LOW CARBON LIVING CRC

RP1006: Viable Integrated Systems for Zero Carbon Housing:

Lochiel Park Monitoring Case Study

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Disclaimer

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Acronyms

CO2-e	Carbon dioxide equivalent
DCCEE	Department of Climate Change and Energy Efficiency
GHG	Greenhouse Gas
GJ	Giga Joules
HVAC	Heating, Ventilation and Air Conditioning
IHD	In-Home Display
kWp	kilo Watt (peak)
LED	Light Emitting Diode
LMC	Land Management Corporation
m2	meters squared
MJ	Mega Joules
PV	Photovoltaic
RCAC	Reverse-Cycle Air Conditioner
SA	South Australia
UDG	Urban Design Guidelines
UniSA	University of South Australia

Executive Summary

This report delivers a part of the first year outputs of the CRC for Low Carbon Living research project 1006: Viable Integrated Systems for Zero Carbon Housing, which is part of Program 1 of the CRC, Integrated Building Systems.

The deliverables from this stage of the project are a review of national and international house energy rating schemes and a review of Australian and some international residential energy monitoring program case studies. Both reviews along with the outcomes of a stakeholder workshop to determine the future project deliverables and plans are reported in an accompanying report.

A significant aspect of achieving credibility, acceptance and large scale adoption of rating tools is the provision of a strong evidence base. This report focuses on one of the foremost Australian based housing energy monitoring programs, the Lochiel Park Green Village in South Australia, which is Australia's leading sustainable housing development. This report summarises the energy consumption and on site generation data collected in Australia's most comprehensively monitored estate and discusses the overall performance of these houses, based on a continuous monitoring period of 24 months.

The results of the Lochiel Park case study demonstrate that low energy housing is currently achievable. The house features and their higher than currently required star ratings are discussed, with particular focus on the average total and net delivered energy consumption, for a large number of houses within the development. The data highlights that modern design concepts and building practices can significantly reduce the energy demand for new houses and significantly reduce our dependence on utility infrastructure and (typically) fossil fuel derived energy sources.

Introduction

At inception, the Lochiel Park Development was intended to be 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 (Land Management Corporation, 2010). It was established with the aim of becoming a model, best practice, green village which would showcase the mainstream use of as many sustainable technologies as possible in a relatively small, high density housing estate, through adherence to comprehensive design guidelines. The construction phase of Lochiel Park is nearing completion and already, a number of successful examples of highly sustainable households, with either low or zero energy based greenhouse gas emissions, have been identified through detailed monitoring of household energy and water use.

UniSA played a key role in developing the sustainable energy elements of the Lochiel Park Green Village, since the early stages of the project. Contributions made by the University of South Australia (UniSA) team included: input to the Urban Design Guidelines (UDG); selection and performance estimation of various proposed innovations and components; analysis and rating of house designs; selection and performance evaluation of water heaters, heating and cooling systems, solar photovoltaic systems and other major fixed appliances; as well as developing a monitoring program for energy and water use. Further details on the project inception and early results are provided in Saman et al. 2011.

Some key targets for the Lochiel Park development were to facilitate the construction of houses that achieved:

- Near zero energy-related greenhouse gas emissions in relation to all household appliances and rooftop energy generation
- Peak electricity and potable water demand that was 20% that typically required by a comparable SA home
- Thermal performance of the building envelope that was twice as effective as the current requirement for SA homes at the time the guidelines were drafted

House Features

The concept of developing near zero carbon housing development was based on the ability to mandate the following features in all houses (Saman, 2013):

-- Passive solar design

-- Low energy appliances and smart technologies

-- On site solar hot water and electricity generation

All houses constructed at Lochiel Park were required, prior to planning consent, to complete a sustainability assessment, using an electronic “Sustainability Rating Tool”. This tool detailed the numerous sustainable household characteristics required of proposed Lochiel Park dwellings and included requirements such as maximising the efficiency of, and peak load relating to,: the building envelope for passively maintaining thermal comfort; major appliances such as water heaters, Heating, Ventilation, Air-Conditioning (HVAC) and refrigeration appliances; other significant household appliances such as dishwashers, clothes dryers and washing machines; water fixtures such as low-flow showerheads and faucets; lighting fixtures such as high efficiency fluorescent and light-emitting diode (LED) lighting. The tool also provided information to prospective Lochiel Park residents in relation to their options for maximising the environmental sustainability of their household through choices relating to the construction and contents of their proposed dwelling.

As previously mentioned, stringent requirements for building passive thermal performance were put in place, which mandated that at least a 7.5 energy star rating was required, when modelling the building envelope, using the AccuRate software package. Large scale use of double glazing has formed a significant part of this passive design in most houses, along with uncharacteristically high levels of wall and ceiling insulation. All houses were also required to have an In-Home-Display (IHD), to be fed energy and water data through smart metering technologies. IHD’s were incorporated to improve householder awareness of their energy and water use and therefore facilitate reduction or elimination of wastage. The IHD devices selected and rolled out to the Development also incorporated an integrated remote data acquisition (monitoring) system, which has been used extensively by UniSA to gather valuable detailed household energy and water consumption data, and a load limiting system, which could also be used by householders to voluntarily reduce their peak electrical load. Highly efficient water heating systems were also a significant mandate with at least 70% of household water heating energy to be supplied by renewable resources. This has meant that most houses use solar water heaters with roof-mounted collectors being a defining feature on the Lochiel Park landscape.

PV Systems

The Lochiel Park Development mandated the inclusion of on-site electricity generation to all houses. This mandatory generation was set at a minimum of 1kWp per 100m2 of habitable floor area, with additional generation required if certain, less sustainable household attributes were proposed, such as HVAC appliances with energy ratings above the limits set by the Development. As previously mentioned, a number of households have achieved very low or zero energy based, greenhouse gas emissions and it should be noted that this is primarily the result of onsite photovoltaic generation.

There are currently 69 houses within Lochiel Park that have PV systems installed and monitored. A summary of the panel ratings is shown in Figure 1; the average PV system has panels rated at 2.3kW. Although no records of recently installed panel types exist, it is suspected that the recent trend is to install mono-crystalline panels, as these typically required half of the same roof area compared to amorphous panels of the same power rating; poly-crystalline panels are not installed within the development.

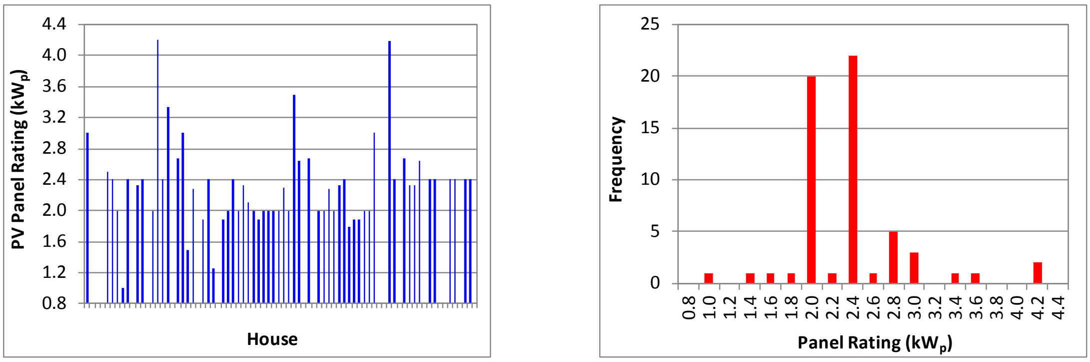

Figure 1 Installed PV system size and histogram of installed solar system panel sizes

Figure 2 (Whaley et al. 2014) shows a more in-depth analysis of the installed PV systems, where (a) compares the PV panel and inverter ratings, whilst (b) summarises the panel to inverter power ratio as a function of panel azimuth and inclination angles. The dotted green line represents the proper design case where where the inverter and panel ratings match. Ideally, the inverter should be rated to handle more than the rated panel output.

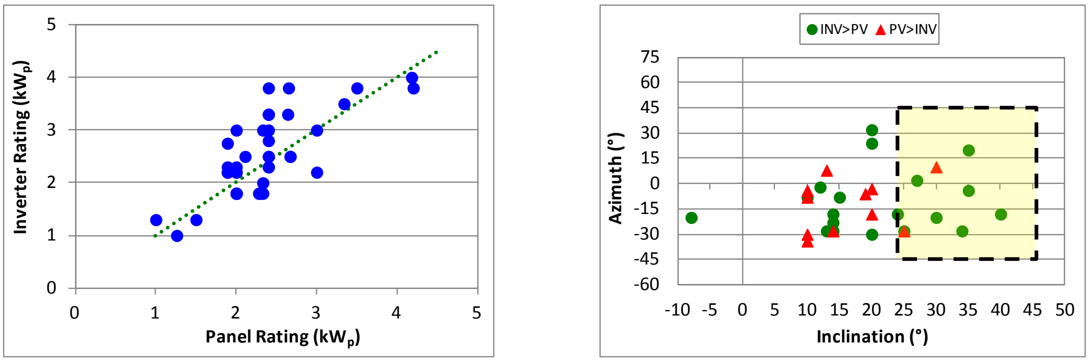

Figure 2 Summary of installed solar system panel vs. inverter ratings, and panel azimuth vs. inclination angles

Figure 2 (b) shows that 11 of the 69 installed systems utilise an inverter that is rated below that of the panels, which is less than ideal. The dashed box shows the suggested configuration for Adelaide, given the latitude, L, of 35° South, which is equal to L ± 10°, and for azimuths of North ± 45°. The figure shows that the majority of PV systems fall outside of this suggested range, and that one system has been installed where the panels are facing South, shown as a negative inclination. Note that low inclinations are due to normal building practice which has roof pitch angles below 25°.

Monitoring System Summary

As previously mentioned, the monitoring system was incorporated into the IHD and all houses were fitted with this equipment. There were two different levels of monitoring conducted at Lochiel Park residences, which have been termed 'Detailed' and 'Basic' Monitoring. All residences were fitted with the equipment required for basic monitoring, which allowed total imported, exported and onsite renewably generated electricity to be separately monitored, along with total mains gas consumption. In addition, this equipment also allowed monitoring of total mains potable water, recycled water and rainwater. All of the aforementioned measurements are monitored at one-minute intervals, allowing the resulting data to have maximum value from a research perspective.

In addition to the Basic Monitoring regime undertaken in all households, a Detailed Monitoring regime was implemented in ten of these households. This Detailed Monitoring involved separately monitoring all household electrical circuits, thus facilitating the analysis of electrical end-use data and further adding to the research value of these data streams. In some of these houses, a significant major gas appliance was also monitored separately. Rainwater tank level sensors have been installed in most of the Detailed Monitored houses to allow householders to keep track of their rainwater resources. Finally, temperature sensors were installed in three zones throughout each of these ten houses to facilitate a better understanding of the thermal performance of the building envelope and its response to ambient climatic conditions and ability to achieve thermal comfort using installed HVAC equipment. As with the Basic Monitoring, all data in relation to Detailed Monitoring were collected at one-minute intervals and represent sufficiently high resolution for a multitude of research purposes.

Development Status Update

The Lochiel Park Green Village is a development that contains 103 dwellings, i.e. 23 apartments and 80 houses, which includes two separately monitored Mews. At the time of publication, each of the 23 apartments have had monitoring systems installed and commissioned, whilst 67 houses (including two mews) have had monitoring systems (intelligent sensors and the IHD) installed and commissioned. Figure 3 shows an overview of the original master plan as well as the most recent aerial photograph (September 2012, obtained from Nearmap.com). The data provided in this report focus on 60 detached houses which had monitoring systems installed and commissioned. Figure 4 shows examples of two Lochiel Park houses at street level, which highlights the solar technologies, i.e. the flat-plate collectors associated with solar boosted water heaters and the PV panels.

Figure 3 Lochiel Park housing development master plan and latest aerial photograph (courtesy: NearMap)

Figure 4 Examples of Lochiel Park houses showing integrated solar technologies

Available Data

The data presented in this report corresponds to that for the 24 month period July 2011 – June 2013. This follows on from the preliminary data presented by Saman et al. (Saman et al. 2011), which corresponds to data from the first 18 months of data monitoring. Additionally, charts similar to that of Figure 14, Figure 18 etc., appear in recent publications by Berry et al. (Berry et al. 2013).

Note that the data shown is based on monthly summaries of individual houses, and that data is excluded if it is missing more than 2 days data for any given month. At this stage any missing data is not extrapolated, due to the associated uncertainty inherent in the extrapolation procedure.

In addition, note that the charts showing monthly average data indicate the number of houses used in the average calculation, within the square brackets along the x-axis adjacent each month label e.g. JUN12 [45] indicates that the average data shown for June 2012 is based on data from 45 houses.

Reliable Data Sets – General Monitoring

Figure 5 shows the number of Lochiel Park houses for which valid data is available for the following measured / calculated parameters: electrical and gas energy, and greenhouse gas emissions (both gas and net electrical energy data is required for this). The number of valid data sets increases over the 24 month period due to the increased number of completed and occupied houses and the subsequent commissioning of the installed monitoring systems within these.

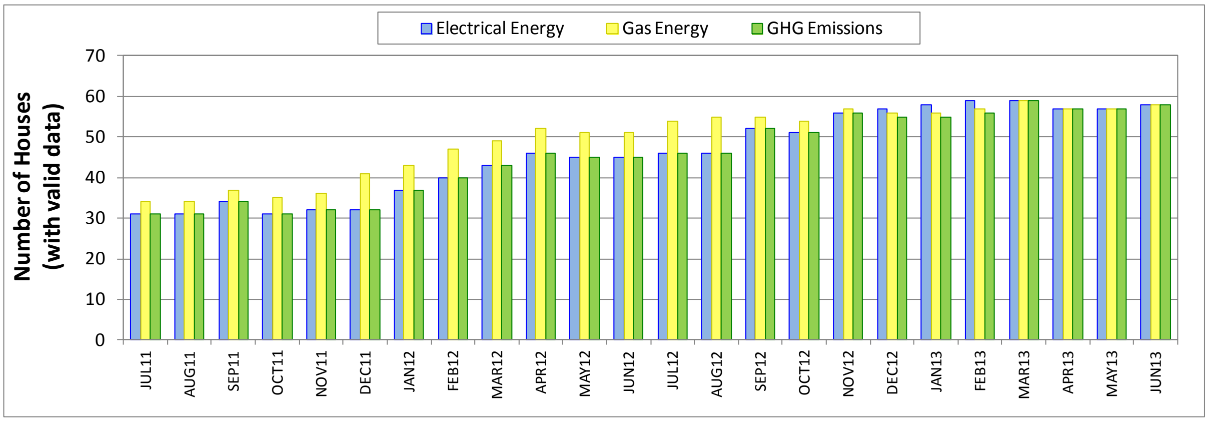

Figure 5 Summary of valid energy and hence greenhouse gas (GHG) emission data sets

Note it is mentioned above that in September 2012, 60 houses had their monitoring systems installed and commissioned, however, Figure 5 shows that only 52 of these houses yielded reliable data in this month. In this instance, eight houses did not have correctly programmed import / export meters, which prevented the the monitoring system from giving accurate total electrical energy consumption data, and 6 houses did not have properly connected gas meter sensors or incorrect (incompatible) gas meters installed at their property.

This highlights one of the issues with data monitoring on a large scale, such as a housing development, i.e. at times problems arise that limit the amount of useful data that can be extracted and processed. The main cause of issues encountered to date within the Lochiel Park development are listed below (Whaley et al. 2010), whilst a more comprehensive summary is reported by Saman et al. (Saman et al. 2011).

Monitoring Issues Encountered

Sensors

- A small number of water and gas sensors were nonoperational when installed.
- Some sensors, e.g. gas, rain tank level, temperature are not readily available.
- Some sensors, such as Wattmeters, temperature and rain level sensors are not correctly labelled, installed and or configured.

Wiring

- Some cables connecting sensors to other parts of the monitoring system have been unintentionally severed by people, whilst some are cut short, requiring extensions or re-cabling.
- Some communication cables, i.e. Ethernet and serial cables, were not correctly terminated.

- A small number of EcoVision (IHD) power supplies required replacing, and were not correctly installed.

Metering

- Incorrect gas, water and electricity meters have been installed on some properties. These are incompatible with their respective sensors and must be replaced by utility personnel. Meter replacement, in some instances, has taken several months.
- Incorrect program entered into import / export electricity billing meter. This can only be corrected by utility personnel, who have taken many months to rectify, causing significant delays.
- Some rain water tanks are fitted with only one water meter, instead of the required two. Other properties have one of these rain tank meters installed in the incorrect direction or in the incorrect location.

Appliance Installation

- The grid-connected inverter of one property was not installed, whilst the solar hot water system of another had its water and gas inlets incorrectly connected.

In-Home Displays

- A number of IHD (screens) crash / freeze.
- Some systems do not automatically restart following a power outage (black out).

Resident Interference

- Some residents cannot provide access to houses during business hours, or restrict access to billing meters.
- Some residents shut down their IHD, or have not restarted these following a power outage.

Reliable Data Sets – Detailed Monitoring

Table 1 summarises the current number of detailed monitored Lochiel Park houses for which full data is available, and within these, how many have reliable data sets for the following measured parameters:

- Individual electrical appliances, e.g. oven, dishwasher, laundry/ kitchen circuits, air conditioning, refrigeration etc.,
- Indoor temperature and relative humidity of three rooms (at least one bedroom upstairs, and at least one living room down stairs),
- Rain water tank level.

The table below indicates that of the listed detailed monitored houses (a privacy code is used), the majority have appliances such as air conditioners, ovens and lighting monitored well, however, other appliances and power circuits, such as dishwashers, laundry appliances, kitchen appliances and refrigerators, are not monitored well. In addition, very few houses have rain water level sensors installed and calibrated.

Table 1 Summary of additional monitoring in the detailed monitored Lochiel Park houses

	Light 1	Light 2	Light 3	Total Lights	AC	Water Heater	Pool / Spa	Laundry	Oven	Ind HP	Combi Oven	DW	DW + Others	Kitchen	Kitchen + bathroom	Fridge(s)	US Beds + utility	Solar HWS	Total	3 rooms?	Tank level
L02OZ	✓	✓		✓	✓				✓			✓							✓	×	×
L62OF	✓	✓	×	✓	✓	✓	✓	✓	✓			✓		✓		✓	✓	N/A	N/A	✓	✓
L03TS	✓	✓		✓	✓				✓			✓							✓	✓	×
L01TS	✓	✓		✓	✓				✓				✓	✓					✓	✓	✓
L04FO	✓	✓		✓	✓				✓			✓						✓	✓	✓	✓
L06FS	✓	✓		✓	✓				✓				✓						✓	✓	×
L05SZ	✓	×		✓					×			×							✓	✓	×
L68SO				✓	✓			✓	✓	✓		✓			✓	✓		✓	✓	×	✓
L26ST	✓	✓		✓	✓			✓	✓				✓			✓		✓	✓	✓	×
L22SS	✓	✓		✓	✓				✓	✓	✓	✓							✓	✓	×
L23SS	✓	✓		✓	✓			✓	✓			✓						✓	✓	✓	×

Note that the additional sensors used in the detailed monitored houses operate differently to those used for the general monitoring, i.e. these do use magnetic reed switches, and they do not contain batteries etc. As such, these additional sensors / meters are not prone to breaking down, i.e. they either work as required or they do not.

Energy Analysis

Electrical Energy

This section shows the average electrical energy consumed, generated and imported from / exported to the grid, throughout the last 24 months. It also shows the houses that import the most and export the most of electrical energy per month, along with how much PV generated energy is used locally and exported to the grid.

Consumed Electrical Energy

Figure 6 shows the household average monthly electrical energy that is consumed within the dwellings, that generated by the roof-mounted photovoltaic (PV) systems, and the net consumption delivered from the grid. The figure clearly shows the seasonal variation of electrical energy usage, i.e. the minimum amounts are used during autumn and spring, whilst the consumption increases for summer and winter. This is mainly due to the fact that neither heating nor cooling is generally required during autumn and spring, while it is required during the extreme seasons. The figure shows that on average, more electrical energy is consumed in winter compared to summer, which is most likely due to prolonged periods of heating and lighting; the majority of Lochiel Park houses use reverse-cycle air conditioners for heating and cooling.

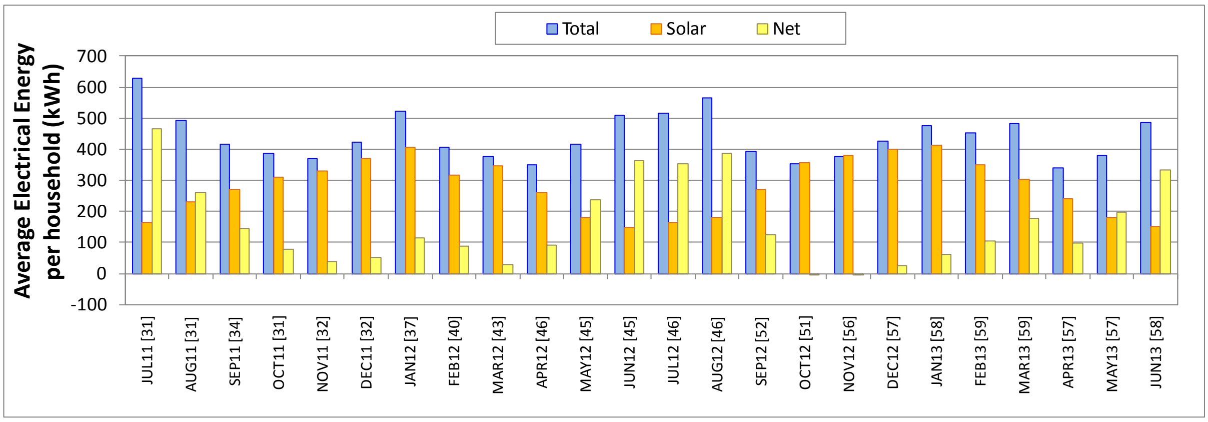

Figure 6 Monthly average household electrical energy consumption, solar generation and net electrical consumption

Although both spring and autumn require little cooling or heating, the above figure indicates that of these seasons, it is spring that requires the least amount of net energy. In addition to comfortable weather conditions, this is also due to increased solar energy generation, compared with that of autumn, hence reducing the amount of energy drawn from the grid. Note that to date, October and November 2012 are the only two months where the average solar generation has exceeded the average electrical energy consumption, hence resulting in negative net electrical energy consumption from the grid.

Note that the net energy is defined as the difference between that imported and exported energy, and as such can be negative if more energy is exported to rather than imported from the grid. This net energy is also equal to the difference between the total consumption and that generated by the PV systems. The net electrical energy is further discussed in the Net Electrical Energy Section.

Combined Solar Generated Energy

Figure 7 shows a breakdown of the combined household electrical energy that has been consumed during the 24 month monitoring period (units of kWh). The figure shows that almost 65% of the consumed electrical energy was generated locally, by the collective roof-mounted PV systems.

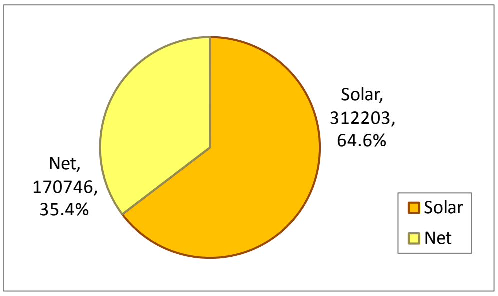

Figure 7 Breakdown of the total combined household electrical energy consumption, by energy source

Figure 8 shows a breakdown of the gross solar energy end use, i.e. whether this was used locally (within the Lochiel Park houses) or exported to the electricity grid. The figure indicates that almost 41% of the gross PV energy generated was used locally, whilst the majority was exported to the grid. The quantities shown have units of kWh.

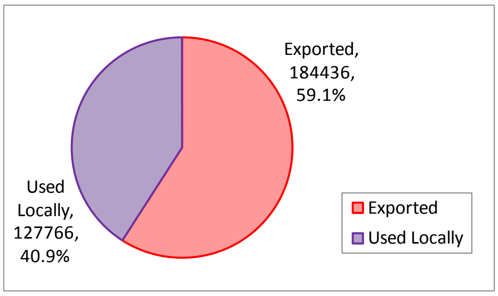

Figure 8 Breakdown of the total gross solar energy end use

The impact of gross solar generation is further discussed in the Delivered Energy Section.

Net Electrical Energy

Figure 9 shows the monthly average electrical energy that is imported from and exported to the grid. More energy is imported in the winter months than the summer months as the energy consumption is at its highest (see Figure 6), whilst the solar energy generation is at its lowest.

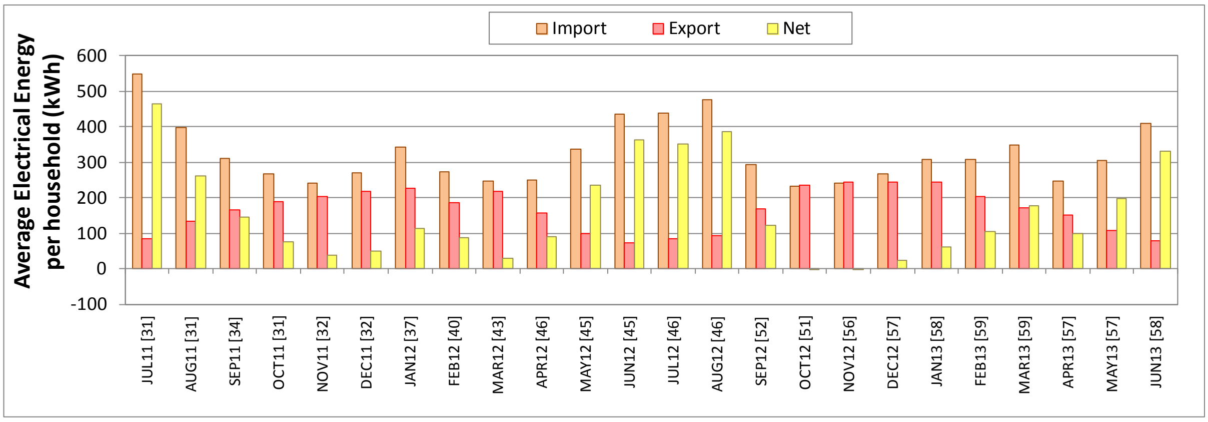

Figure 9 Monthly average household imported, exported and net energy consumption

Figure 10 shows the monthly average net electrical energy consumption, plus or minus one standard deviation (shown as error bars), and also the monthly minimum and maximum net household electrical consumption. The figure shows that for each of the 24 monitored months, at least one house has a negative net electrical consumption. The figure also shows a large difference between the average net electrical energy consumption and the house consuming the most. This, together with the distance between this data and each month's upper error bar (one standard deviation) implies that these houses are likely one of a few.

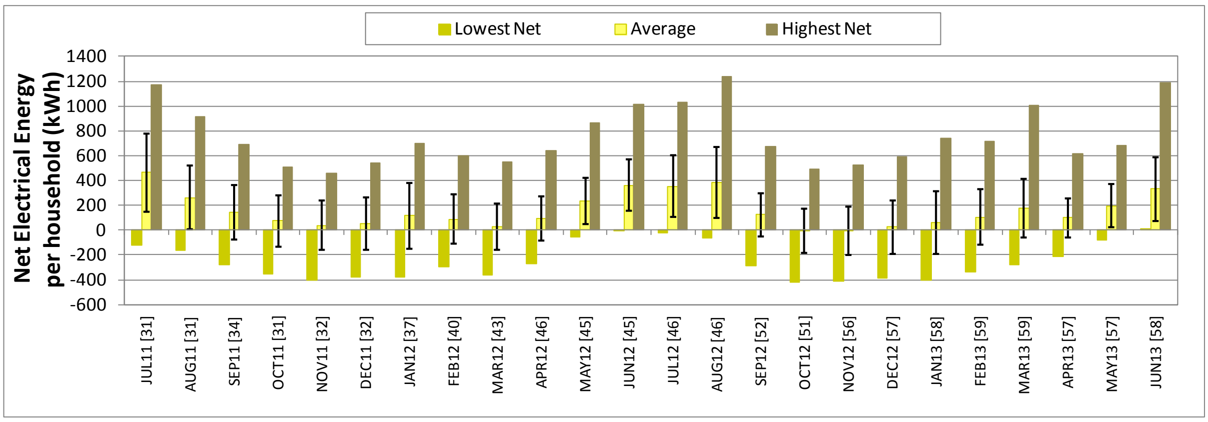

Figure 10 Monthly minimum, maximum and average household net electrical energy consumption

Note that in many cases, the houses that consume the minimum and maximum net electrical energies are neighbouring properties, each with two residents. The large difference is linked to a number of factors, such as age group, size of PV system, number of electrical/electronic equipment, lifestyle / house use (business or just home), etc. These, along with other behaviour aspects have been investigated in some detail, but are not further discussed in this report.

Appliance End-Use Energy Breakdown (Detailed Houses Only)

Figure 11 summarises where and which appliances consume energy in the Lochiel Park houses for a 12 month monitoring period, i.e. June 2011 – May 2012. The figure shows that the majority of energy is used by 'other' appliances that are not specifically listed in the legend. Heating and cooling follow, making up about 26% of the total energy consumed. Water heating accounts for 16% energy consumption, whilst refrigeration accounts for 13%.

Table 2 summarises this information and compares this to 12 month appliance end usage data obtained from a similar monitoring exercise carried out by UniSA at the Mawson Lakes development in 2002-2003.

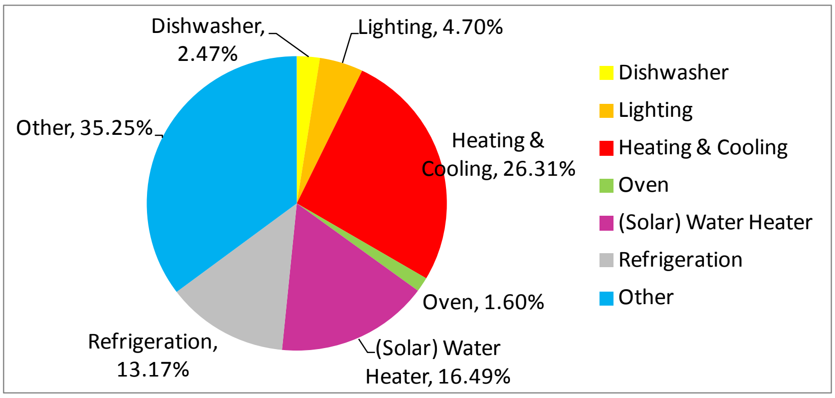

Figure 11 Breakdown of Lochiel Park house energy use, by end usage / individual appliances

Note that the Lochiel Park house data shown corresponds to data obtained from June 2011 – May 2012, rather than the last 24 months; this is due to missing data sets. Despite this, this period covers a continuous 12 month period to reflect appliance operation in all seasons / months. Also note that the average electrical heating and cooling load is compared, for those houses that use only reverse-cycle air conditioners, in the bottom row. Note that No. HH represents the number of households for which valid data was available.

The table below indicates that the detailed monitored Lochiel Park houses consume significantly (45%) less energy than the average Mawson Lakes house. Despite this, some appliances such as lighting, oven, dishwashers and reverse-cycle air conditioners use approximately the same percentage of the overall energy. Other appliances, such as refrigerators and 'other' consume a higher percentage of energy within the Lochiel Park development, despite actually consuming less energy than their Mawson Lakes counterparts. This is likely due to the increased number of electronic appliances in the Lochiel Park houses, and the reduction in energy consumption by other appliances, e.g. reverse-cycle air conditioners, dishwashers, lighting etc. The comparison not only shows the exemplary performance of the Lochiel Park households in requiring less

Table 2 Breakdown of individual appliance energy usage, for Lochiel Park and Mawson Lakes houses, for a 12 month monitoring period

	Lochiel Park (June 2011 - May 2012)			Mawson Lakes (April 2002 - March 2003)		
Appliance	AVG Energy (MJ) per year per House	Breakdown	No. HH	AVG Energy (MJ) per year per House	Breakdown	No. HH
Dishwasher	698.8	2.47%	5	1,615.9	3.10%	1
Lighting	1,330.1	4.70%	8	2,478.1	4.75%	6
Heating and Cooling*	7,445.2	26.31%	9			
Oven	452.6	1.60%	8	860.1	1.65%	4
(Solar) Water Heater	4,665.9	16.49%	9			
Refrigeration	3,727.1	13.17%	1	5,166.6	9.91%	4
Other	9,973.6	35.25%	9	9,255.4	17.74%	6
Total	28,293.4			52,161.4		
Heating and Cooling	4,975.0	17.58%	6	8,410.6	16.12%	6

(RCAC only)**		

* Energy values include gas

** Focuses on only houses that use reverse-cycle air conditioning (RCAC) for both heating and cooling

energy for most appliances, but also highlights the increased proportion of energy consumption of "other" appliances such as televisions, entertainment units, computers and home office equipment.

Note that the above table shows how many houses are used to determine the average, e.g. the Lochiel Park refrigeration usage data is based on one house, which is clearly not ideal, or even statistically valid. This is mainly due to poor workmanship and the builders' lack of understanding of the (at the time) new house designs / specifications. There is a need to increase the number of major appliances being monitored within these Lochiel Park houses, and as such there is a need to purchase additional portable monitoring equipment.

Total Energy Analysis

The above section focuses on the electrical energy consumption. Although the consumed and solar energy data is encouraging, this does not represent the entire picture as the energy associated with gas consumption is not yet included. This section hence analyses the combined (consumed and delivered) electrical and gas energy, although this is regarded by many as inappropriate as this does not accurately reflect primary energy consumption.

Consumed Energy

Figure 12 shows the average household breakdown of consumed energy, based on fuel type; units of MJ. This shows that approximately 65% of the average total household energy is consumed by electrical appliances, whilst the remaining 35% is consumed by gas appliances.

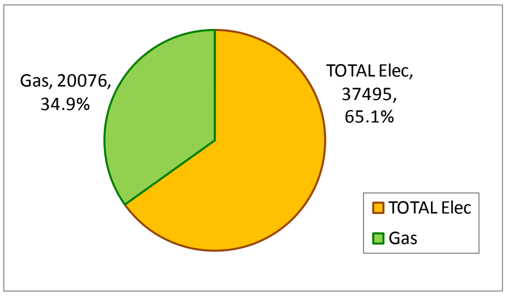

Figure 12 Average breakdown of the total combined household electrical energy consumption, by energy source

Figure 13 shows the average monthly energy consumption by fuel type, i.e. electricity and gas, for the 24 month monitoring period ending June 2013. Despite the clear differences in electrical energy consumption of the autumn / spring months and the summer / winter months, the figure shows that there is generally a small amount of variance throughout the monitoring period; the highest average monthly electrical energy consumption is 85% larger than that corresponding to the minimum monthly average electrical energy consumption. This is likely due to the increased demand for heating and cooling in winter and summer months respectively, indicating that there is likely a fairly constant baseline electrical energy load within these houses.

In contrast, there is a much larger seasonal variation in gas energy consumption; the highest monthly average gas consumption is 593% larger than the minimum monthly gas energy consumption. This large seasonal variation is due to the high penetration of gas-boosted solar water heaters (only 3 houses are electrically boosted), despite a small number of houses using gas for space or hydronic underfloor heating. Although these houses consume more gas than the Lochiel Park average, the small number does not significantly affect the average monthly gas consumption.

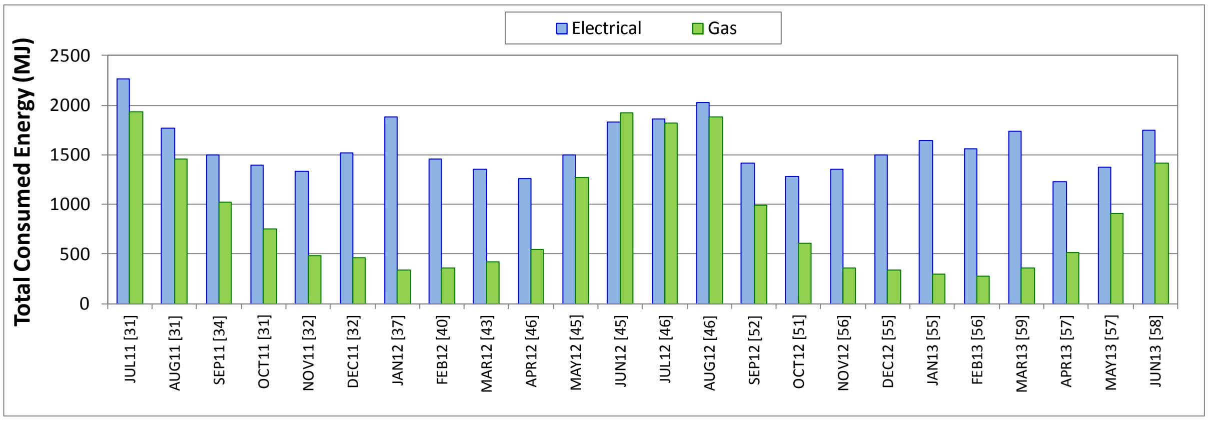

Figure 13 Monthly average household consumed energy by fuel type

Figure 14 shows the household monthly average total (gas + electrical) energy consumption for the same 24 month monitoring period, along with error bars that represent one standard deviation. In addition, this figure also shows the minimum and maximum household energy consumption, to indicate the level of variance, between similarly designed and built houses. The figure shows a low standard deviation during the months November – June, indicating a small variance between the mean and the individual household energy consumptions, whilst a large standard deviation is shown for months July – October, implying that there is a large spread of household energy consumption data. At this stage it is unclear why this is the case, and will be investigated in the future however, it is suspected that this is partially due to increased gas usage (during the latter winter months – see Figure 13) for water heating, and for space heating in a small number of houses.

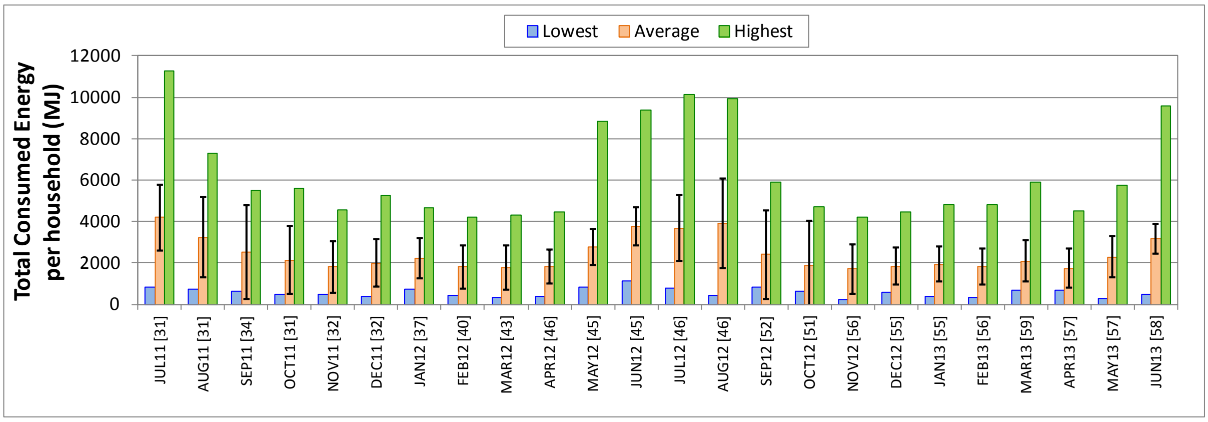

Figure 14 Monthly minimum, maximum and average household total consumed energy

Figure 15 below shows a histogram of the total household energy consumption of the 44 Lochiel Park houses monitored for a 12 month period (May 2012 – April 2013). The figure shows that a number of households consume very little energy (four in the lowest histogram bin, i.e. 12-14GJ/yr), whilst there are a small number of individual houses that use more than average (42GJ/yr), including the highest user that consumes 72-74GJ/yr. This histogram more closely represents a Weibull distribution, compared with a normal distribution (bell-shaped curve), as many houses are closely grouped together at the low-mid energy consumption region, whilst a small number of houses consume well above that of the average house. Note the average annual consumption is 30,750MJ.

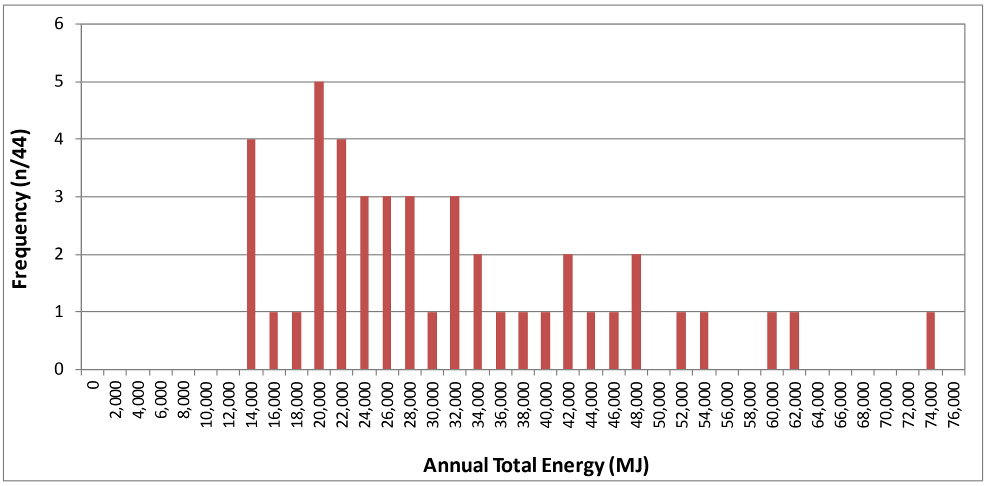

Figure 15 Histogram of total annual household energy consumption for 44 Lochiel Park monitored houses

Further analysis of the actual data shows that two similarly designed houses (with the same level of thermal heating / cooling load, i.e. 7.5 stars), one house can consumes 5.5 times of the other. This is a significant difference and is likely due to a number of factors, including size of household, lifestyle, number of appliances etc., which are not further discussed here.

Delivered Energy

The delivered energy is the combined delivered (net) electrical and gas energy consumed within the property, and can be negative for individual households if their solar (PV) system generates more energy than their combined electrical and gas consumed energy.

Figure 16 shows the source of the average monthly household energy consumption, whether that is from the combined roof-mounted PV systems, or from the combined electricity and gas utilities. The figure clearly shows that the combined solar systems supply a higher percentage of the household energy demand, in the spring and summer months. This is expected due to higher solar gain, e.g. longer days and increased peak sunshine hours during these months, as well as the higher altitude of the Sun. Note that the majority of PV systems within this development are optimised for summer / spring months due to the pitch of the panels, which is generally equal to the roof pitch.

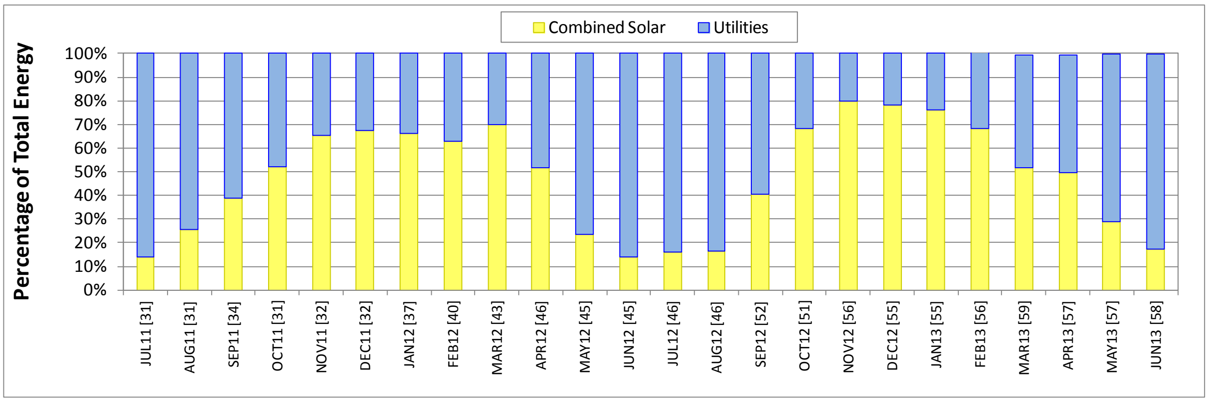

Figure 16 Breakdown of monthly average household energy by source

Figure 17 shows a breakdown of the average 24 month delivered energy consumption by fuel type. Approximately 60% of all delivered energy is accounted for by gas appliances, whilst the remaining 40%, is accounted for by electrical appliances. Note the quantities quoted have units of MJ.

Figure 18 shows the average monthly household delivered energy, including error bars that represent one standard deviation, along with the monthly minimum and maximum household delivered energy per month. The figure clearly shows the significantly higher average delivered energy for the winter months, due to increased gas consumption of water heaters, compared to summer months. The delivered energy is lowest in the summer months (despite the demand for cooling) due to increased solar gain which generates more electrical and solar thermal energy; the latter offsets the energy consumption of the solar water heaters. This is

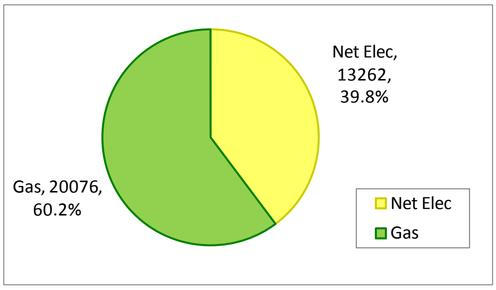

Figure 17 Breakdown of average delivered household energy, for 24 months, by energy source.

more clearly seen in Figure 19, which shows a breakdown of the monthly average household energy consumption by source, i.e. that which is delivered by the gas and electricity utilities, and that which is generated locally by the roof-mounted PV systems.

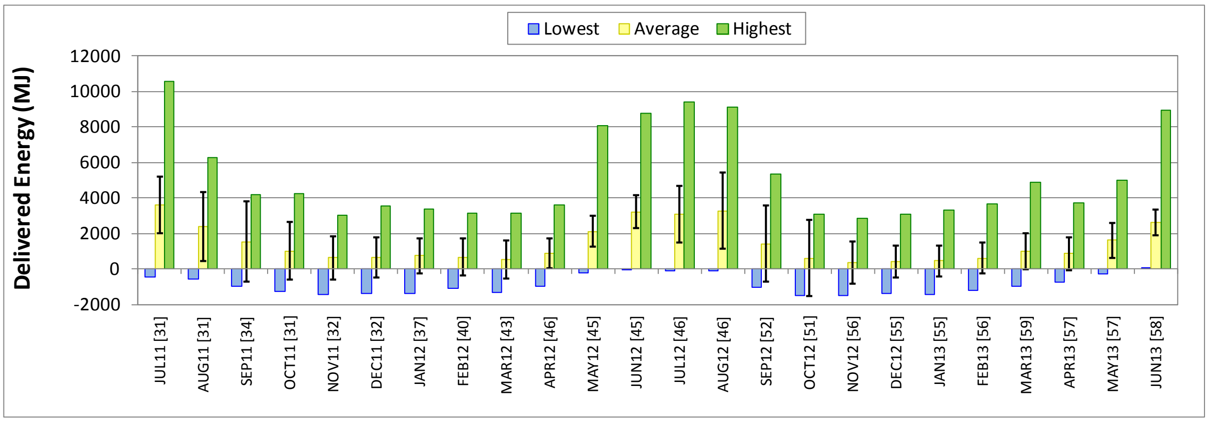

Figure 18 Monthly minimum, maximum and average household delivered consumed energy

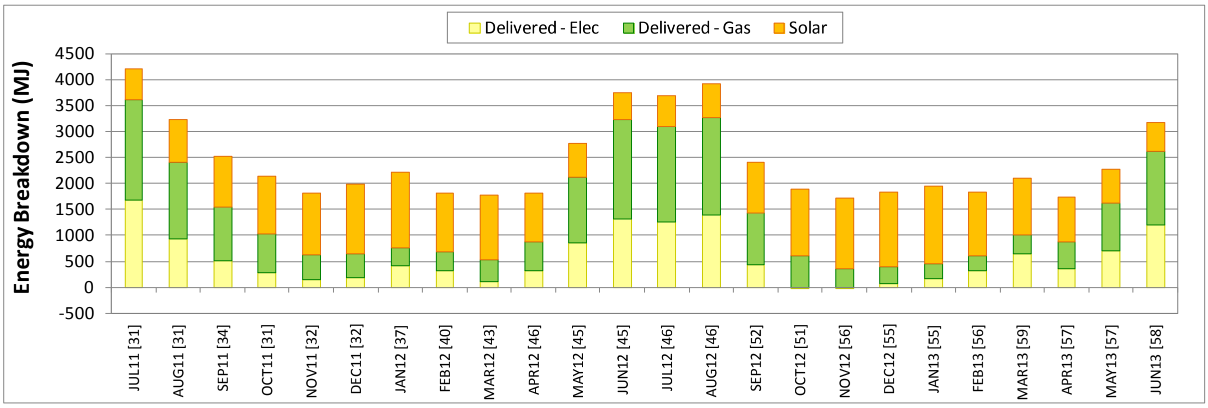

Figure 19 Monthly average household total consumed energy breakdown, showing delivered energy from gas and electricity utilities, and that offset by roof-mounted solar systems

Note that the delivered electrical energy (net electrical energy) is negative for the months of October and November in 2012.

Greenhouse Gas Emissions

Emission Coefficient by Fuel Types

The greenhouse gas emissions are calculated using the greenhouse gas emission factors obtained from the Department of Climate Change and Energy Efficiency for 2011-2013 (DCCEE 2011, DCCEE 2012). The values used for South Australia are summarised in Table 3, for standard units as well as per MJ. Note that the net electricity factor quoted is the summation of scope 2 and scope 3 coefficients, whilst that for gas is the summation of direct and scope 3 coefficients. The relatively low and decreasing electricity emission factor is due to the penetration of renewable energy (wind and solar) in the South Australian electricity generation.

Table 3 Annual gas and electricity greenhouse gas emission factors

Fuel	2011-2012	2012-2013
Electricity (kg CO2-e/kWh)	0.81	0.79
Gas (kg CO2-e/m3)	2.421	2.421
Electricity (kg CO2-e/MJ)	0.2250	0.2194
Gas (kg CO2-e/MJ)	0.0616	0.0616

Greenhouse Gas Emission Performance

Figure 20 shows the minimum, maximum and average greenhouse gas emissions for the 24 month monitoring period. The average also shows error bars that represent one standard deviation from the mean. This figure appears similar to that showing monthly delivered energy (Figure 18), however, the increase in winter greenhouse gas emissions did not rise as dramatically as it for delivered energy. This is due to the smaller greenhouse gas emission factor of gas, compared to that of (net) electricity, when comparing per MJ of delivered energy.

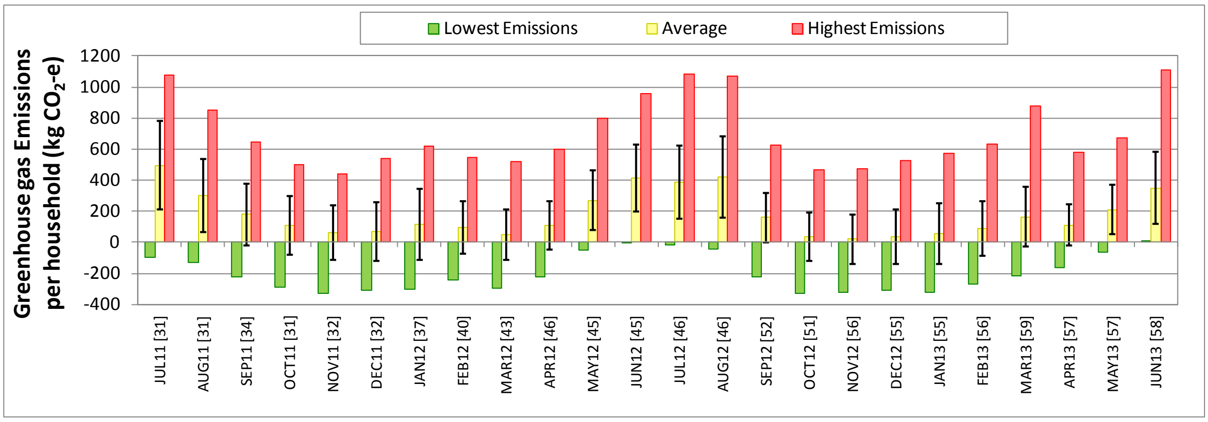

Figure 20 Monthly minimum, maximum and average household greenhouse gas emissions

The house corresponding to the lowest emissions, from the above figure, is the same house that consistently consumed the least delivered energy per month (see Figure 18). This occurred as this house is one of a few all-electric houses, and as such do not need to offset energy usage or greenhouse gas emissions based on gas consumption. In addition, the occupants are also frugal with their energy consumption, and they installed a larger PV system than the minimum required based on floor area, i.e. 4.2kWp vs. 2.4kWp.

Source of Greenhouse Gas Emissions

Figure 21 shows a breakdown of the average greenhouse gas emissions for the 24 month period, by delivered fuel; units are kg CO2-e. It is clearly seen that the greenhouse gas emissions by net (delivered) electricity is far more dominant that those caused by gas consumption – this is somewhat expected due to the significantly higher emission factor of electricity (see Table 3), despite electricity making up only approximately 40% of the delivered energy (see Figure 17).

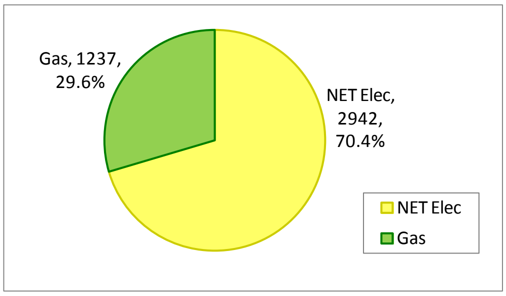

Figure 21 Breakdown of the total combined household greenhouse gas emissions, by energy source

Net Zero Carbon Performance?

The above sections have examined the average performance of houses in terms of total and delivered energy, and greenhouse gas emissions. It was observed that one house consistently consumed negative delivered energy (generated more solar energy than their energy consumption), and that as a result mitigated more greenhouse gas emissions than the amount emitted. The question, however, remains - how many other houses have the potential to perform similarly?

This is answered in Figure 22, which shows the percentage of houses (each month) that offset their electrical energy consumption, their total energy consumption (negative delivered), and their greenhouse gas emissions. The figure shows encouraging results, i.e. during the summer period (October – March): 44% of households offset their electrical energy consumption, 26% offset their total energy consumption, and that 37% offset their greenhouse gas emissions.

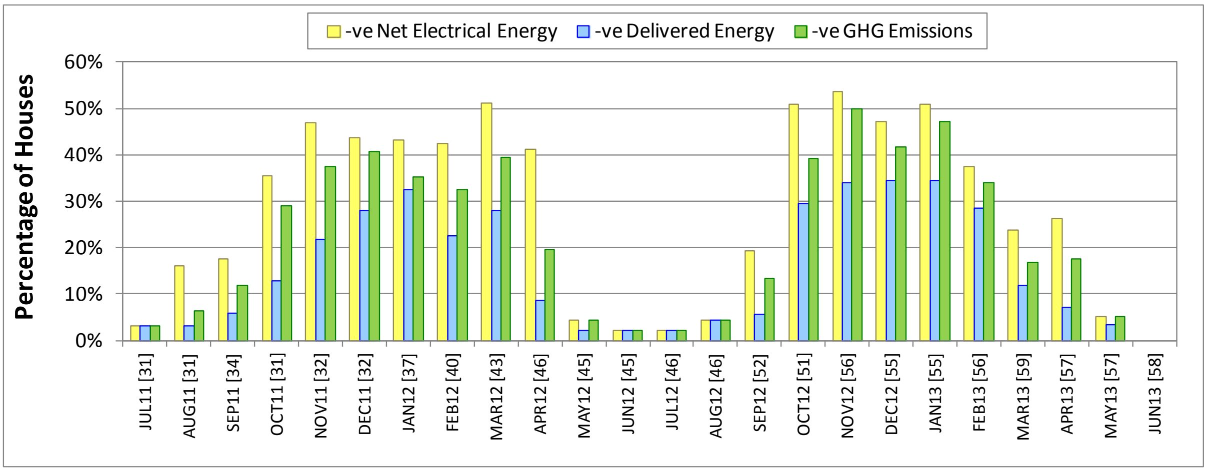

Figure 22 Monthly summary of Lochiel Park house performance, showing how many offset their: electrical and or total energy consumption, and their greenhouse gas (GHG) emissions

Energy Comparison with other Housing Stock

A comparison of the preliminary performance of the Lochiel Park houses, is presented by Saman et al. (Saman, et al. 2011, Saman, et al. 2012), which focussed on data from the first 18 months of the monitoring period. A comparison is made with available data on average house hold consumption in South Australia and nationally. Another comparison was made with detailed monitoring data for a cluster of home of similar size and demographics which was gathered by the UniSA team at Mawson Lakes in South Australia during the period 2002-2004 (Saman, et al. 2003).This initial comparison (Saman, et al. 2011) showed that Lochiel Park households use significantly less electrical and gas energy than the average South Australian, national or Mawson Lakes households. The reduction in energy consumption and hence greenhouse gas emissions, is caused by i) the high star rating of each house, ii) the use of highly efficient reverse-cycle air conditioners and other electrical appliances and equipment, iii) the use of gas-boosted solar hot water heater systems. Note that these energy reductions occurred despite an increase in the Lochiel Park house habitable floor area compared with the national and South Australian averages, which significantly reduced the energy consumption density of these houses (Saman et al. 2011).

The results also showed the impact of PV systems, i.e. they reduced the amount of energy purchased from the grid (delivered electrical energy), which drastically reduced the houses total energy consumption and their subsequent greenhouse gas emissions (Saman et al. 2011).

Energy Comparison per Unit Floor Area

Figure 23 compares the normalised (a) total energy and (b) delivered energy consumption of the Lochiel Park houses, to those from the Mawson Lakes development, along with data sets relating to state and national averages; referred literature is listed by Saman et al. (Saman et al. 2011). Figure 20 (a) and (b) show the significant energy reduction of the Lochiel Park houses for 2011-12 and 2012-13, where on average, these houses consumed about half of that of the South Australian state average, and less than half the national average and those houses in the Mawson Lakes development. Figure 20 (b) shows the impact made by solar systems installed at Lochiel Park, which show that the delivered energy of these houses is 25-30% of those from Mawson Lakes and the state and national averages.

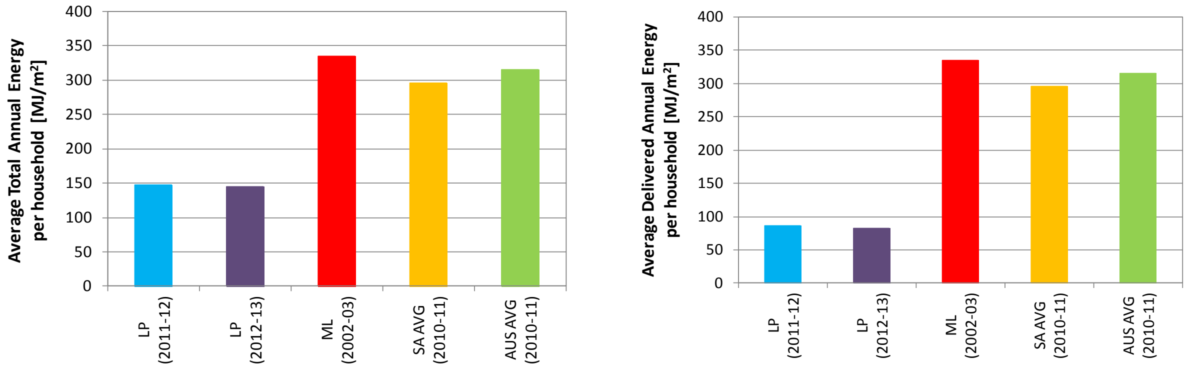

Figure 23 Comparisons of Lochiel Park (LP) house normalised total energy consumption against a sample of Mawson Lakes (ML) households, and both state (SAAVG) and national (AUSAVG) averages for (a) total annual energy use; and (b) delivered annual energy

Note that due to limited information and initial uptake of PV systems, the 2010-11 data assumes that there was a low penetration of installed PV systems that would not significantly reduce the delivered energy figures shown in (b) for either the national or South Australian averages. The monitored houses within Mawson Lakes, however, did not have solar systems installed.

Figure 24 compares the total energy consumption, per square metre, of 10 houses that only use reverse-cycle air conditioning for both heating and cooling, (Berry et al. 2013). The six Lochiel Park houses, on average, consume half of the average energy consumed by the four houses from the Mawson Lakes development. Note that this data is based on that obtained for a 12 month monitoring period, unlike the data presented elsewhere throughout this report. Further evaluation of energy consumption patterns and quantums for other major energy consumiming systems and appliances such as lighting, cooking, washing machines, dryers and fridges is currently under way.

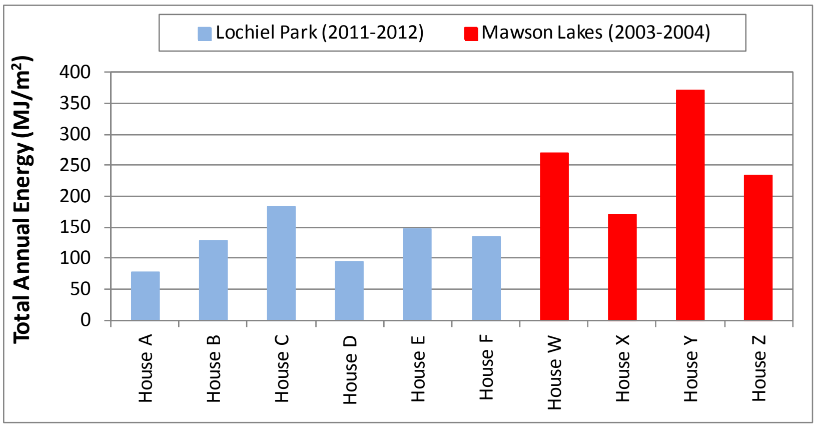

Figure 24 Comparison of normalised total energy consumption of six Lochiel Park houses against four Mawson Lakes households that use reverse-cycle air conditioning for heating and cooling

Figure 25 compares the normalised (a) total energy and (b) delivered energy consumption of the Lochiel Park houses (per household), to those from the Mawson Lakes development, along with data sets relating to state and national averages.; referred literature is listed by Saman et al. (Saman et al. 2011). Figures 22(a) and (b) show the impact of solar systems installed at Lochiel Park. Note that due to limited information and initial uptake of PV systems, the 2010-11 data assumes that there was a low penetration of installed PV systems that would not significantly reduce the delivered energy figures shown in (b) for either the national or South Australian averages. The monitored houses within Mawson Lakes, however, did not have solar systems installed.

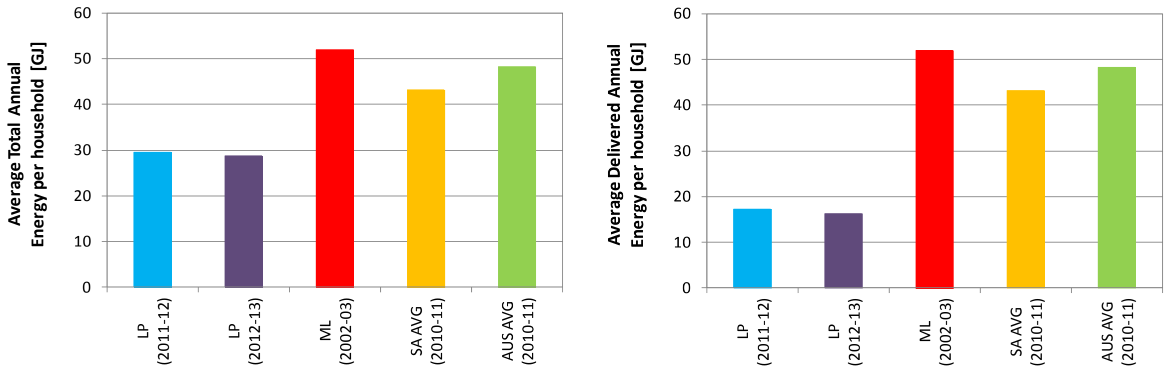

Figure 25 Comparisons of Lochiel Park (LP) house normalised total energy consumption against a sample of Mawson Lakes (ML) households, and both state (SAAVG) and national (AUSAVG) averages for (a) total annual energy use; and (b) delivered annual energy

Summary and Conclusions

This section summarises the performance of houses within the Lochiel Park Green Village, based on analyses of individual household monitored data, for a number of houses and over a continuous period of two years.

The conclusions made from the results include:

- Despite having similar designs and AccuRate star ratings, a large variation of energy consumption exists. This is due to a number of factors such as the number of the occupants, the age group, the types and number of and appliances, as well as lifestyle and behavioural choices. Current and future work aims to link energy consumption with these factors
- Despite the fact that planning for this development commenced almost a decade ago, these houses consume far less energy per household and per square meter of habitable floor area than the South Australian state and the national average house, as well as those monitored houses within the Mawson Lakes development. This confirms the technical and economic feasibility of zero carbon housing in Australia.
- The energy consumed by six houses with use reverse-cycle air conditioners for both heating and cooling, is significantly less than the energy consumed within the Mawson Lakes development, despite larger house areas which demonstrates the impact of higher energy star rating.
- The mandatory inclusion of roof-mounted PV systems has significantly reduced the average energy demand from the utilities, i.e. the average Lochiel Park house demands approximately 40 and 34% of energy demanded by the average South Australian and national average house. The results of peak daily consumption/generation demonstrate the benefitial impact on reducing the peak power demand on the grid.
- The mandatory inclusion of roof-mounted PV systems has allowed many houses to offset their electrical and total energy consumption and green house gas emissions; in the summer and those immediately before and after, this is achieved by approximately 44, 27 and 37%, respectively. At least one household consistently produces more electrical energy than it consumes for each of the 24 monitored months.

Future Work

The results summarised in this report were largely obtained prior to the involvement in the CRC for Low Carbon Living. Never the less they provide a significant data base for supporting the research program and milestones associated with project RP1006. The detailed monitoring data for a substantial number of dwellings over an extended time period provides a unique source of information and evidence base for constructing a mothodology for evaluating and regulating energy consumption in Australian housing. The monitoring activities along with the many stories emerging from the technical and the social research demonstrate the feasibility of zero carbon housing in Australia and the associated economic and environmental benefits.

A substantial amount of time and effort is required to collect and filter the incoming data. In addition, a vigilant effort is required to ensure valid data is incoming, by maintaining and proactively monitoring the plethora of sensors within the Lochiel Park development; to date there have been a number of gas and water meter sensor failures, the majority of which require continuous replacement or adjustment. It is the intention to continue the monitoring processes over 9 years to enable a longtudinal technical and social analysis of the results.

It is highly recommended that additional non-intrusive monitoring equipment is installed within these houses to facilitate energy data collection of all appliances and energy consuming devices to create a full picture. Such devices include, but are not limited to, refrigeration, cooking and washing appliances, televisions, computers and other home office equipment. It is important to gain insight into the energy consumption and electrical power patterns of such (information communication and entertainment) devices as the penetration of these devices is increasing with modern lifestyles and as such the energy demanded by these items will also increase, forming a larger proportion of household energy consumption, and how they impact on other issues such as peak power demand.

The high resolution data logging / monitoring will also allow research into specific appliance electrical power use patterns (signatures) to be undertaken. This will strengthen the energy end use appliance information currently available and increase the statistical validity of our research and enable the development of a comprehensive model of both energy consumption and generation based on reliable data.

Other complementary area of the work is further social and economic research to develop a data base for evaluating the economic costs/benefits including co-benefit evaluation of low carbon living.

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