Both water billing meters used in conjunction with the rain water tank (hot water usage and supplementary mains hot water), of one property were installed in the incorrect direction. Hence, the cyble equipped targets within the billing meters do not rotate and subsequently, the EcoVision cannot detect hot water nor supplementary mains hot water usage. A plumber has been contacted regarding this issue, however, has not yet corrected the situation.

The plumber of one property incorrectly installed the rain water tank such that the water inlet pipe directly fed the overflow pipe, not allowing the tank to store any rain water. This issue has been corrected.

The rain water tank billing meters have been incorrectly installed at two properties, which both have underground rain water tanks. One of these properties has managed to connect the rain bank discharge (output) to normally mains connected pipes, i.e. hand basins in bath room, whereas the rain bank discharge of the other is feds only the hot water system inlet (standard installation). The incorrect location of the hot water usage meter (on the rain bank rain water input, instead of the rain bank discharge) implies that negative rain water readings are recorded by the EcoVision system in the event of an empty rain water tank.

The gas-boosted solar hot water system of one property (lot ??) was installed incorrectly, where its gas inlet was connected to the mains water and vice-a-versa. This has been corrected.

Gardeners

The cyble sensor for one property has been cut close to the sensor on the mains water meter, causing the EcoVision to display zero water usage. This is likely caused by thick vegetation near the billing meter and cyble sensor, i.e. the person might not have seen the cyble sensor wire and accidentally cut through it. This issue has not yet been addressed.

UTILITY PERSONNEL / SERVICE PROVIDERS

Water

The incorrect types of billing water meters were installed at two properties. The first meter was missing the cyble equipped target, which is required for the cyble sensor to detect water usage. The second meter was another type that is incompatible with the cyble sensor. Both billing meters were replaced by SA Water.

Gas

Two properties have had incorrect gas billing meters installed, which are incompatible with the elsetr (gas) sensors. The meters have since been replaced; the process has taken 12 and 2 weeks, respectively.

Another non-standard gas billing meter has been installed at one property, due to the number of high gas outlets in the house. Unlike the two mentioned above, this meter has an in-built digital pulse output. The drawback, however, is that this meter has one tenth the resolution of the standard gas meter, which does not allow gas usage patterns to be determined. Despite this, the total gas usage can be deduced. Discussions with the residents are underway to investigate alternative meters.

Electricity

One property still uses the temporary electricity (import only) meter. This meter is used during the building stage and is upgraded to an import / export meter as part of the PV notification; this is the responsibility of the homeowner. The PV notification was delayed as the residents are renting the property. The temporary meter cannot differentiate between imported and exported electricity, and hence the PV system is not yet connected. As such, the EcoVision is unable to read electricity usage information, i.e. the residents appear to use zero electricity.

The grid-connected inverter was missing from one property. This was followed up by the builders, however, the residents were unable to take advantage of the Sun during the months of to February, and missed out on credits towards their electricity bill.

The most common issue regarding electricity meters is the need for import / export meters to be programmed correctly. The EcoVision systems are configured such that 1 pulse corresponds to 1Wh, whilst often the meters themselves are programmed to give 1 pulse per kWh (instead of 1,000). These meters can only be re-programmed by ETSA staff, who have taken between 3 and 10 weeks to re-program them.

OptiComm

The Optical Network Terminal (ONT) of one property was faulty, causing commissioning delay, and has since been replaced.

The network configuration of one property was accidentally altered during a fault tracing of internet service, which isolated the EcoVision from the Lochiel Park server. This has since been corrected.

Port 4 of the ONT has not been unlocked (or provisioned) before the commissioning stage of 2 properties. This causes short delays during the commissioning stage as the EcoVision cannot access the Lochiel Park server. This issue is often resolved quickly, and usually causes short delays (e.g. 15 minutes).

Residents

Some properties are not accessible during business hours, which causes delays in commissioning the EcoVision or correcting outstanding issues. In these cases, special arrangements have been made, e.g. visiting the residents out of business hours, and leaving the keys to the house with neighbours; the latter also involves arranging a suitable time with the neighbours.

Some residents keep billing meters behind locked gates and or distribution boxes. Access to meters is required to verify raw data readings vs. the difference in meter readings. Gaining access requires organising a time with individuals and or visiting residents outside of regular business hours.

One resident turned her EcoVision screen off at night time as the LED of the Ethernet port was constantly lit, which the resident thought may be wasting energy. The resident was unaware that this action would cause the EcoVision to cease logging data and prevent the Lochiel Park Server from communicating with it, and downloading its data. This issue was resolved within a few days.

Monitoring Systems

Issues caused by the monitoring system, including sensors, EcoVision systems and PLC installations, and storage of raw data, are discussed below.

Sensors / hardware

- Some sensors are not readily available, which causes delays; these include:
  1. Temperature / relative humidity sensors,
  2. Rain water tank level sensors – an incorrect batch was once sent.
  3. Cyble (water) sensors, provided by SA Water.
  4. Elster (gas) sensors, provided by APA.
  5. Second gas meter (and 2nd elster) sensor not yet available, and hence not installed in detailed homes.
- Some sensors have been inoperative, i.e. 3 cyble and 5 elster sensors have been deemed faulty. Faulty sensors will be returned to providers to be replaced. Despite this, delays have and will continue to result as Eslter sensors are in high demand.
- SA Water caused a short delay in providing a batch of rain water (PPP) meters, as they wished to be updated on progress made at Lochiel Park.
- Delays in EcoVision installations / commissioning have resulted from difficulties sourcing PLC hardware, such as 12V power supplies and 4A fuses. As a result of the EcoVision firmware upgrade, the 2015 systems require one 12V power supply, instead of the 24V power supply initially provided. The correct (12V) power supplies are provided by Optimate (QLD).

EcoVision Systems

- The date and time of the early EcoVision systems were configured by the respective electricians, which implies that none of the system clocks were synchronised. The EcoVision time also drifted at a rate between 5 – 10 minutes per month, which made comparing the difference in meter readings with the raw data erroneous. The issue is currently being addressed.

- In the past two months there have been 3 reports of the EcoVision display crashing, i.e. the resident is unable to navigate around the screen or update the display. The solution is to restart the EcoVision in the house; again access to the property must be first arranged with the residents.
- Two issues regarding the detailed monitoring (3015) systems have also been seen:
  1. The room labels which display the temperature and relative humidity of the 3 rooms where the sensors are located are not accurate. This is more important for residents as they wish to see the temperature of certain rooms. The labels need to be customised per house and are corrected by Optimate personnel. The process has taken between 1 – 12 weeks.
  2. The Analyse page, which shows the breakdown of electricity usage, was initially configured to show the power usage of Pool / Spa pumps (none of the residents in the detailed monitored houses have either), rather than Air Conditioners. The affected systems have been corrected.

Raw Data

- Initially there was a large delay (about 8 weeks) in establishing the required Remote Desktop Connection at UniSA, due to network and security issues at UniSA.
- The initial raw data (CSV) files started at midnight in Coordinated Universal Time (UTC), i.e. not in Adelaide time. This implied that each CSV file, which is separated into lot number and month was missing either 9.5 or 10.5 hours of data, depending on whether Day Light Saving had started or not. This issue has been resolved.
- The process of transferring data from the Lochiel Park Server to local computers at UniSA, appeared to corrupt data, i.e. additional information was found in the CSV past the expected end of file. This was caused by the encryption used at UniSA and an alternative procedure is now used to transfer data from the Server.
- Some entries in the CSV file shown NA rather than decimal values, these are caused by one of 3 things:
  1. PLC read failure,
  2. Invalid Value blocked by the EcoVision sytem, or
  3. If in relation to a Calculated Sensor – not all sensors calculated had valid data or PLC read.

  These NA values have been seen during periods of incoming data, e.g. in the middle of 10 minutes of mains water usage, and do affect the overall value. Despite this, over the course of 1 month, there appears to be 1 NA entry per 4,000 data entries.
- Some CSV files have different column headers in different columns. Although this should not pose a problem when using databases to store and analyse data, UniSA is currently using Microsoft Excel to preliminary process and analyse data. Macros were created for one file layout and hence do not work all CSV files.

Other Issues

The following are other issues that should be addressed: these do not impact on data collection.

- The top of the box which houses the PLC and power supplies is not mounted flush with the wall in one house and hence poses a threat as power supply terminals can be reached by fingers; these are 240V wires and hence the top of the box should be covered.
- There is no outdoor weather data, i.e. to analyse AC usage vs. temperature, we need to gather data from other sources, e.g. BOM or data-logging weather station.

APPENDIX E – STATUS OF MONITORED HOUSES

General Monitored Houses

Lot	Date	Commissioned		Digital Sensors							
	Sensors	System	Load	Water Meters				Gas	Electricity		
	Checked		Manag't	Mains	Recyc.	Hot Use	Suppl	Meter	SOLAR	Imp	Exp
L30OO	30/08/2010	26/08/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L35OT	12/10/2010	12/10/2010	✓	✓	✓	✓	✓	✓	×	×	×
L37OT	2/03/2011	2/03/2011	✓	✓	✓	✓	✓	✓	✓	×	×
L7OF	30/04/2010	18/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓
L8OS	16/04/2010	4/03/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L9OE	14/04/2010	18/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓
L10ON	12/04/2010	3/03/2010	✓	✓	✓×	×	×	N/A	✓	✓	✓
L34TT	30/09/2010	N/A	××××	✓	✓	✓	✓	✓	✓	✓	✓
L11TE	16/03/2010	27/01/2010	✓	✓	×	✓	✓	✓	✓	✓	✓
L13TN	16/03/2010	10/09/2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
L12TN	16/03/2010	3/11/2009	✓	✓	✓	✓	✓	×	✓	✓	✓
L14TO	14/04/2010	4/02/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L24TT	27/10/2010	N/A	××××	✓	✓	✓	✓	✓	✓	✓	✓
L15TT	17/03/2010	11/03/2010	✓	✓	✓	✓	×	× ✓	✓	✓	✓
L40TF	18/05/2011	18/05/2011	✓	✓	✓	×	✓	✓	✓	✓	✓
L16TN	6/05/2010	6/05/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L38FT	2/03/2011	2/03/2011	✓	✓	✓	✓	✓	✓	✓	✓	✓
L17FF	26/05/2010	26/05/2010	✓	✓	✓	✓	✓	✓	×	✓	✓
L39FS	20/04/2011	20/04/2011	✓	✓	✓	✓	✓	✓	✓	✓	✓
L18FT	6/10/2010	6/10/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L19FF	17/03/2010	17/02/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
L20FF	17/03/2010	11/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓
L21FE	17/03/2010	18/12/2009	✓	✓	×	✓	✓	✓	✓	✓	✓
L29FN	26/08/2010	26/08/2010	✓	✓	✓×	✓	✓	✓	×	✓	✓
L27SF	20/07/2010	20/07/2010	✓	✓	✓×	✓	✓	N/A	✓	✓	✓
L25SS	2/06/2010	2/06/2010	✓	✓	✓×	✓	✓	✓	✓	✓	✓
L41SO	25/05/2011	25/05/2011	**by VL**	✓	✓	×	×	✓	✓	×	×
L33ST	7/09/2010	26/08/2010	✓	✓	✓×	✓	✓	✓	✓	✓	✓
L31ST	31/08/2010	31/08/2010	✓	✓	✓×	✓	✓	N/A	✓	✓	✓
L36SS	28/10/2010	28/10/2010	✓	✓	✓×	✓	✓	✓	✓	✓	✓
L32SN	31/08/2010	31/08/2010	✓	✓	✓×	✓	✓	✓×	✓	✓	✓
L28EO	18/08/2010	18/08/2010	✓	✓	✓×	✓	✓	✓×	✓	✓	✓

Detailed Monitored Houses

Lot	Date Sensors Checked	Commissioned		Digital Sensors								Analogue sensors				Correct Labels?	
		System	Load Mang	Water Meters				Gas	Electricity			Rain level	Temp. / RH			T/RH rooms	AC, not pool
				Mains	Rec.	HW	Sup		Solar	Imp	Exp		1	2	3		
L2OZ	16/03/2010	3/02/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	×	✓
L3TS	16/03/2010	16/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
L1TS	16/03/2010	12/01/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L4FO	16/03/2010	19/01/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L6FS	16/03/2010	11/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
L5SZ	30/04/2010	19/01/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
L26ST	2/08/2010	2/07/2010	✓	✓	×	×	×	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
L22SS	9/06/2010	9/06/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
L23SS	4/06/2010	4/06/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓

APPENDIX F – WATTMETER AUDIT OF DETAILED MONITORED HOUSES

Lot L2OZ

Date/Time: 3rd June 5 PM

Appliance Name	No. Power Points	Labelled	At PLC
Downstairs Air Conditioning	n/a	A/C	X14
Ensuite	2	P2	X10
Entrance Passage	1	P2	X10
Garage	1	P1	-
Kitchen	2	P1	-
Landing Upstairs	1	P2	X10
Laundry	1	P2	X10
Lights (Entrance/Lounge Room/Laundry/Garage)	n/a	L2	X5
Lights (Kitchen, Outside, Dining Room)	n/a	L1	X22
Living Room	2	P1	-
Lounge Room	2	P2	X10
Master Bedroom	6	P2	X10
Microwave	n/a	-	-
Outside	1	P1	-
Oven	n/a	Oven	X7
Pantry	1	-	-
Upstairs Air Conditioning	n/a	A/C	X14
Upstairs Bathroom	1	P2	X10
Upstairs Bedroom 2	1	P2	X10
Upstairs Bedroom 3	1	P2	X10
Upstairs Hallway	1	P2	X10
Upstairs Lights	n/a	L2	X5

Number of Wattmeters (Excluding Solar): 7

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Couldn't get to dishwasher

When any appliance is connected to P1 watt meter it does not flash on PLC

Missed powerpoints in upstairs bedroom 2, 3 and living room

Lot L3TS

Date/Time:

Appliance Name	No. Power Points	Labelled	At PLC
Bedroom 2 (upstairs)	2	P1	X4
Bedroom 3 (upstairs)	3	P1	X4
Dining		P2	X10
Dishwasher	1	DW	X6
Downstairs Air Conditioning	-	AC	X14
Downstairs Lights / ceiling fans		L1	X22
Family (front of house)	2	P1	X4
Fridge		P1	X4
Front Enterance		P2	X10
Garage	2	P2	X10
Kitchen	3	P1	X4
Laundry		P2	X10
Lounge Room (TV)		P2	X10
Master Bedroom (upstairs)	3	P1	X4
MB Ensuite		P1	X4
MB Ensuite (ceiling heater)		L2	X5
Meter Box (front)		P1	X4
Microwave		P1	X4
Outdoor (front) ppt		P1	X4
Outdoor (rain pump)	2	P2	X10
Oven	-	Oven	X7
ppt under stairs		P1	X4
Upstairs Bathroom		P1	X4
Upstairs Bathroom (ceiling heat)		L2	X5
Upstairs Lights / ceiling fans		L2	X5
Upstairs Passageway		P1	X4

Number of Wattmeters (Excluding Solar): 7

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Lot L1TS

Date/Time: 6th June 2 PM

Appliance Name	No. Power Points	Labelled	At PLC
Bedroom 1	3	P2	X10
Dishwasher	n/a	D/W	X6
Downstairs Air Conditioning	n/a	A/C	X14
Ensuite	3	P2	X10
Garage	1	P3	X12
Kitchen	2	P4	X23
Kitchen Island	1	D/W	X6
Laundry	1	P3	X12
Lights (Downstairs: entrance way/study)	n/a	L2	X5
Lights (Downstairs: Kitchen/Garage)	n/a	L1	X22
Lights (Downstairs: living room/garage/laundry)	n/a	L2	X5
Lights (Upstairs)	n/a	L2	X5
Living Room	2	P3	X12
Master Bedroom	2	P2	X10
Outside 1	1	P2	X10
Outside 2	1	P3	X12
Oven	n/a	Oven	X7
Pantry	3	P4	X23
Study	3	P2	X10
Upstairs Air Conditioning	n/a	A/C	X14
Upstairs Bathroom	1	P2	X10
Upstairs Bathroom 2	2	P2	X10

Number of Wattmeters (Excluding Solar): 9

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Couldn't Get behind television

Missed a powerpoint in the master bedroom

Lot L4FO

Date/Time: 3rd June 10 AM

Appliance Name	No. Power Points	Labelled	At PLC
Air Conditioning	n/a	A/C	X14
Dining Room	1	P1	X10
Dishwasher	1	D/W	X6
Downstairs Lights (kitchen/Dining Room/Study)	n/a	L2	X5
Downstairs Lights (Laundry/Lounge Room/Staircase)	n/a	L1	X22
Front Entrance	1	P1	X10
Inside Shed	1	P1	X10
Kitchen	3	P1	X10
Laundry	1	P1	X10
Lounge Room	1	P1	X10
Lower Kitchen	1	P1	X10
Outside	1	P1	X10
Outside Rain Pump	1	P1	X10
Oven	n/a	Oven	X7
Study	2	P1	X10
Upstairs Bathroom	1	P1	X10
Upstairs Bedroom 1	3	P1	X10
Upstairs Bedroom 2	2	P1	X10
Upstairs Ensuite	2	P1	X10
Upstairs Landing	1	P1	X10
Upstairs Lighting & Fans		L1	X22
Upstairs Main Bedroom	3	P1	X10

Number of Wattmeters (Excluding Solar):6

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Lot L6FS

Date/Time:

Appliance Name	No. Power Points	Labelled	At PLC
Air Conditioning		8	X14
Dishwasher		3	X6
Eastern Bedroom (upstairs)		2	X4
Fridge		5	X12
Front Bathroom (Ensuite)		4	X10
Front Room		4	X10
Garage		2	X4
Kitchen		4	X10
Kitchen Island (ironing, kettle)		3	X6
Laundry		2	X4
Living DS (Northern wall)		4	X10
Living DS (Southern wall)		5	X12
Master Bedroom		4	X10
Microwave		4	X10
Outside		4	X10
Oven / Grill		1	X7
Toilet (under stairs)		5	X12
Top of Stairs		2	X4
TV ppt		4	X10
Upstairs Bathroom		2	X4
Western Bedroom (upstairs)		2	X4

Number of Wattmeters (Excluding Solar):8

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Pulses seen on L1, but not on L2

Lot L5SZ

Date/Time: 6th June 12 PM

Appliance Name	No. Power Points	Labelled	At PLC
Bathroom	1	P2	X10
Dishwasher	1	D/W	-
Downstairs Bedroom	1	P1	-
Downstairs Lights	n/a	L1	X22
Garage	1	P1	-
Kitchen	2	P2	X10
Living Room	2	P2	X10
Outside	3	P2	X10
Oven	n/a	Oven	
Upstairs Balcony	1	P1	-
Upstairs Bathroom	2	P1	-
Upstairs Bedroom	1	P1	-
Upstairs Lights	n/a	L2	-
Upstairs Master Bedroom	1	P1	-

Number of Wattmeters (Excluding Solar): 8

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Missed fridge in garage

Missed two powerpoints in kitchen

Missed one powerpoint in living room (gas heater)

Missed one powerpoint in passage

Missed one powerpoint in bathroom

Missed one powerpoint in bedroom

Missed one powerpoint under stairs

Missed one powerpoint in upstairs bedroom 2

Missed one powerpoint in master bedroom

Couldn't to air conditioner. Cover on

Lot L26ST

Date/Time: 3rd June 3.30 PM

Appliance Name	No. Power Points	Labelled	At PLC
Dishwasher	1	7	X6
Ensuite	1	3	X4
Fridge	-	5	X13
Garage	2	-	-
Kitchen	5	-	-
Kitchen Air Conditioning	n/a	8	X14
Laundry	1	Laundry	X23
Lights & Fans (Upstairs)	n/a	4	X5
Lights (Kitchen, Garage, Laundry, Lounge, Toilet)	n/a	1	X22
Lights (Main Bedroom/Ensuite)	n/a	4	X5
Lounge Room	4	-	-
Main Bedroom	2	3	X4
Main Bedroom Air Conditioning	n/a	-	-
Microwave	1	7	X6
Outside	3	-	-
Passage (Near Garage)	1	-	-
Studio Air Conditioning	n/a	-	-
Studio Air Conditioning	n/a	-	-
Upstairs Bathroom	1	3	X4
Upstairs Bedroom 1	1	3	X4
Upstairs Bedroom 1 & 2 Air Conditioning	n/a	-	-
Upstairs Bedroom 2	1	3	X4
Upstairs Landing	2	3	X4
Upstairs Studio	10	-	-
Upstairs Studio (Ceiling)	1	3	X4
Upstairs Studio (Front of House Wall)	1	3	X4
Utility Room	-	-	-
Oven	n/a	6	X7

Number of Wattmeters (Excluding Solar): 8

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Lot L22SS

Date/Time: 6th June 10 AM

Appliance Name	No. Power Points	Labelled	At PLC
Air conditioner (Evap)	n/a	A/C	X14
Bottom Bathroom	2	P3	X12
Dishwasher	1	D/W	X6
Downstairs Bedroom	3	P1	X4
Garage	3	P1	X4
Heat Pump	n/a	A/C	X14
Induction Hot Plate	n/a	Induction HP	X11
Kitchen	4	P3	X12
Laundry (Washing Machine)	n/a	P1	X4
Lights (Downstairs Bathroom)	n/a	L2	X5
Lights (Downstairs: Study/Rumpus Room/Bedroom)	n/a	L1	X22
Living Room	4	P3	X12
Living Room (North West Corner)	4	P2	X10
Living Room	n/a	L2	X5
Downstairs Bedroom	4	P2	X10
Bedroom Lights	n/a	L2	X5
Outside (Entertainment Area)	1	P2	X10
Outside (Hot Water System)	n/a	P2	X10
Oven	n/a	Oven	X7
Upstairs Bathroom	1	P1	X4
Upstairs Bathroom (Western Side)	2	P2	X10
Upstairs Master Bedroom	2	P1	X4
Upstairs Rumpus Room	3	P1	X4
Upstairs spa pump	n/a	-	-
Upstairs Study	4	P1	X4

Number of Wattmeters (Excluding Solar): 11

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes:

Lot L23SS

Date/Time: 3rd June 12 PM

Appliance Name	No. Power Points	Labelled	At PLC
*Powerpoint 1	1	-	-
*Powerpoint 2 (Between Kitchen Laundry)	1	Bedroom	X4
*Powerpoint 3 (Hot Water)	1	Bedroom	X4
*Powerpoint 4 (Tank Pumps)	1	Bedroom	X4
*Powerpoint 5 (Conn. to Orbit)	1	Didn't	Check
Dining Room	1	-	-
Dishwasher	1	D/W	X6
Downstairs Bedroom 1	1	Bedroom	X4
Downstairs Bedroom 2	1	Bedroom	X4
Downstairs Bedrooms A/C	n/a	A/C	X14
Downstairs Living Area A/C	n/a	A/C	X14
Ensuite	1	Bedroom	X4
Garage	3	-	-
Kitchen	3	-	-
Kitchen Microwave	1	-	-
Laundry	1	Laundry	X23
Lights (Downstairs Bedrooms)	n/a	L2	X5
Lights (Kitchen/Living Area)	n/a	L1	X22
Lights (Study/Bathroom/Studio)	n/a	-	-
Lounge Room	2	-	-
Outside	5		
Oven	1	Oven	X7
Study	2	Bedroom	X4
Studio	5	-	-
Studio A/C	n/a	A/C	X14
Studio Microwave	1	-	-
Study A/C	n/a	A/C	X14
Upstairs Bathroom	1	Bedroom	X4
Upstairs Bedroom	1	Bedroom	X4
Upstairs Bedroom A/C	n/a	A/C	X14

Number of Wattmeters (Excluding Solar):8

PLC Identification	
X4	Bedroom Power
X5	Light Circuit 2
X6	Dishwasher
X7	Oven
X10	Living Room Power
X11	Spa/Pool Pumps
X12	Kitchen Power
X13	Fridge
X14	Air Conditioner
X21	Solar Generated Meter
X22	Light Circuit 1
X23	Laundry

Notes: