CSIRO INTELLIGENT GRID CLUSTER

PROGRESS REPORT

Project P6: The Intelligent Grid in a New Housing Development

Period: January - June 2010

Second Progress Report Covering:

Analysis of the First 6 Monthly Data – milestone 6b
Analysis of first householders survey – milestone 6a
Other progress related to the project – milestone 7

Authors

Prof. Wasim Saman
Dr. Edward Halawa
Dr. David Whaley
Dr. Jane Edwards
Mr. Lachlan Mudge

Revised December 2010

Disclaimer

Acknowledgements

The UniSA P6 Project Team acknowledges financial support from CSIRO's Intelligent Grid Cluster, Energy Transformed Flagship Program and the cooperation of iGrid Project Coordinator and other IGrid researchers. We also acknowledge the support provided by the South Australian Land Management Corporation who manages the project and the cooperation of the Lochiel Park householders involved in the household survey and the monitoring program.

Table of Contents

EXECUTIVE SUMMARY

Under the CSIRO Energy Transformed Flagship, a three year collaborative research project was established between five Australian universities: University of Technology, Sydney, University of Queensland, University of South Australia, Queensland University of Technology and Curtin University. University of South Australia is working on the P6 project titled: The Intelligent Grid in a New Housing Development. This project started in July 2008 and will end in June 2011.

This report summarises the project progress within the period January – June 2010 which covers the following milestones:
(1) analysis of the first 6 months monitoring data – M6b,
(2) analysis of the first household survey results – M6a,
(3) other progress related to the project which constitutes milestone M7.

As of the end of June 2010, 25 houses (21 homes and 2 display homes, including the Sustainability Centre + Mews) have been completed. The 21 homes have been occupied with 8 homes under detailed monitoring and 13 homes having general monitoring.

The implementation / installation of the EcoVision data acquisition system (DAS) with dedicated server has been accomplished. Since February 2010, the UniSA team members have been directly accessing the EcoVision server and the data being stored.

During the first six months of data acquisition some technical and non-technical issues arose which can be classified into two groups, i.e. (1) those caused by people involved in the house construction, cable wiring and installation of monitoring systems, and (2) those associated with the monitoring systems. Some of the issues have been resolved and the rest being addressed by the UniSA team in cooperation with the parties involved (LMC, EcoVision, Builders, households).

A selected set of the data collected has been processed and analysed and presented in this report. The results presented are not exhaustive; however, they provide a general indication of the pattern of operation of and the power inputs (required) by some appliances such as air conditioning, lighting, oven and dishwasher, and the power generated by the installed solar PV panels. The preliminary findings reveal that air conditioning is, as expected, the dominant factor which causes peaky power demands on hot days. From these preliminary results, it was also found that solar panels, while being able to reduce household energy consumption or even producing an energy surplus, do not always provide a significant contribution to the reduction of electrical power demand due to a mismatch between the time of solar power generation and the time of high power demand which is normally caused by the need for air conditioning. However, the results also demonstrate the reduced general power demand in comparison with standard housing. The values of peak demand on a hot day are substantially lower than those encountered in standard houses.

The qualitative phase of the first household survey has been completed. Ten in-depth, semi-structured interviews have been carried out involving 18 individuals focusing on people's experience of thermal comfort in their homes, the use of particular appliances including monitoring equipment, attitudes to environmental issues, kinds of 'green behaviour' practiced by households, the influences on those behaviours and the reasons for choosing to live in Lochiel Park. The preliminary analysis of this data reveals that people experience a conflict between their 'roles' as citizens and consumers. As citizens, they wish to engage in pro-environmental behaviour; as consumers, they wish to maximise comfort and convenience, while minimising costs and these factors are not always compatible with pro-environmental outcomes. People's interaction with the design features of their houses, including energy and water consumption, is the outcome of a complex calculus of comfort, cost and convenience.

Abbreviations

AuSES – Australia Solar Energy Society
DAS – Data Acquisition System
ETSA - The Electricity Trust of South Australia
ISES – International Solar Energy Society
LMC – Land Management Corporation
ONT – Optical Network Terminal
ONU - Optical Network Unit
PEB – Pro-environmental behaviour
PLC – Programmable Logic Controller
VPN – Virtual Private Network
WREC – World Renewable Energy Congress

Key Words

green village, energy rating, star rating, thermal comfort, smart metering, distributed generation, distributed energy resources, solar panel, peak load, water use; behavioural responses

1 INTRODUCTION

This report outlines the work undertaken during the period January – June 2010 on the iGrid Project P6: The Intelligent Grid in a New Housing Development.

The components of work described here are the following two milestones: (1) Analysis of the first six months data and (2) Analysis of the first household survey results.

To date, 25 homes have been completed which includes 21 homes, 2 display homes, the Sustainability Centre and Mews. The 21 homes have been handed over and occupied with 8 homes undergoing detailed monitoring and 13 homes with general monitoring. Of the 10 homes designated for detailed monitoring, data of 8 homes have been verified. Similarly, of the 106 designated for general monitoring, data of 13 homes has been verified.

Regular recording and processing of the monitoring data has been carried out since early February 2010 with the quality of data being recorded varying from house to house. The recording and processing of monitoring data has not gone smoothly due to various commissioning problems which are discussed in Section 3. Some of these issues have been rectified while the solutions to some other issues are being sought and discussed with the LMC and other parties involved.

For the benefit of the reader of this report, prior to the presentation of the results of the preliminary data, the data logging and monitoring systems being implemented at houses with general and detailed monitoring is briefly described.

Some of the data available for 6 houses with detailed monitoring (identified as houses L1TS, L2OZ, L3TS, L4FO, L5SZ and L6FS) has been analysed and presented in this report. The results presented in this report in the form of graphs were obtained from the data recorded during the period February – April 2010. In these graphs the electrical power input of individual appliances (air conditioning, lighting, oven and dishwasher) and PV system are plotted against time to enable the observation of the performance profiles of each of the devices. Temperature profiles at conditioned spaces of some homes are also presented to observe how the room temperatures are affected by both the outside weather conditions and the operation of the installed air conditioning systems. The results presented here are not exhaustive, however, they provide a general indication of the pattern of operation of and the power inputs (required) by some appliances such as air conditioning, lighting, oven and dishwasher. In some of the graphs, the power generated by solar PV panels is also presented.

The qualitative phase of the research of the first household survey has been completed and the results are presented in this report.

2 OVERVIEW OF MONITORING SYSTEMS

2.1 MONITORING LEVELS AND DATA LOGGING

The monitoring program at the Lochiel Park Green Village is being implemented at the following three levels (Saman et al., 2010):

- detailed monitoring of electricity, gas and water consumptions and comfort variables (temperature and humidity) in 10 nominated homes. EcoVision System 3015 is installed in each home to monitor this data.
- record of total electricity and gas consumption and water (mains drinking water and recycled water) in all remaining 96 homes. EcoVision System 2015 is installed in each home to monitor this data.
- network monitoring of total energy (electricity and gas) and water (mains drinking and recycled water) at subdivision meters

Figures 1 - 3 show the variables to be recorded for each of the three levels of monitoring mentioned above. These include: electrical energy / power, gas energy / power, water consumption, and air temperature and relative humidity.

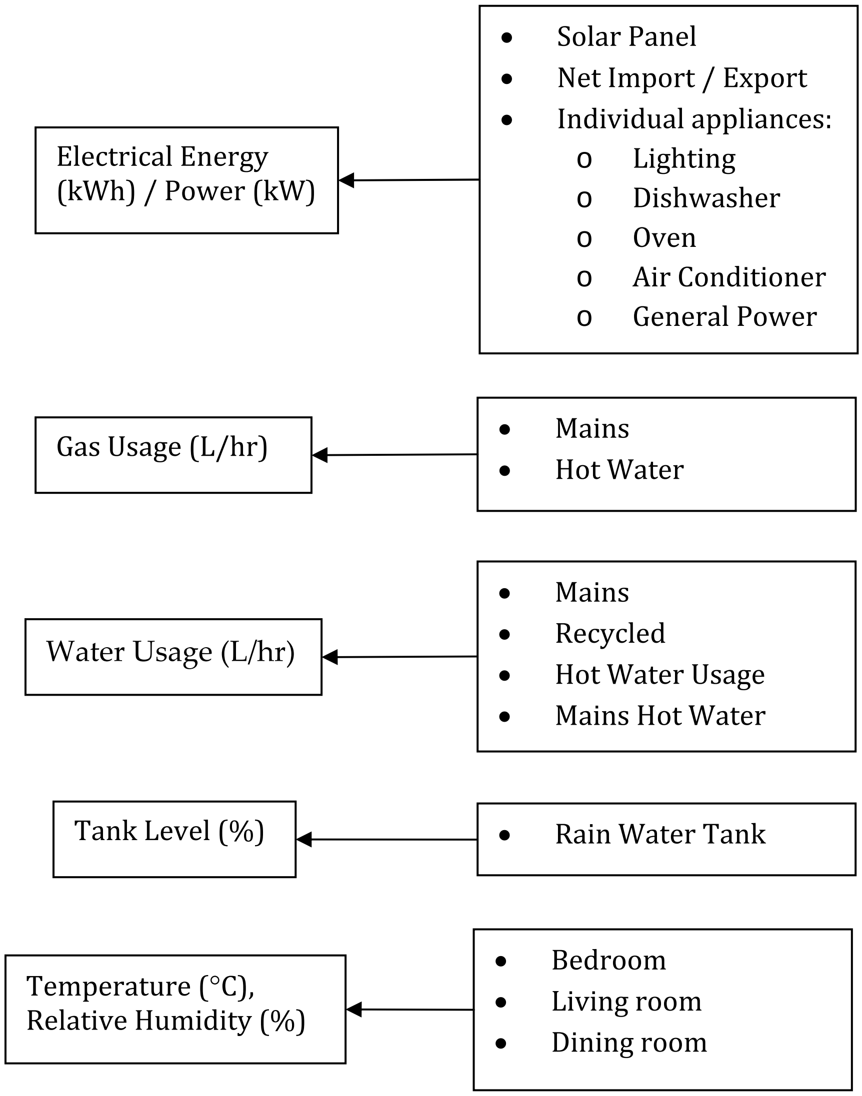

Figure 1: Variables being recorded for detailed monitoring program for 10 homes

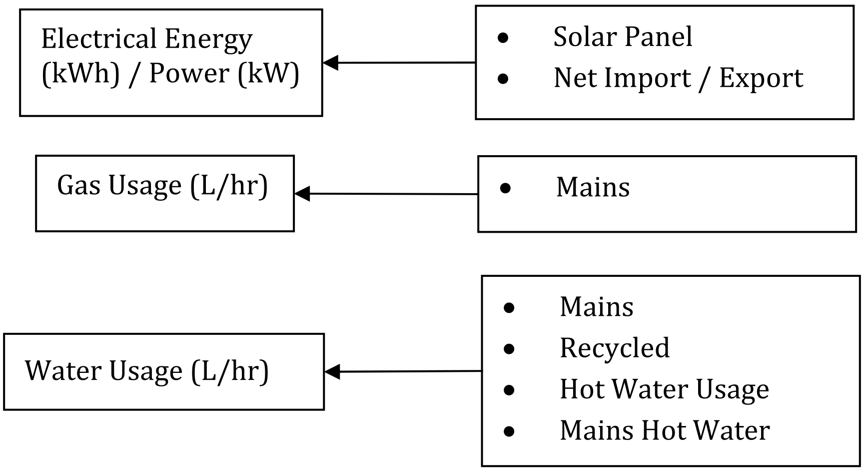

Figure 2: Variables being recorded for all 106 homes

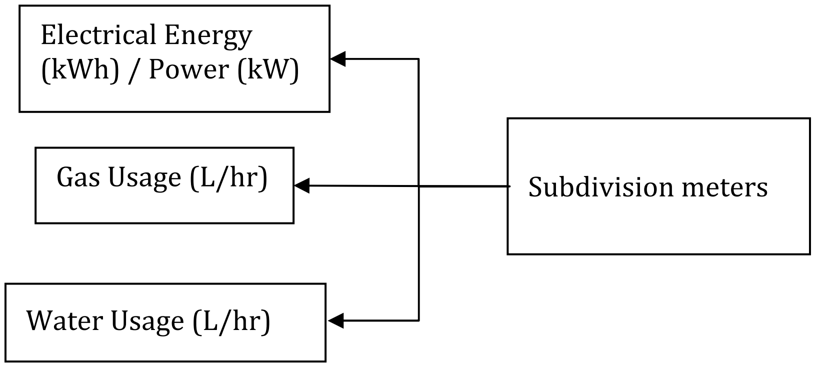

Figure 3: Variables to be recorded at subdivision meters

The EcoVision system, installed in each house, continuously records and logs data from the various sensors. The information is shown on the screen in real-time and is transferred daily to the central server located at Lochiel Park, allowing remote access to each EcoVision system.

2.2 Data Logging At Detailed Monitoring Homes

To date, 8 homes have been occupied and their data is being collected and checked; 7 have been verified. Of the 10 detailed monitoring homes, 3 are terraced and the remaining are detached homes. All homes have a minimum star rating of 7.5 (6 homes) and a maximum of 7.6 (4 homes). All have 3 bedrooms, expect one with 4 bedrooms. All have 2 bathrooms and the majority with 3 toilets with the exception of 2 with 2 toilets.

Figure 4 shows a typical installation of an EcoVision monitoring system (system 3015) at a detailed monitoring home. It is seen that up to 20 digital and 7 analogue sensors (which are identified in the figure) are directly connected to the programmable logic controller (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 Optical Network Terminal (ONT) and the Virtual Private Network (VPN), using Ethernet and Fibre Optic cables, respectively. This arrangement also allows the EcoVision to display local weather data, and allows UniSA to remotely login to each EcoVision system.

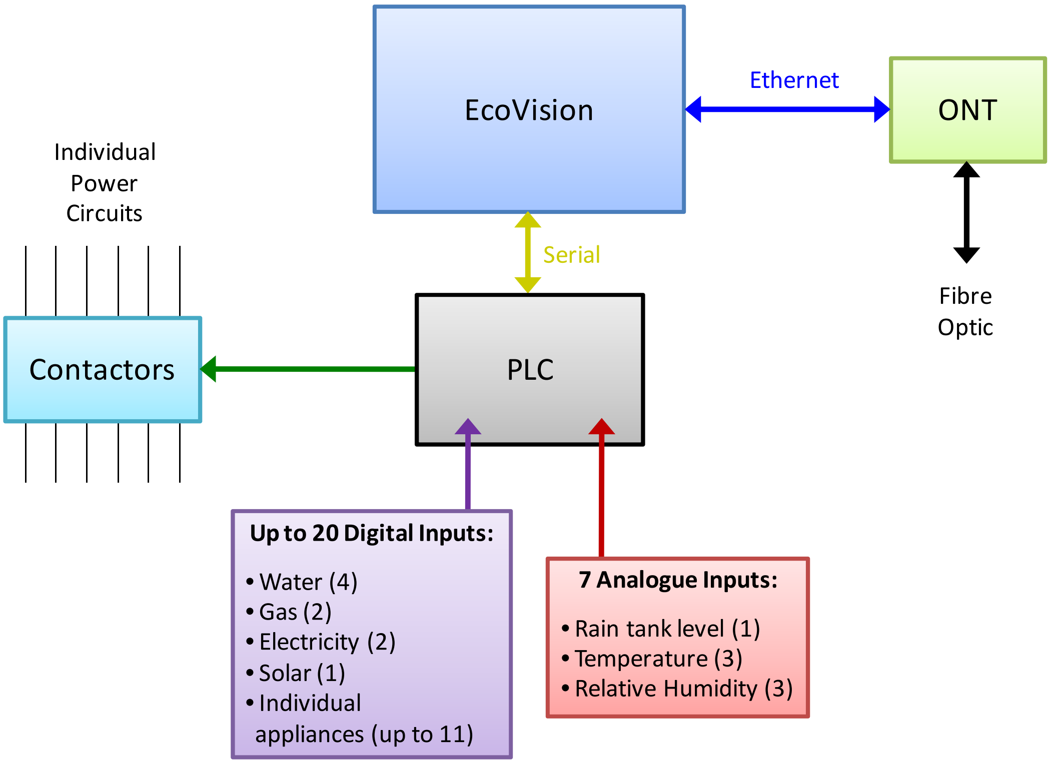

Figure 4: Overview of detailed monitoring (3015) system.

Figure 4 above also shows a series of contactors, which form part of the Load Management system. If enabled and activated, the contactors open, interrupting power to individual appliances and or power circuits; this is controlled by the EcoVision and executed by the PLC. Up to 6 contactors 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 induction cooker can be controlled by Load Management system.

Table 1 shows the latest status of the measuring devices installed in each home. As shown, most sensors have worked well whilst some (main and recycled water, rain level sensors) need to be rectified. Although data logging has started since January 2009 (Saman et al., 2009), reliable data has not been available until February 2010 when the first EcoVision systems were thoroughly checked.

Table 1 - Status of Sensors at Detailed Monitoring Homes

House ID	Date Sensors Checked	Commissioned		Digital Sensors								Analogue sensors				Correct Labels?		Solar HW
		System	Load Mangt	Water Meters				Gas	Electricity			Rain	Temp. / RH			T/RH	AC, not	using 10L
				Mains	Recyc.	Hot Use	Sup		Solar	Imp	Exp	level	1	2	3	rooms	pool	per hour?
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	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×
L22SS	9/06/2010	9/06/2010	✓	✓	✓	✓ ×	✓ ×	✓ ×	✓	×	×	×	×	×	×	×	✓	??
L23SS	4/06/2010	4/06/2010	✓	✓	✓ ×	✓	✓	×	✓	✓	✓	×	✓	✓	✓	×	✓	×

2.3 DATA LOGGING AT GENERAL MONITORING HOMES

Of the 106 homes to be monitored, 96 will have general monitoring systems installed. To date, 16 homes have the monitoring systems installed. Of the 96 general monitoring homes being or to be built, 26 are terraced, 16 are apartments, 3 are townhouses and the remaining 43 are detached homes. Due to varying stages of construction or construction planning, the complete information regarding the star rating, number of bedrooms, bath rooms and toilets of these houses is not available at the time of completion of this report. All homes, however, are expected to have a minimum star rating of 7.5, the minimum requirement stipulated by the design guidelines.

An overview of a typical installation of a basic 2015 EcoVision system is shown in Figure 5. It is similar to the detailed 3015 system shown in Figure 4, however, it does not use analogue sensors, and requires only 8 digital inputs (which are identified in Figure 5), making it somewhat less comprehensive than the detailed 3015 system. Despite the reduction of sensors, the basic 2015 EcoVision system operates in the same manner as the detailed 3015 system, i.e. it displays resident's water, gas, solar and electricity usage information. The 2015 system, does not however, sense or display temperature, relative humidity, rain water tank level or breakdown electricity usage to individual appliances / power circuits.

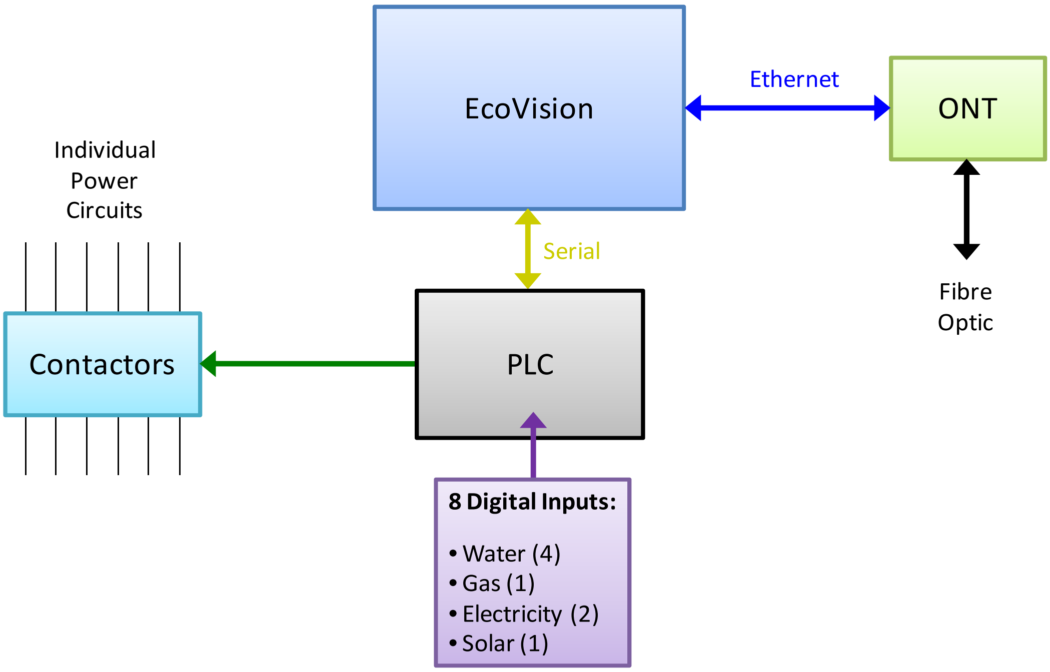

Figure 5: Overview of basic monitoring (2015) system.

Table 2 shows the latest status of the measuring devices installed in each home. As shown, most sensors have worked well whilst some (main and recycled water, rain level sensors) need to be rectified. Although data logging has started since January 2009 (Saman et al., 2009), reliable data has not been available until January 2010 when the first EcoVision system was thoroughly checked. Note that at the time of the completion of this report, one home is not accessible due to the absence of its ONT.

Table 2 - Status of Sensors at General Monitoring Homes

House ID	Date Sensors Checked	Commissioned		Digital Sensors								Solar HW using 10L per hour?
		System	Load Manag't	Water Meters				Gas	Electricity			
				Mains	Recyc.	Hot Use	Suppl	Meter	SOLAR	Imp	Exp	
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	✓	✓	✓	N/A
L11TE	16/03/2010	27/01/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	×
L12TN	16/03/2010	10/09/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
L13TN	16/03/2010	3/11/2010	✓	✓	✓	✓	✓	×	✓	✓	✓	×
L14TO	14/04/2010	4/02/2010	✓	×	✓	×	✓	×	✓	✓	✓	×
L24TT												
L15TT	17/03/2010	11/03/2010	✓	✓	✓	✓	×	× ✓	✓	✓	✓	×
L16TN	6/05/2010	6/05/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L17FF	26/05/2010	26/05/2010	✓	✓	✓	✓	✓	✓	×	✓	✓	×
L18FT	20/05/2010	12/05/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L19FF	17/03/2010	17/02/2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L20FF	17/03/2010	11/02/2010	✓	✓	×	✓	✓	✓	✓	✓	✓	✓
L21FE	17/03/2010	18/12/2009	✓	✓	×	✓	✓	✓	✓	✓	✓	×
L25SS	2/06/2010	2/06/2010	✓	✓	✓×	✓	✓	✓	✓	✓	✓	×

3 ISSUES AND SOLUTIONS

The first six months period of data collection, processing and analysis has not gone smoothly. A number of issues arose which have caused delays in commissioning the EcoVision systems and hence collecting their respective data. While some teething problems were anticipated in the commissioning stage, a number of unexpected issues also came up. These issues can be classified into two groups, i.e. those caused by people, and those associated with the monitoring systems. They are detailed in Appendix 1 in order to provide information and lessons for future installations.

On the data processing and analysis front, the quantity of data already collected, although limited to 14 houses, still comprises a very large data set. Data is logged every minute for each sensor in each house that is monitored in detail, representing over two million values every month. The UniSA Team has requested Ecovision to increase the logging interval to 5 minutes but this has not yet been followed up. The analysis of data for a small number of houses therefore requires considerable data storage and processing capability. Use of the existing server at Lochiel Park for data processing has been deemed inappropriate and likely to interfere with the machine's main purpose of collecting data directly from each Lochiel Park household. The upper threshold for the capability of existing data analysis tools and techniques has been reached. UniSA has therefore made the necessary arrangements to host a 'Virtual Server' for the purposes of local data storage and processing, utilising Microsoft SQL Server software to store and process all data in a purpose built database. UniSA researchers require training to optimise the use of the SQL Server. The aforementioned training will be administered by Dimension Data Learning Solutions, a UniSA preferred training provider. Training will commence on 2nd of August and finish in late September 2010. The resulting database, and associated improved data processing capacity, will ensure that the long-term requirements of the project are achieved and optimise all aspects of associated data analysis which provide a rich resource for the evaluation of house and appliance utilisation and household interaction.

The issues and solutions discussed above have been accepted for presentation as a peer reviewed paper in the Solar 2010 Conference and appears as Appendix 2.

4 ANALYSIS OF THE FIRST SIX MONTHS DATA

In this section, examples of results of the first six months data from a number of houses are presented. The results presented here are not exhaustive, however, they give a general indication of the pattern of operation of and the power inputs (required) by some appliances such as air conditioning, lighting, oven and dishwasher. In some of the graphs, the power generated by the solar PV system is also presented. In addition, the total energy electricity consumption for each house being monitored during the period of January – June 2010.

4.1 POWER AND TEMPERATURE PROFILES

Figures 6 – 11 show selected graphs obtained from the data recorded during the period February – April 2010. In these graphs the electrical power input of individual appliances (air conditioning, lighting, oven and dishwasher) and PV system are plotted against time to enable the observation of the performance profiles of each of the devices. Temperature profiles at conditioned spaces of some homes (i.e. detailed monitoring homes) are also presented to observe how the indoor temperatures are affected by both the outside weather conditions and the operation of the installed air conditioning systems.

Figures 6 show graphs constructed directly from data collected with 1 minute interval. This graph shows in more detail the magnitudes of the quantities being analysed. Figures 7 – 20 represent 1 hour averages of the quantity involved.

For privacy reasons, the identities of the houses being analysed are concealed and labelled here as L1TS, L2OZ, L3TS, L4FO and L5SZ.

It must be stressed that, due to very limited data involved in the analysis presented in this report, any conclusions drawn should be taken as indicative only on what might be the general trend of energy related performance of the house.

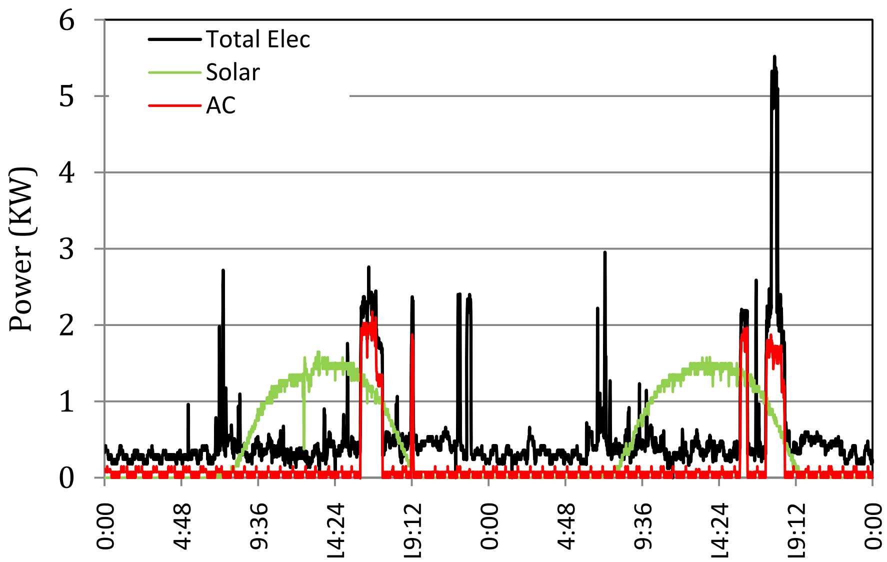

Figure 6: Electrical power profiles, 16 – 17 February 2010 (L1TS)

(1 minute interval data)

Figure 7 shows the data for L1TS on a hot day in summer where the air conditioner is the main contributor to the peak load of the house[1]. In both days (16 – 17 February), peak demand occurred at around 5.00 pm while solar PV contribution peaked earlier at around 2.00 pm. It is evident in this case that solar PV has significant contribution on reducing the peak demand from the grid. The peak electrical demand on the first day (16 February 2010) was almost entirely due to the air conditioner which highlights the impact of hot weather and also shows the otherwise low power demand of the household at that time. The air conditioner demand for the second day (17 February) was less significant, however the total peak demand was slightly higher than the first day implying significant demand from other appliances. Figure 7 also suggests similarity between solar power generation on each day, showing that the household has received a similar amount of solar radiation on both days. However, the cooling load on the second day is significantly less, even though it is apparent that the household is occupied both days at similar times (suggested by use of other appliances). Greater data availability will allow the significance of such trends to be explored in more detail. It is worth noting at this stage that the magnitudes of the peaks being observed generally demonstrate some 50% reduction in comparison with typical Adelaide homes (Saman, et al, 2008).

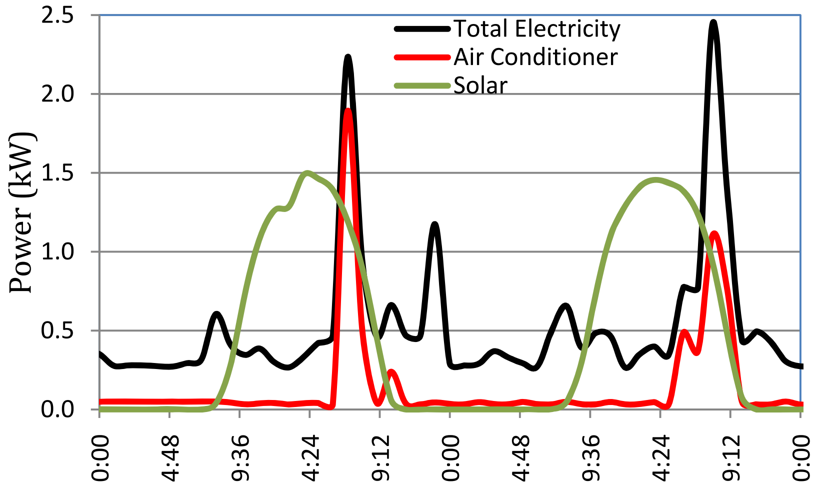

Figure 7 – Electrical power profiles, 16 – 17 February 2010 (L1TS)

(1 hour averaged profile)

The same house – during a relatively cool weather – has even higher demand as shown in Figure 8. When full year data is available, it is possible to establish the annual or seasonal electrical peak demand of the house.

Figure 9 show temperature profiles of three rooms (upper floor and master bedrooms, and lounge/dining room) in the L1TS house. As shown, the temperatures at upper floor bedroom reached up to 35°C during unoccupied time but dropped down to comfort levels during the nights. The temperature hikes during unoccupied times are mainly due to combined external heat gain from the building envelope. It is worth noting that, whilst the air conditioner was turned on only on the first day (16th March) at around 15.00, the temperatures in those

[1] In all of the graphs, "Total Electricity" is the total electrical power consumed in the house, which can be wholly supplied by the grid, or from the grid and solar panels.

rooms were mainly within the comfort range during the subsequent days despite the temperature exceeding 35°C on the 17th and 18th March.

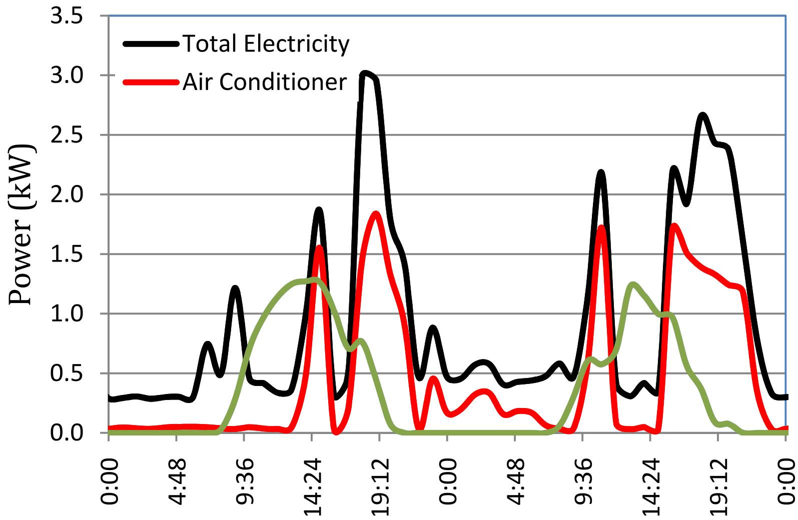

Figure 8: Electrical power profiles, 19 – 20 February 2010 (L1TS)

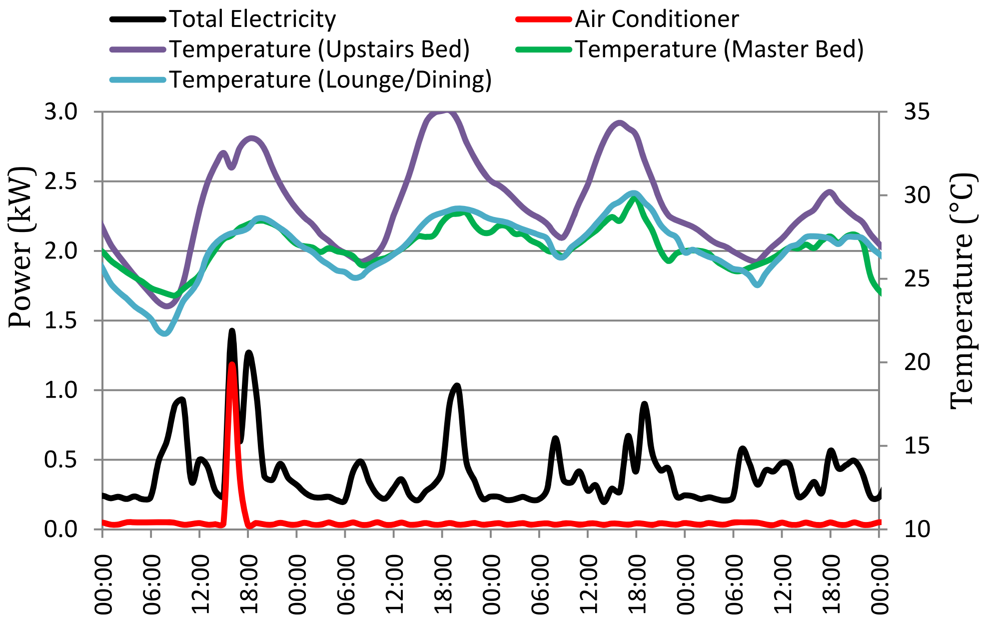

Figure 9: Air Conditioning Power and Room Temperature Profiles, 16 – 18 March 2010 (L1TS)

[16/3 - 34.9°C, 17/3 - 36.0°C, 18/3 - 35.6°C, 19/3 - 26.9°C]

Figures 10 and 11 show the cases where the moderate electrical power consumed by the house is mainly supplied by the installed solar PV panels on days of high solar radiation. At certain hours the power generated by the solar PV panel exceeded the house requirements which enabled this energy surplus to be exported to the grid.

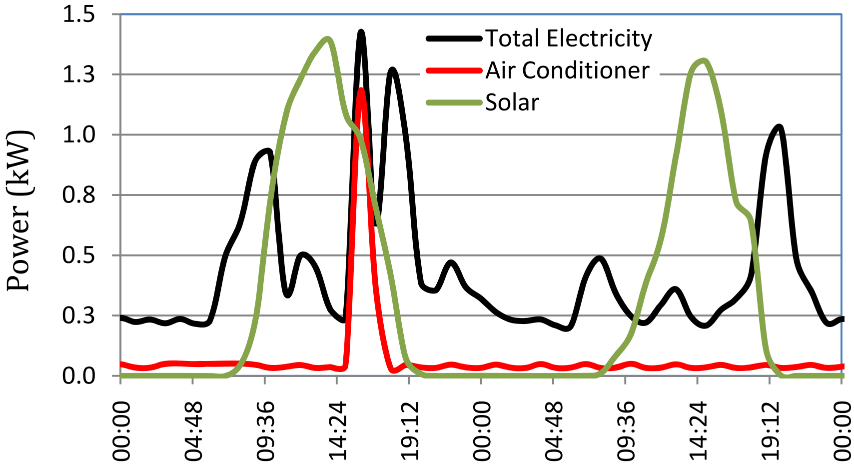

Figure 10: Electrical power profiles, 16 – 17 March 2010 (L1TS)

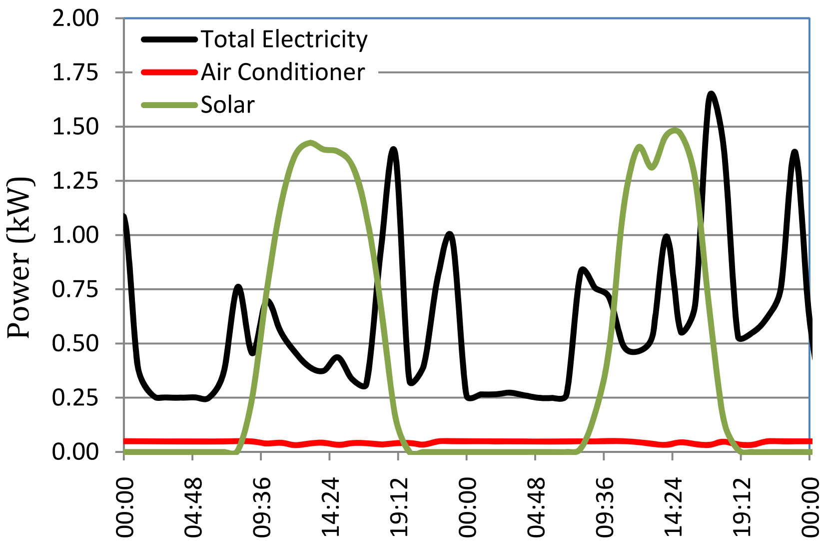

Figure 11: Electrical power profiles, 2 – 3 April 2010 (L1TS)

Figure Figure 12 shows the break down of total electricity demand in major appliances at the L2OZ house for 10 days in March. It is evident that these were cool days where air conditioning was not required. Most power consumption was in general power (mainly entertainment and computer use). The power requirement for lighting was marginal compared to other appliances whilst the dishwasher when in operation can contribute a very significant power demand with the maximum demand seldom exceeding 1 kW and the standby around 300 W.

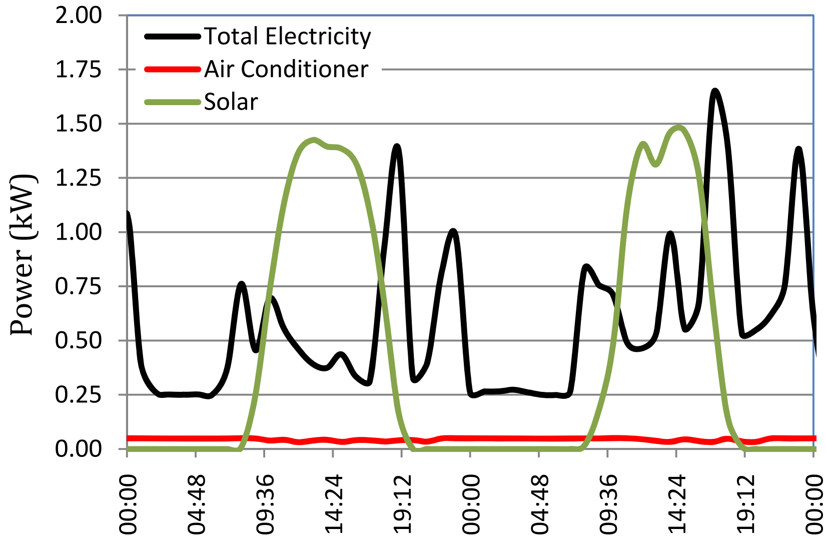

Figure 12: Electrical power profiles, 2 – 3 April 2010 (L1TS)

Profiles of total electricity and air conditioner consumption, dining and bed room temperatures for the same house in another week are shown in Figure 13. As in many instances, the peak demands are attributed to the operation of air conditioner at warm days. Observing the temperature profiles and the air conditioner load profiles, one can see that the occupants switched the air conditioner on during the afternoon and evening where outside air is still at its peak or near peak value. During the night time, the temperatures in the rooms dropped down to comfort levels without the need for air conditioning.

It can also be inferred that the occurrence of consecutive days of high outside temperatures could result in higher air conditioning load in later days as the thermal mass becomes saturated as shown in Figure 13.

Comparing the total electricity demands shown in Figure Figure 12**Error! Reference source not found.** and 13 it is also evident that when air conditioning is needed, the power for air conditioning represents up to twice the combined power demand for other appliances resulting in higher peak demand ratio of up to about 6.

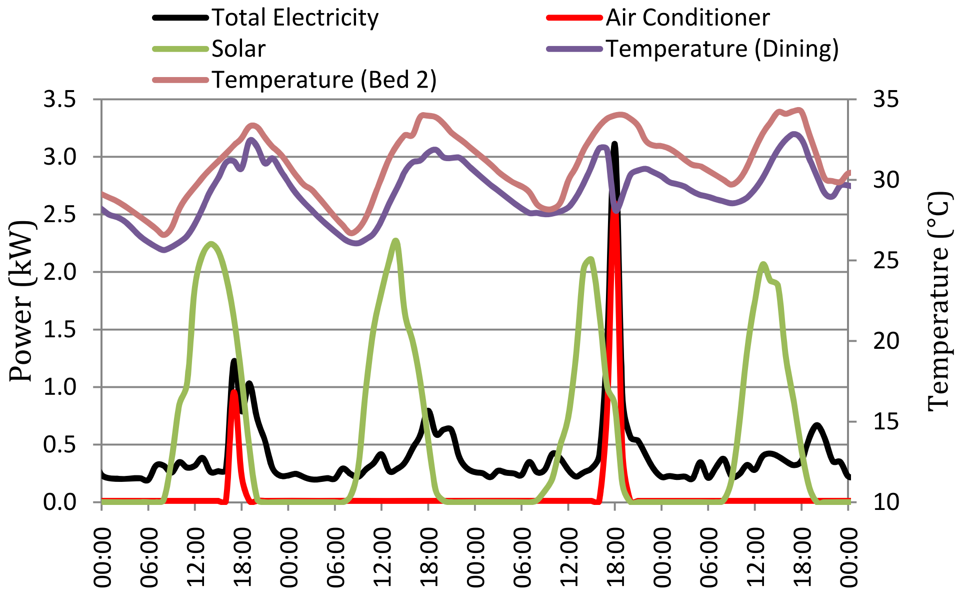

Figure 13: Air Conditioning Power and Room Temperature Profiles, 15 – 18 March (L2OZ) [15/3 - 32.1°C, 16/3 - 34.9°C, 17/3 - 36.0°C, 18/3 - 35.6°C]

Figure 14 shows another example where power requirement for air conditioning represents the major part of the electrical power demand. Three consecutive hot days entailed the operation of air conditioner during the night times which extended to the next cooler day (26.9°C). This can be again explained by the thermal mass effect where some of heat absorbed during previous hot days was retained and later released during the cooler day. Again, the peak demand ratio is very high.

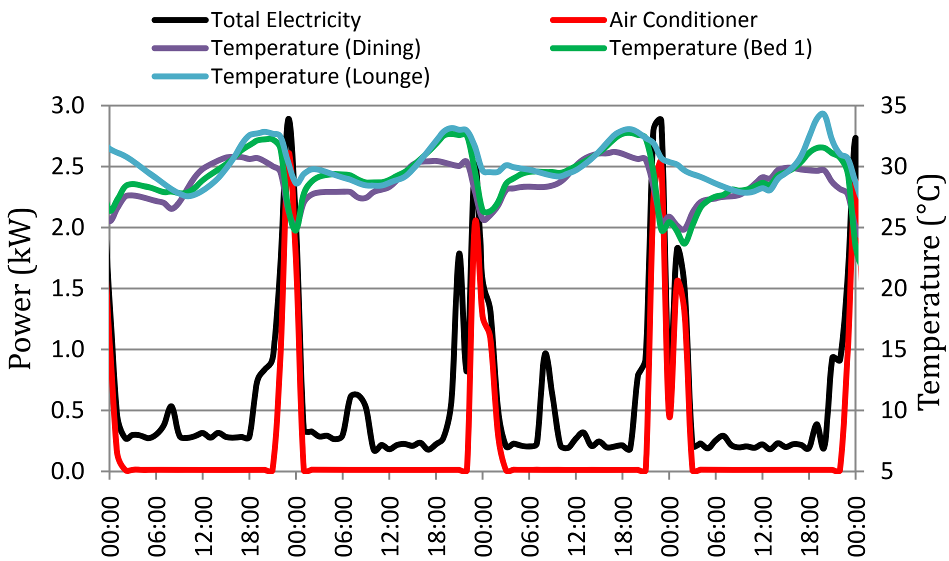

Figure 14: Air Conditioning Power and Room Temperature Profiles, 16 – 19 March 2010 (L3TS) [16/3 - 34.9°C, 17/3 - 36.0°C, 18/3 - 35.6°C, 19/3 - 26.9°C]

Figures 15 and 16 show two cases where electrical power generation by the solar panels occurred at periods of low electrical demand by the house. In this case, the solar panel generated a surplus which was exported but did not contribute to the reduction of the electrical peak demand.

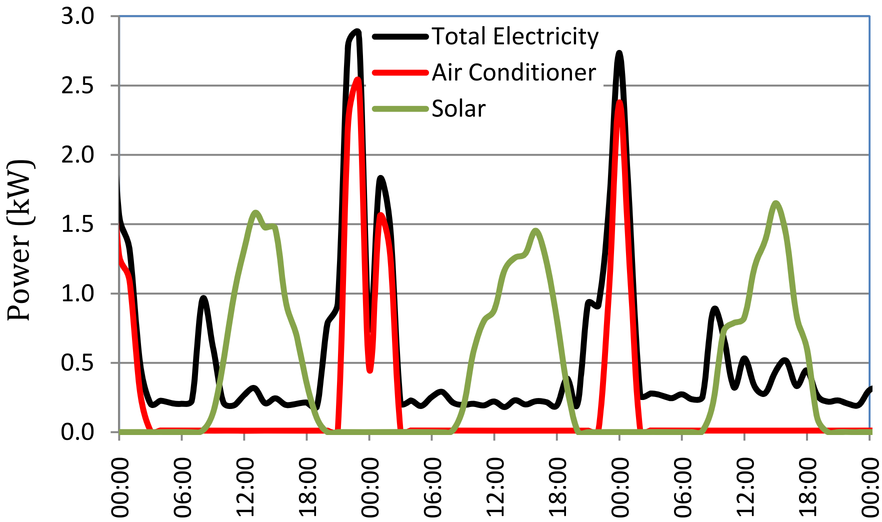

Figure 15 – Air Conditioning Power and Room Temperature Profiles, 18 – 20 March 2010 (L3TS)

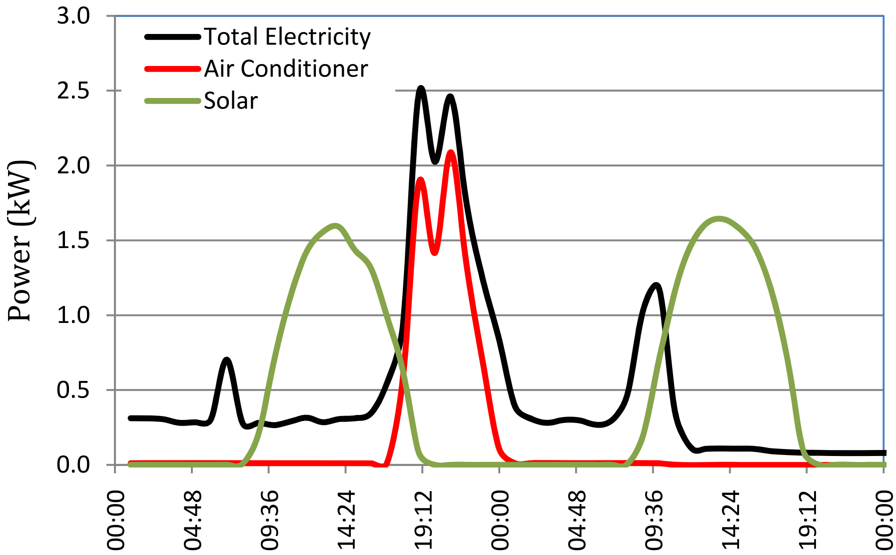

Figure 16: Electrical power profiles, 1 – 2 April 2010 (L3TS)

Figures 17 – 19 show profiles for three different situations for house L4FO. In Figure 17, the electrical power demands of various appliances on 14 February 2010 are shown where the power demand is mainly due to general power. As in the previous case, the power demand for lighting was relatively small.

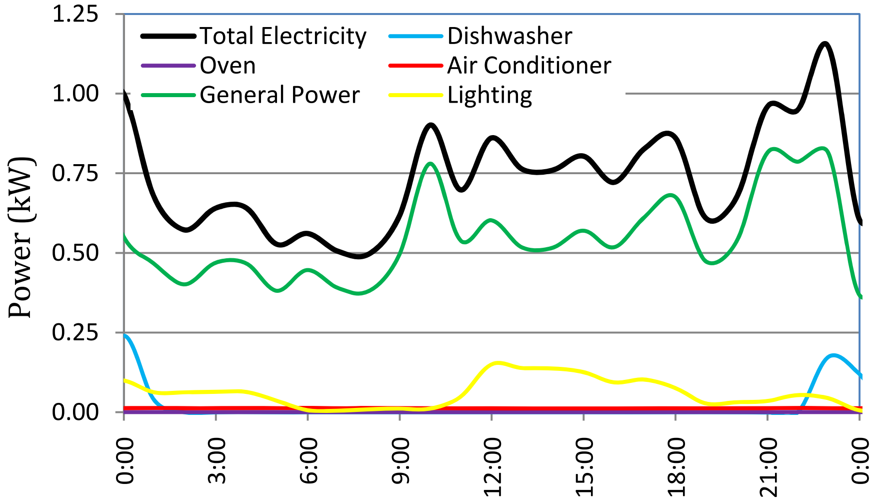

Figure 17 - Electrical power profiles, 14 February 2010 (L4FO)

Figure 18 and 19 show again how the need for air conditioning increases significantly the peak demand ratio and the magnitude of the peak demand of the house. Figure 19 shows the mismatch between the power generation by solar PV panel and the power demand of the house.

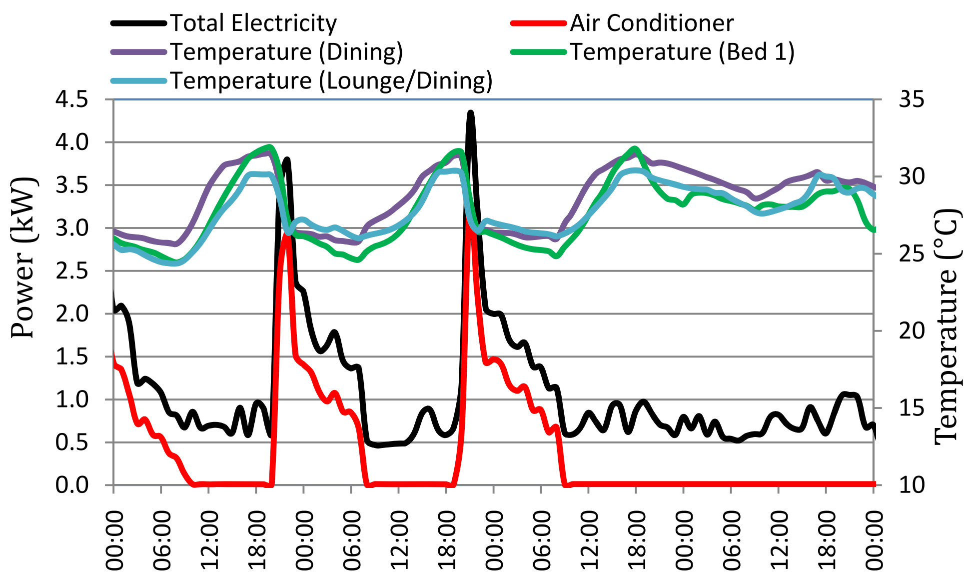

Figure 18: Air Conditioning Power and Room Temperature Profiles, 16 – 19 March 2010 (L4FO)

[16/3 - 34.9°C, 17/3 - 36.0°C, 18/3 - 35.6°C, 19/3 - 26.9°C]

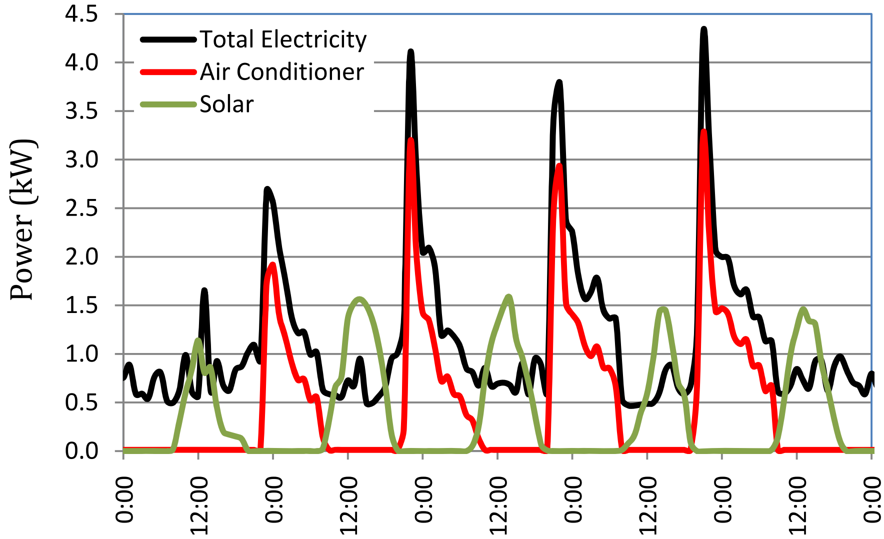

Figure 19: Electrical power profiles, 14 – 18 March 2010 (L4FO)

Figure 20 (for house L5SZ) shows that comfort conditions on mild days can be attained without the operation of the air conditioner.

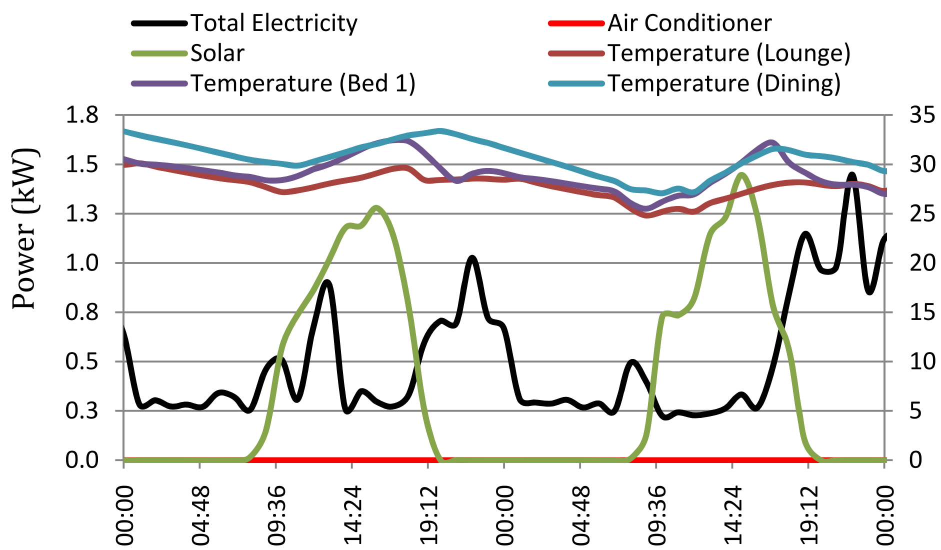

Figure 20: Electrical power profiles, 19 – 20 March 2010 (L5SZ)

Another interesting finding is that the installed solar panels, while contributing to reducing the energy consumption or even producing energy surplus to houses, do not always contribute significantly to the reduction of peak demand due to time mismatch between the two. The following graphs, Figures 21 – 24, for L6FS show four possible cases in which (1) solar PV panels generate high electrical power when air conditioning is not required, (2) high electrical power is generated when the air conditioner is switched on, (3) solar panels generate low power when no air conditioning is required, and (4) solar panels generate very low power at the peak of air conditioning demand.

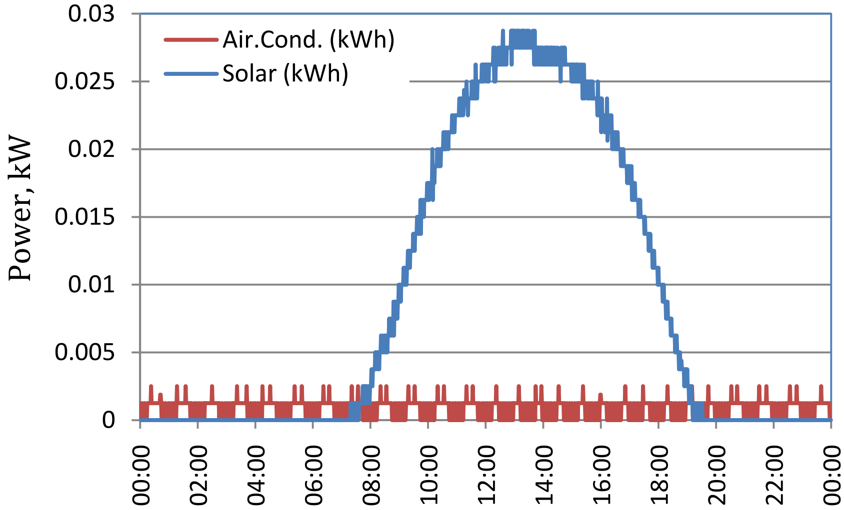

Figure 21: High Solar Contribution Day – 1 March 2010 - Solar & A/C Data (kWh) - L6FS

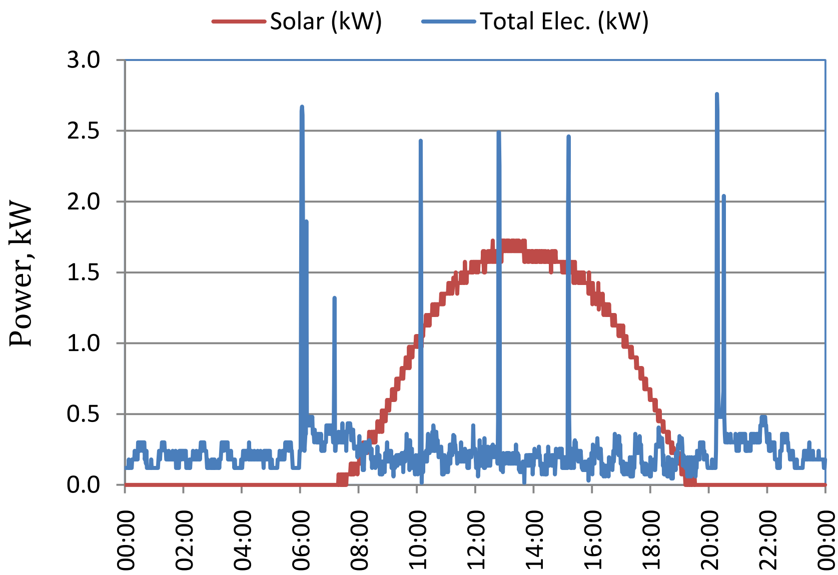

Figure 22: High Solar Contribution Day, 01 March 2010, Electricity Data (kW) – L6FS

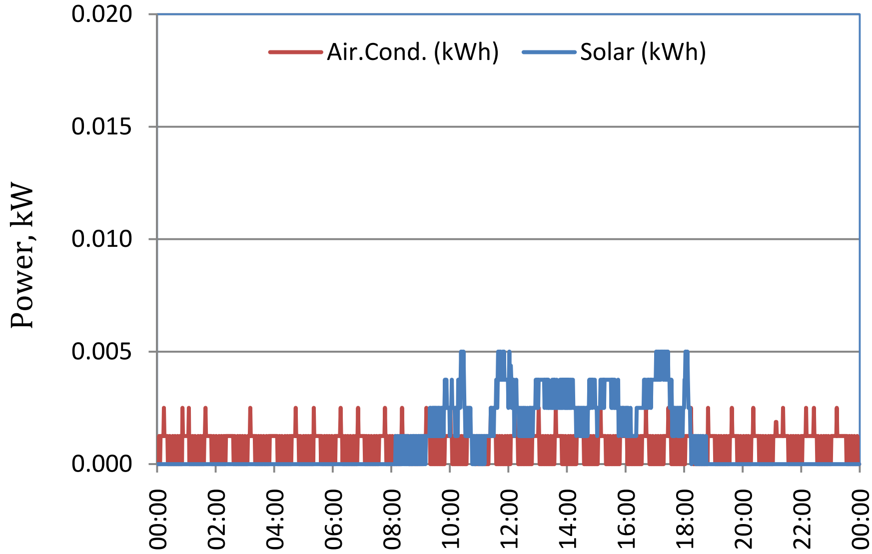

Figure 23: Low Solar Contribution Day, 28/03/2010, Solar & A/C Data (kWh) – L6FS

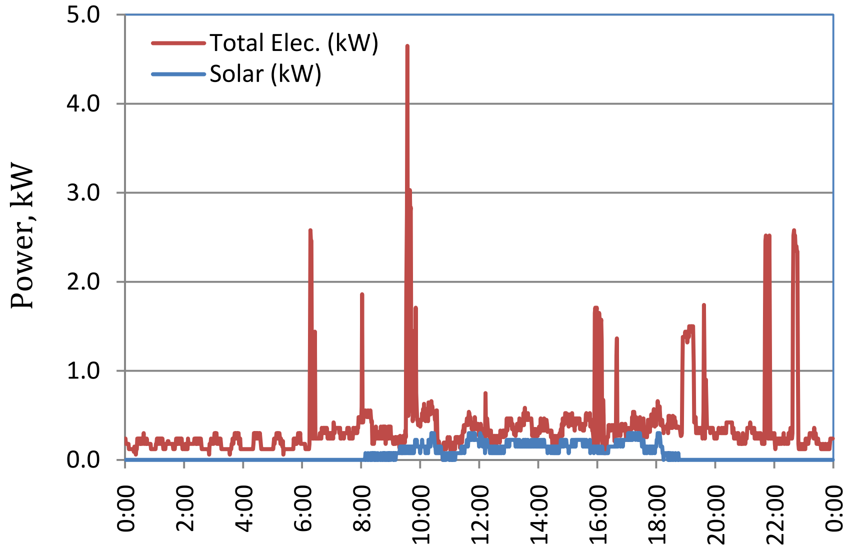

Figure 24: Low Solar Contribution Day, 28/03/2010, Electricity Data (kW) – L6FS

4.2 ENERGY CONSUMPTION/GENERATION

Table 3 summarises the total electrical energy consumption and solar PV generated electricity for the period: January – June 2010. It should be noted that the starting dates of recording of the data vary from house to house and some results have not been fully scrutinised. Therefore a full interpretation of the figures shown in Table 3 could not be made at this stage. It is also noted that gas and water consumption data are to be fully reviewed and have not been included in this report. As shown, the monthly average consumption ranges from 244.8 kWh in January to 474.7 kWh in June which in some months is matched by the energy generated by the solar PV panels resulting in low electricity demand from the grid. For the period monitored, the average net monthly electricity consumption is 127kWh with 64% of the consumption being generated on the roof of the house.

With the reservations highlighted above in mind, it is evident that both electricity use and associated greenhouse gas emissions are substantially lower than typical Adelaide homes. Monitoring data carried out in the 2002-2003 (Saman and Mudge 2003) show that typical average monthly electricity consumption for similar size houses is over 600 kWh.

Table 3 – Total Electricity Consumption and Solar PV Electricity Production for the period: January – June 2010

Month	No. of houses monitored	Electricity (kWh)		
		Total consumption	Solar energy production	Net
January	3	244.8	258.4	-13.6
February	8	370.1	263.1	107.0
March	14	327.9	261.1	66.8
April	18	295.9	227.6	68.3
May	18	376.9	181.4	195.5
June	21	474.7	139.0	335.7
Average		348.4	221.8	126.6

5 IMPACT ON THE ELECTRICAL GRID

While waiting for monitoring data to be gathered and analysed over a statistically acceptable monitoring period, a semi theoretical analysis of the impact of the effect the integrated approach of passive design, energy efficient appliances, local renewable energy generation and the introduction of a number of smart features in the Green Village homes on the thermal performance of the houses has been carried out. The results are presented in two conferences. The two papers appear as Appendices 3 and 4. It is anticipated that more meaningful data will be available for analysis by the end of 2010.

6 ANALYSIS OF THE FIRST HOUSEHOLD SURVEY RESULTS

The qualitative phase of the research is now complete. Ten in-depth, semi-structured interviews have been done with 18 individuals focusing on people's experience of thermal comfort in their homes, the use of particular appliances including monitoring equipment, attitudes to environmental issues, kinds of 'green behaviour' practiced by households, the influences on those behaviours and the reasons for choosing to live in Lochiel Park. The preliminary analysis of these data reveal that, as the literature suggests, people experience a conflict between their 'roles' as citizens and consumers. As citizens, they wish to engage in pro-environmental behaviour; as consumers, they wish to maximize comfort and convenience, while minimising costs and these factors are not always compatible with pro-environmental outcomes. Neither the design features of the houses in Lochiel Park, nor the attitudes nor knowledge levels of the residents will accurately predict the pro-environmental outcomes of Lochiel Park. People's interaction with the design features of their houses, including energy and water consumption, is the outcome of a complex calculus of comfort, cost and convenience. More specifically, the following themes have emerged from the data:

- Pro-environmental behaviour (PEB) is defined as a mix of:
  - Behavioural responses
  - Household features (eg insulation, tanks, types of heating and cooling systems)
  - Household design (building orientation; thermal mass; materials etc)

- Gender did not figure prominently in the way respondents conceptualized and responded to issues. The most significant difference is in relation to PEB in that women focussed more on individual and household behaviour, while men placed greater emphasis on household design.
- The arenas which most people identified as relevant to PEB are:
  - Recycling
  - Energy use
  - Water use
  - Private transport use
- Reduced levels of personal consumption are not considered as part of pro-environmental behaviour by the overwhelming majority of respondents.
- People rate the sustainability of their households as low prior to living in Lochiel Park, but consider it is or will be greatly improved by the move to Lochiel Park.
- Most people say that the various subsidies they received for things such as PV Cells are important elements in having these facilities; many said they could not have afforded them without subsidy and rebate schemes.
- The exercise of PEB is not shaped solely by knowledge or attitudes:
  - Economic costs
  - Household and individual comfort
  - Household and individual convenience

  also influence people's practice of PEB. If PEB interferes with economic well-being, comfort or convenience, people are less likely to practice it.
- Most people said that certain rooms in their houses (particularly upstairs ones) became hot in summer and required air-conditioning to maintain comfort.
- People have chosen to live at Lochiel Park for a variety of reasons:
  - To have an environmentally sustainable life
  - The location of Lochiel Park
  - The aesthetic qualities of the area
  - The deliberate attempts to foster a cohesive local community
- Environmental concerns were not a sufficient reason for choosing to live in Lochiel Park for almost all respondents.

- People are enthusiastic about the potential of monitors to change behaviour in principle, but most consider that it won't have a marked impact on their behaviour.

A more detailed report on the analysis of the householders survey has been completed. However this report is under consideration by the Land Management Corporation and has not yet provided the permission for public release.

CONCLUSIONS

The milestones report on the progress of the P6 UniSA iGrid project covering the period January – June 2010 has been presented. During the period, recording and processing of monitoring data of 21 houses have been carried out on a continuing basis with installation of monitoring equipment being implemented for the houses under construction. Some commissioning issues related to the monitoring system installation and data analysis have been identified and were found to contribute to the unsmooth acquisition of the monitoring data. Most of these issues have been resolved and the rest are being addressed. Preliminary analysis of the samples of monitoring data has shown that in general, thermal comfort conditions in the houses can be achieved even during the hot summer days. As expected, air conditioning was found to be the dominant factor which causes peak power demands. Never the less, the magnitude of peak is well below typical Adelaide homes under the same weather conditions. The installed solar PV panels contribute to reduced reliance on grid electricity from and even generated surplus energy for some houses during the monitoring period analysed; however they do not always contribute significantly to reducing peak electrical power demand.

The qualitative analysis of the first household survey has been completed. The analysis reveals that people experience a conflict between their roles as citizens and consumers. As citizens, they want to engage in pro-environmental behaviour whilst as consumers they wish to maximise comfort and convenience which is not always compatible with pro-environmental outcomes.

The issues discussed in Section 3, along with delays in the construction, completions and occupancy of houses at Lochiel Park, have made it impossible at this stage of research to produce definite conclusions regarding trends of energy savings, peak demand reduction, greenhouse gas emissions and thermal comfort due to the following:

- The size of the sample is still small
- The duration and seasonality of data. Good judgements can only be made after a full year data for a sufficient number of houses has been gathered. The results so far have covered the winter season when PV generation is at its minimum and there are no significant summer peak demand problems. Therefore the percentage energy savings cannot be extrapolated to a full year.

While more definitive findings and conclusions should be obtained as further data is collected from the current houses as well as from new houses that come into the monitoring program, the observed trends of gathered data are pointing to substantial energy consumption and peak demand reductions. The results are also demonstrating the significant impact of individual household behaviour on these trends.

PUBLICATIONS

W. Saman: *Towards Zero Energy Homes Down Under*, Invited paper to be presented at the World Renewable Energy Congress IX, Abu Dhabi, UAE, 25-30 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*, to be presented at the Australia Solar Energy Society (AuSES) Solar2010 Conference, Brisbane, 1st -3rd December 2010.

MEETINGS / CONFERENCE

- 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 16 March 2010 at the Sustainable Energy Centre - UniSA, Mawson Lakes, to discuss the handling of the monitoring data.
- P6 Project – LMC monitoring meeting on 30 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 8 June 2010 and with Phil Donaldson (LMC) gave a presentation titled: “Lochiel Park CEIC Smart Grid Energy Efficiency Technology Clinic”.

REFERENCES

- Saman, W., Halawa, E., Mudge, L., Edwards, J. & Whaley, D., 2009: *Progress Report of the Project P6: The Intelligent Grid in a New Housing Development, Period: July – December 2009*. Submitted to the Intelligent Grid Cluster Coordinator.
- Saman, W. & Mudge, L.T. 2003, *Development, Implementation and Promotion of a Scoresheet for Household Greenhouse Gas Reduction in South Australia: Final Report*, Sustainable Energy Centre, University of South Australia, Mawson Lakes, Adelaide.
- Saman, W., Oliphant, M., Mudge, L. & Halawa, E., 2008: *Study of the Effect of Temperature Settings on AccuRate Cooling Energy Requirements and Comparison with Monitored Data* - Final Report, http://www.nathers.gov.au/about/pubs/accurate-coolingsettings-0608.pdf
- LP 2009 – *Spreadsheet on Status Report of Construction of Homes at Lochiel Park Green Village* – Land Management Cooperation (LMC).

APPENDIX 1 – COMMISSIONING ISSUES IDENTIFIED AND RESOLVED

1.1.Tradespeople

1.1 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.

1.2 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.
  - 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.

1.3 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 was installed incorrectly, where its gas inlet was connected to the mains water and vice-a-versa. This has been corrected.

1.4 Gardener

- 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.

1.2.TUTILITY PERSONNEL / SERVICE PROVIDERS

1.3.

1.4. 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.

1.5.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.

1.6.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.

1.7.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).

1.8.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.

1.9.Monitoring Systems

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

1.10. 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).

1.11. 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.

1.12. 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.

1.13. 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 2 – PAPER SUBMITTED AT THE AuSES SOLAR2010 CONFERENCE, BRISBANE 1 – 3 DECEMBER 2010

Lessons Learnt From Implementing Intelligent Metering And Energy Monitoring Devices In A New Housing Development

D.M. Whaley, W.Y. Saman, E. Halawa, L.T. Mudge

Sustainable Energy Centre
University of South Australia
Mawson Lakes
South Australia 5095
david.whaley@unisa.edu.au

ABSTRACT

This paper describes the lessons learnt from monitoring energy and water usage of houses in a leading Eco-friendly housing development. The various issues faced during the installation and commissioning of the monitoring systems are discussed, along with recommendations to prevent such problems. The paper also shows some examples of results, discusses resident's feedback regarding the use of in-home monitoring systems, and gives examples of both positive and negative experiences using such equipment.

Keywords – EcoVision, energy monitoring, in-home display, water monitoring, zero energy home

INTRODUCTION

Currently, residential buildings represent approximately 20% of Australia's greenhouse gas emissions, with 30-40% of this figure being attributed to heating and cooling (Wilkenfeld *et al.* 2002, ABS 2010). As the number of dwellings, and their average area continue to increase, it is anticipated that heating and cooling requirements will also increase. This will further escalate the peak electrical demand, which is already largely caused by residential buildings (Koomey & Brown 2002, EES 2004, TEPCO 2004).

With this in mind, along with the South Australian State Government's vision for sustainable living, the Land Management Corporation (LMC), has developed the Lochiel Park Green Village. The village is a 106-dwelling demonstration residential development, which exemplifies *South Australia's Strategic Plan* objective 'Attaining Sustainability' (LMC 2009). The residents in Lochiel Park will be highly energy efficient as each house is designed to maximise benefits from environmental elements and reduce energy consumption. LMC have established the following targets:

- 78% saving of drinking water,
- 87% of all water used in the development will be from recycled water,
- 66% reduction in energy use, and
- 74% reduction of greenhouse gas emissions.

LOCATION AND SITE SUMMARY

Lochiel Park Green Village is a leading eco-friendly new housing development situated in Council district of Campbelltown, South Australia. The village is situated along the Torrens River, approximately 8km North East of the Adelaide CBD, as shown in Fig. 1. The figure also shows the 14.7Ha development area, of which 4.2Ha is designated for 106 residential properties, whilst the remaining 10.5Ha is open space, which includes wetlands, ovals, community gardens and a water recycling plant.

Fig. 1: Lochiel Park Green Village (left) location, relative to the Adelaide CBD, and (right) aerial photograph (LMC 2009**)**.

ZERO NET ENERGY DESIGN OF HOUSES

The houses within the Lochiel Park housing development are designed to be net zero energy homes, with a minimum 7.5 energy star rating. This is achieved by appropriately orientating and designing the houses, ensuring residents use energy efficient appliances, and by utilising roof-mounted photovoltaic panels (1kW/100m^2 of liveable area) and gas-boosted solar hot water systems (Saman & Halawa, 2009). Each house also uses its collected rain water, and will make use of recycled storm water, once the water recycling / treatment plant construction is complete.

OVERVIEW OF HOME MONITORING SYSTEMS

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 <u>general</u> 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, 10 houses are monitored in <u>detail</u>. 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 Tab. 1.

Note that several monitoring systems / 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).

Tab.1: EcoVision 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
General	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	×	✓	×
Detailed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

MONITORING SYSTEM OUTLINE

An overview of the detailed monitoring system schematic is shown in Fig. 2. 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 analogue and digital sensors. Note that an overview of the general monitoring system can also be seen in the figure, due to the common components; i.e. the 8 digital sensors surrounded by the dashed box are the only sensors used in this system.

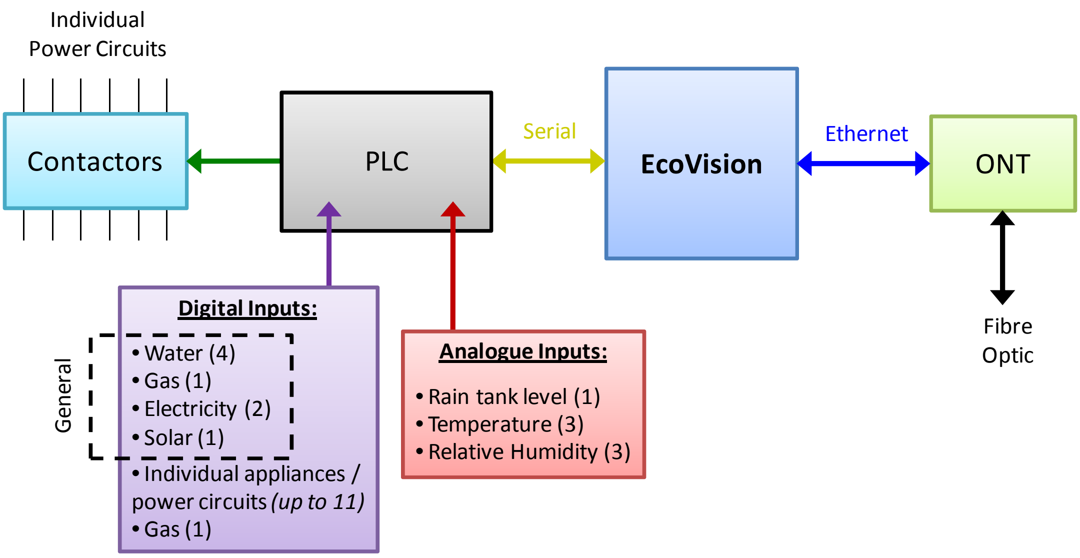

Fig. 2: Overview of the detailed monitoring systems, showing various components. Note that the dashed box represents the sensors used in the general monitoring system.

The figure shows that the various sensors (which are identified in the figure and Tab. 1, depending on which system is considered) 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, using Ethernet and Fibre Optic cables, respectively. This arrangement also allows the local weather data to be displayed on each system.

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 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.

ECOVISION SYSTEM

In-Home Display

The EcoVision computer not only records and stores data, it acts as the in-home display. The touch screen allows users to select i) the type of measured data shown on the screen, e.g. electricity, water, gas, etc. and ii) the time scale, i.e. month, week, day or hour. Fig. 3 below shows various EcoVision screens for random Lochiel Park houses.

Fig. 3: EcoVision screens, showing (left) electricity and (right) gas usage, for 1 day.

Data Storage

The EcoVision continuously samples the PLC and updates a locally-stored CSV data file with information regarding digital input pulses (and analogue values, for applicable detailed monitoring systems) each minute. These files are appropriately identified by lot number, month and year, and are automatically copied to the central Lochiel Park server each night. The CSV files are copied to a local computer (and analysed) by establishing a remote desktop connection to the Lochiel Park server. The typical file size of a general and detailed monitored house, for one month, is 6.1 and 13.1MB, respectively.

ISSUES ENCOUNTERED

Many issues have been faced during the installation and commissioning stages for the first 25 houses. While some initial teething problems were anticipated during the commissioning stage, a number of unexpected issues have also surfaced. These issues, which mainly cause the EcoVision to collect invalid data, or cause significant delays commissioning the systems, are further discussed below.

Hardware Issues

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 PLCs have been unintentionally severed by people, whilst some are cut short, requiring extensions or re-cabling.
- Some cables, i.e. Ethernet and serial, were not correctly terminated.
- Some EcoVision 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.
- About half the electricity billing meters, which are fitted with sensor equipment, were incorrectly configured when installed. This can only be corrected by utility personnel, who have taken some months to carry this out.
- The rain water tanks of some properties are fitted with only one rain water tank 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.
- One faulty ONT was installed, whilst some are not correctly configured.

EcoVision

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

Residents

- Some residents cannot provide access to properties during business hours, or restrict access to billing meters.
- Some residents shut down their EcoVision screen, or did not wish to restart it following a power outage.

PRELIMINARY RESULTS AND ECOVISION EXPERIENCES

This section briefly shows some measured data from a select few houses equipped with the detailed monitoring systems, despite many houses currently operating correctly. The sample data shown is not exhaustive, however, it should give a general indication of the types of data analyses possible, as a result of using the EcoVision systems.

Sample Data

Power and Temperature Profile

Fig. 4 shows the total electricity and air conditioner consumption, dining and bed room temperatures for one house, for 15-18th March 2010. As in many instances, the peak electrical demand is attributed to the operation of air conditioner on hot days. Observing the temperature profiles and the air conditioner load profiles, one can see that the occupants switched the air conditioner on during the afternoon and evening where outside air is still at its peak or near peak value. During the night time, the temperatures in the rooms dropped down to comfort levels without the need for air conditioning.

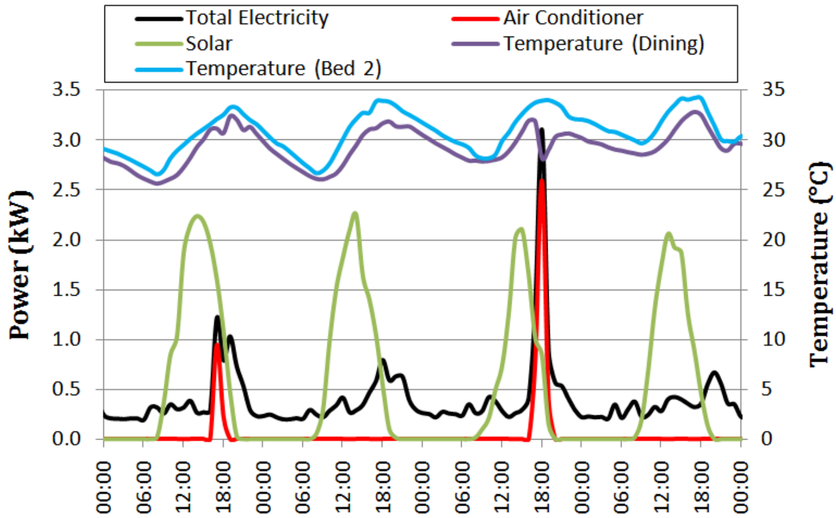

Fig. 4: Total electricity, solar and air conditioner load, and temperature profile of one house. The peak temperatures for 15-18 March 2010 were 32.1, 34.9, 36.0 and 35.6°C.

Average Energy Consumption / Generation

Fig. 5 summarises the monthly average total consumed, generated and net electricity for 2010. The average solar generated energy is shown to peak in January and steadily decrease each month, reaching its trough in June, as expected due to seasonal changes. The average total consumed energy decreases from its summer peaks (January and February), reaching its trough in April. The average total electricity usage then increases in May and peaks in July. Interestingly, the average winter electricity usage peak is about 30% higher than its summer equivalent. For these reasons, the average net energy (supplied from the grid), is steady between summer and autumn and then sharply increases as winter approaches; it reaches its peak in June.

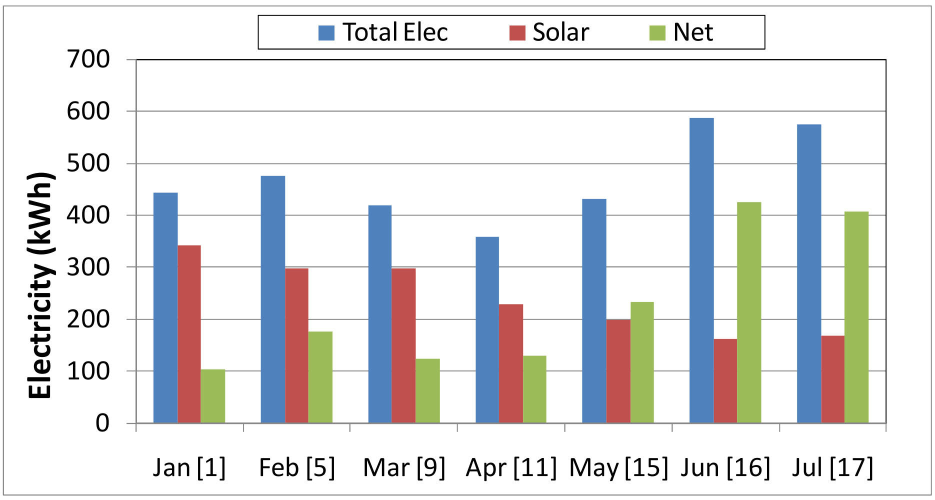

Fig. 5: Average monthly consumed (total), generated (solar) and the net electricity for [the number of lived-in] Lochiel Park houses for 2010.

Note that the number of houses sampled each month varies as houses and EcoVision systems are continuously built and commissioned, respectively. Also note that the data shown has not been fully scrutinised. Therefore a full interpretation of the Fig. 5 should not be made at this stage. Despite this, thus far it appears that the average Lochiel Park house relies on about 210kWh of electricity from the grid each month. This is significantly lower than typical Adelaide houses (of a similar size) monitored in 2002-2003 (Saman & Mudge 2003), which consumed over 600kWh per month.

The average data also indicates that approximately 53% of the energy consumed was generated on the roof tops of the monitored houses, which significantly reduces the greenhouse gas emissions for the housing development. In addition, the use of solar hot water systems, the data of which is not discussed in this paper, further reduces the housing development's greenhouse gas emissions.

EXAMPLE OF POSITIVE OUTCOMES

To date, the EcoVision system has alerted residents to four known leaks at three separate properties. Each leak was detected by observing higher than expected water and gas usage rates of each respective screen. This is explained with the aid of Fig. 6, which shows the water screen of one house with a water leak. The bottom time-varying graph shows an average water usage rate of about 0.5L/min during the early hours of the morning, when there should ideally be zero water usage. The leak was located between the billing meter and the house, and was fixed by a plumber. Despite this, it is estimated that the leak wasted about 41,000L of potable water, as the leak was not detected until several months after the EcoVision system was commissioned.

The water screen of EcoVision system also alerted residents of two other water leaks. The first was caused by a leaking garden tap, whilst the second was caused by a leaking hot water tap. Both leaks were detected by observing unusual water usage rates during the early hours of the morning or late at night, and it is estimated that each leak wasted less than 200L. The property with the leaking hot water tap also had a gas leak. This was detected by the gas fitter when the resident was demonstrating their EcoVision system. The fitter noticed that gas was being consumed by the only gas appliance, i.e. an instantaneous gas booster which forms part of the solar water system, despite not using hot water. After a brief investigation the fitter found the leak at the gas inlet of the gas booster unit and fixed the leak.

Fig. 6: EcoVision screen showing water usage page. Two sections are zoomed showing the water flow rates before (red) and after (green) a major water leak was fixed.

Negative Outcomes

Thus far, two residents have reported negative experiences with the EcoVsision system; both relate to the Load Management features. Although all residents are briefed about the load management system and are made aware of the voluntary use of such a system, many do not understand the need for such a load shedding system and vow not to use it, as they would prefer to be comfortable. One resident, whose air conditioner was tripped during a hot summer's day, felt that the system should have automatically re-energised their air conditioner, and when they discovered that this does not occur for safety reasons, they decided to deactivate this feature.

Another resident had a negative experience using the load management system, when they unintentionally activated the system and did not realise that their dishwasher and laundry appliances had their power interrupted. The resident called in the services of their preferred electrician who did not receive specialised training and was hence was unaware of the in-home monitoring system. This electrician took two days to determine the cause of the problem, which could have been solved by a phone call to either the developers, the people monitoring data, or to one of the project's preferred electricians.

Resident's Feedback

Despite the above negative experiences, the majority of residents are thrilled to be able to monitor their water, electricity and gas usage using their EcoVision system. The real-time display allows residents to determine energy usage profiles of their appliances. This, along with knowledge of the electricity feed-in tariff, allows residents to optimise their appliance usage and solar credits by using energy intensive appliances after sunset. Many residents have mentioned that they use the EcoVision display to determine total daily water, gas and electricity usage. They then challenge themselves to consume less water and energy the following day until they find a comfortable level. Note that the net feed-in tariff offered to South Australians was $0.44 / kWh, at the time of publication.

In contrast, there are some residents that do not use their EcoVision systems to reflect upon their water, gas or electricity usage. Although they understand the reasons behind the system, they are determined to continue living the lifestyle they want, and do not wish to change their behaviour, regardless of their energy and water usage patterns.

In addition, despite residents receiving an overview of the EcoVision system and its Load Management features, during the commissioning stage and also in one of two 'after hours' training sessions, a small number of residents have expressed concern over lack of documentation. These residents have requested a detailed instruction manual, which covers the EcoVision system, including its Load Management features. Such a manual does not yet exist, however, EcoVision staff are currently addressing this.

SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

This paper has described the Lochiel Park housing development, given an overview of the intelligent monitoring equipment, discussed problems associated with developing, installing and commissioning such a new evaluation and monitoring system. The paper has also shown some preliminary data, and has discussed resident's experiences and feedback regarding the use of the EcoVision home monitoring system.

Recommendations

To prevent the reoccurrence of the delay causing problems mentioned above, it is highly recommended that all trades-people involved in such a large project, are appropriately trained, and are judged competent to install and commission intelligent monitoring equipment. It is critical that tradespeople are aware of the need for long cables between the sensors and the PLC, and that they work diligently to avoid damaging these.

It is also recommended that utility personnel are appropriately trained, such that they i) provide the correct types of billing meters, and ii) appropriately configure and verify correct operation of these billing meters.

To further prevent resident associated delays, training sessions should be periodically run that explain the function of the EcoVision system, especially the load management system features. These should also explain the need for access to properties and meter boxes to verify correct operation of the systems.

Conclusions

The main conclusions from this paper are:

- Although preliminary, the data for the limited period of monitoring suggests that the average Lochiel Park houses consume less electrical energy than typical average Adelaide houses of a similar size.
- The roof-mounted PV systems generate about half the total development's electrical energy consumption.

- The majority of residents are delighted with their in-home monitoring systems, they regularly review their data and some attempt to modify their lifestyles to reduce their water, and energy usage.

REFERENCES

ABS, (2010), *Energy in Focus; Energy Efficiency in Australian Homes,* Australian Bureau of Statistics.

EES, 2004: *Electrical Peak Load Analysis – Victoria 1999* – 2003, Energy Efficient Strategies, prepared for VENCORP.

EV, 2010, EcoVision Systems website (accessed 10 February 2010): http://www.ecovisionsolutions.com.au/

Koomey, J. & Brown, R.E., 2002: *The role of building technologies in reducing and controlling peak electricity demand*, Energy Analysis Dept. – Environmental Energy. Technologies Division – Ernest Orlando Lawrence Berkeley National Laboratory – University of California – Berkeley, CA 94720, September – available online at http://enduse.lbl.gov/Info/LBNL-49947.pdf

LMC, 2009, *LMC Projects: Lochiel Park–Adelaide's Green* Village, Land Management Corporation website (accessed 30 July 2010):

http://www.lmc.sa.gov.au/home/inner.asp?pageid=292&mainid=20&subid=46

Saman, W. & Halawa, E., (2009), *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.

Saman, W. & Mudge, L.T. 2003, Development, Implementation and Promotion of a Scoresheet for Household Greenhouse Gas Reduction in South Australia: Final Report, Sustainable Energy Centre, University of South Australia, Mawson Lakes, Adelaide.

TEPCO, 2004: Electricity Market in Japan – Tokyo Electric Power Company website: http://www.tepco.co.jp/en/news/presen/pdf-1/0406-e.pdf - accessed 27 March 2009

Wilkenfeld, G. and Associates (2002), *Australia's National Greenhouse Gas Inventory, 1990, 1995 And 1999, End Use Allocation*, Department of Climate Change, Canberra.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding and support provided by the CSIRO's Intelligent Grid Cluster. They would also like to thank the support and information provided by LMC, in particular Andrew Bishop and Phil Donaldson.

BRIEF BIOGRAPHY OF PRESENTER

David Whaley is a Research Engineer for the Sustainable Energy Centre, at the University of South Australia. He obtained his PhD in Electrical and Electronic Engineering, from The University of Adelaide in 2009, and is a member of Engineers Australia and the IEEE. His research interests include renewable energy technologies.

APPENDIX 3 – PAPER PRESENTED AT ISES SOLAR WORLD CONGRESS, 11-14 OCTOBER 2009, JOHANNESBURG, SOUTH AFRICA

THE IMPACT OF PASSIVE DESIGN AND SOLAR ENERGY USE IN A HOUSING DEVELOPMENT ON THE ELECTRICAL GRID

W. Saman, E. Halawa
Institute for Sustainable Systems and Technologies
University of South Australia, Mawson Lakes SA 5095
Mawson Lakes, Australia
e-mail: wasim.saman@unisa.edu.au

Abstract

Passive design combined with energy efficient appliances and active solar systems have been implemented in many new house designs. However their impact on the electrical grid has not been sufficiently documented. A new housing development at Lochiel Park, Adelaide, Australia, is being constructed using a number of passive, active and demand side management features. To evaluate the impact of these green features on the electrical grid, the thermal performance of three dwellings having identical form, building structure and orientation but different fabric and appliances, are compared. The first is a house with typical conventional Australian design features while the second represents a newly built house satisfying Australia's current minimum energy rating requirements. The third home represents state of the art solar housing which is the type of house being built at the Lochiel Park Green Village. With the use of energy efficient electrical appliances, solar hot water and grid connected electricity, the study shows that the introduction of the above green features can lead to energy self reliance and the easing of peak demand problems often faced by energy utilities.

1. INTRODUCTION

Extreme heat waves that hit southern Australia in recent years have resulted in a dramatic increase of use of air conditioners and a consequent rise in the state peak electricity demand. The load shedding that occurred on the 30 January 2009 at 1.30 pm – 4.00 pm resulted in a power shortfall of 90 MW affecting 17,000 customers in 83 suburbs in Adelaide (NEMMCO, 2009a; ETSA Utilities, 2009). The recorded peak demand during this shedding period was 3 295 MW (NEMMCO, 2009b) compared to average demand of around 1600 – 1880 MW in normal summer weather. This is a drastic increase that only last for a number of hours during the year. According to a news reports, up to 80 sudden deaths were reported in Adelaide as a result of this heatwave. On the day of the peak heatwave (Friday, 30 January 2009) with record temperature in Adelaide of 45.3°C, 23 sudden deaths were recorded, a 10-fold increase from the Friday before. And the toll on Sunday (2 February) was 25 sudden deaths, according to police records (www.news.com.au, 2009).

The recently escalating phenomenon of high power factors and consequent power blackouts occurring during this extreme heat wave is a logical consequence of total reliance of dwellings on air conditioners powered by conventional centralised electricity generation. Passive design and distributed energy generation is a potential solution which can have a significant impact on easing peak demand by reducing the need for air conditioning and shaving off some of the load from the conventional grid. The effect of this alternative, however, has not been thoroughly investigated and understood. A number of distributed energy systems have been installed in many parts of the world. However, an extensive literature search has not found published information on the impacts of interaction between the distributed energy in a housing development and the grid. In order to understand the reasons cited for installation of distributed energy connected to the grid, Poore et al.

(2002) surveyed a number of distributed energy plants across the United States and presented 4 case studies of plants interconnected with the grid namely: (1) Narrow Coastal Island, (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 distributed plans 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 chlorofluorocarbons (CFCs).

This paper aims to show how the new generation of energy efficient homes together with the widespread introduction of distributed energy generation using solar energy will ease the electricity peak demand problem as well as reducing the electricity cost and consequent greenhouse gas emission from the housing sector. This study is part of a three year project on the investigation of the impact of intelligent grid in a housing development at Lochiel Park, Adelaide, South Australia.

2. HOUSING DEVELOPMENT AT LOCHIEL PARK – AN OVERVIEW

The Lochiel Park Green Village has the objective of "building ecologically sustainable homes within a natural bush and parkland settings ..." (Lochiel Park Website, 2009). The Green Village master plan was finalised in 2005 and released to market in November 2006. Upon completion at the end of 2010 it will have 106 houses including social housing. The homes being built in the Green Village have green features which include among others: optimised allotment design for maximum benefits from environmental elements, passive design with high envelope energy rating, mandatory use of best available energy efficient appliances in each home, use of solar electricity (1kW per 100m^2 of floor area), installation of electrical load limiting devices, and gas boosted solar hot water systems. Each dwelling has a smart meter and energy usage display. There is an arrangement with the utility for special bundled tariff incorporating green power. The development has many other sustainability features for water usage, waste management and community development.

3. THE CASE STUDY

3.1 House specification

In this study the energy performance of the three dwellings having identical form, building structure and orientation but different fabric are compared. The three dwellings have 2.5, 5 and 7.5 star energy rating, respectively, according to Nationwide House Energy Rating Scheme (NatHERS) used in Australia and implemented using the AccuRate energy rating software (NatHERS website 2009). NatHERS rates the building envelope of dwellings on a scale of 1 to 10 stars according to their total energy performance (i.e. heat required in winter and extracted in summer without considering appliance performance) in satisfying occupants' thermal comfort. Dwellings with more stars require less heating or cooling to deliver thermal comfort to occupants with a 10 star home requiring no additional heating and cooling. The rating is dictated by the following factors: the layout of the dwelling, the construction of the roof, walls, windows and floor, the orientation of windows, shading and local climate. (NatHERS website, 2009).

Table 1 show the energy star bands for rating houses in Adelaide, Australia. According to the table, a 2.5 star dwelling has an annual (cooling and heating) energy requirement of 270 MJ/m^2, more than twice the consumption of a 5 star dwelling. The 7.5 star dwelling consumes less than 60 MJ/m^2 of energy, less than half the energy requirement of the 5 star dwelling. The 2.5 star house is typical conventional Australian design of the nineties while the 5 star represents a newly built house satisfying Australia's current minimum energy rating requirements. 7.5 stars is the minimum rating required for homes being built at the Lochiel Park Green Village. These houses must also comply with environmental guidelines that set out additional requirements including high energy efficiency appliances solar water heating and electricity.

Table 1: NatHERS Star Band for Adelaide:
Number of stars and corresponding annual Energy Requirement (MJ/m^2)

1 Star	2 Star	3 Star	4 Star	5 Star	6 Star	7 Star	8 Star	9 Star	10 Star
480	325	227	165	125	96	70	46	22	3

Table 2 shows the design and appliance specifications of the house selected for this investigation. To achieve 2.5 and 5 star ratings for the same house plan, the following changes shown in Table 3 are made in the construction material properties:

Table 2 – Specifications of the 7.5 Star house

Dwelling type	Detached
AccuRate energy star rating	7.5
Area-adjusted heating requirement	15 MJ/m^2-annum
Area-adjusted cooling requirement	37.5 MJ/m^2-annum
Number of floors	2
Habitable floor area, m^2	197.1
Conditioned floor area, m^2	156
Number of bedrooms	4
Number of bathrooms	3
Roof/ceiling insulation	R 4.0
External wall insulation	R 3.5
Roof / ceiling construction	Corrugated colorbond with air gap
External wall	Reverse brick veneer with R 2.5 insulation batts
Floor	Standard concrete with carpet and felt underlay
Windows	Double glazed 4 mm clear with 12 mm argon filled and low E film.
Door	Solid construction
Cooling / heating system	Reverse cycle (6 star)
Hot water system	Solar / gas boost
Hot water tank size	300 L
Installed PV system capacity, kW	2.4

Table 3 – Specifications of the 7.5, 5 and 2.5 star rated houses

Item	7.5 star Home	5 star home	2 star Home
Floor	Standard concrete with carpet + felt underlay	Standard concrete with carpet + felt underlay	Concrete slab
Roof insulation	R4	R2.5	R2.5
Roof construction	Metal deck	Metal deck	Terracotta tiles
Ceiling	R2 insulation with ceiling fan	R2 insulation with ceiling fan	R1 insulation no ceiling fan
External wall material	Reverse brick veneer with insulation	Brick veneer un-insulated	Brick single skin
Shading devices	Holland blind	Heavy drapes only	Open weave
Windows tightness	Weather-stripped	All windows gap	All windows gap

		size set to medium	size set to large
Door tightness	Weather-stripped	All door gap sizes set to medium	All door gap sizes set to large
Glazing	Low E double glazing	Single glazing	Single glazing

3.2 Appliance specifications

Table 4 shows electrical inputs and assumed number of operating hours per day of appliances used in each of the three houses. It should be noted that it is difficult to select a representative value for each of the items listed in the table and therefore those figure should be regarded as indicative. The choice of these values is somehow influenced by long term monitored consumption results reported in Saman & Mudge (2002), Fung et al. (2003) and Wan & Yik (2004). Other additional information is described below.

Heating and cooling system

It is assumed that the three houses use reverse-cycle air conditioners with the cooling mode energy efficiency ratio (EER) of 2.61, 2.82 and 5.2 and heating coefficient of performance (COP) of 3, 3.47 and 4.8. The systems represent Australia's current 2, 3 and 6 star energy rating for space conditioning appliances (ER, 2009). It was also assumed that the system is correctly sized to satisfy the house energy requirement for cooling and heating. The systems are non-ducted therefore have no delivery losses and they are newly installed so that their performance is unaffected by their age. The annual cooling energy consumption was evaluated using the methodology developed recently (Saman et al., 2009). The heating energy consumption was estimated based on the heating energy requirement calculated with AccuRate with the appropriate COP set above.

Hot water heating system

It is assumed that the water heating for the 2 star home comes from a 300 L electric storage heater (ORER, 2008) and that for the 5 star home from instantaneous gas water heater (AS/NZS 4234-2008). The 7.5 star home has a gas boosted solar hot water system. A 300 L system exposed to Adelaide weather data is used with a RECs value of 35 (ORER, 2008). 1 REC (renewable energy certificate) is 1 MWh electrical energy saved annually by an installed solar energy system.

Cooking, lighting and standby energy

Whenever possible, the information for 7.5 star home is obtained from the house specifications. The figures for 2.5 and 5 star houses are based on typical practice. In the absence of specific data based on monitoring, it is assumed that appliances in the 2.5 and 5 star houses require 30% and 20% more electrical power inputs, respectively, than those used in the 7.5 star house.

Table 4 – Electrical power consumption and hours of use of appliances

House Star rating	2.5		5		7.5	
Appliance	Power, W	Hours	Power, W	Hours	Power, W	Hours
Water heater	3600	4.5	0	0	0	0
Reverse cycle	6700	0.0	3660	0.0	1430	0.0
Fridge	160	5.0	160	5.0	160	5.0
Dishwasher	70	1.0	70	1.0	70	1.0
Microwave	1000	0.8	1000	0.8	1000	0.8
Oven	2000	1.0	2000	1.0	2000	1.0

Other kitchen appliances	1000	1.0	1000	1.0	1000	1.0
Video	45	0.8	45	0.8	45	0.8
Television set	200	5.8	200	5.8	200	5.8
Computer	250	3.5	200	3.5	150	3.5
Washing Machine	600	1.0	600	1.0	600	1.0
Lighting						
Outdoor	100	1.0	40	1.0	20	1.0
Living room	60	4.0	50	4.0	15	4.0
Study Room	60	4.0	50	4.0	15	4.0
Kitchen	60	1.0	50	1.0	15	1.0
Bedrooms	60	2.0	40	2.0	15	2.0
Other rooms	100	1.0	75	1.0	20	1.0
Iron	1000	0.9	1000	0.9	1000	0.9
Vacuum cleaner	250	0.3	250	0.3	250	0.3
Hair dryer	1000	0.3	1000	0.3	1000	0.3

Locally Generated Electrical Energy Source
All houses being built at Lochiel Park Green Village are required to have a minimum of 1 kW solar PV system per 100 m^2 of the roof area. The 7.5 star house being analysed has an installed PV system of 2.4 kW. The assumed PV system coefficient of annual energy production is 0.6 and the system is estimated to operate for 3000 hours annually. The other two houses have no locally generated electrical energy source.

3.3 Peak Load Rating
Various studies have shown that the main contributor to the surge of utility peak load in summer is air conditioning (Koomey & Brown (2002), TEPCO (2004), EES (2004), Saman et al. (2009)). In order to evaluate the contribution to each house to the utility electrical peak demand, the peak demand ratio (PDR) of each house is evaluated and compared.

The peak demand ratio can be defined as (Saman & Halawa, 2009):

$$PDR = \frac{PPD}{APD} \qquad (1)$$

where:
PPD = peak power demand, kW
APD = average power demand excluding space conditioning, kW

The peak power demand consists of peak portion of load coming from the use of cooling or heating system and the average power demand. The former is estimated from energy requirement calculated by AccuRate with appropriate EER or COP of the relevant cooling/heating system. The higher this ratio, the larger is the required electricity infrastructure to meet the peak demand. Many technical innovations and pricing mechanisms are being introduced in order to shave the peak and reduce this ratio. Accordingly this is the metric being proposed by the authors as appropriate for ranking residential buildings to determine their impact on their local energy networks.

A methodology for estimating the peak demand for Australian and New Zealand residential buildings has been proposed and reported in Saman & Halawa (2009). From AccuRate energy calculation, the 10 days with greatest seasonal peak demands are identified. These values are then converted into electricity demand using the values of EER and COP given previously. The average value is used in determining the peak demand of that house.

The household average power demand can be estimated from the total energy consumption (Saman & Halawa, 2009). The values given in Table 4 are used to calculate the average power demand of the three houses.

4. RESULTS AND DISCUSSIONS

4.1 Energy consumption and greenhouse gas emissions profiles

Table 5 shows the total energy consumption of the three houses which includes energy for water heating, space heating, space cooling, cooking, lighting, and others including standby energy. The 2.5 star house represents a nearly all electric house with very high electrical energy consumption for water heating and space conditioning. The 5 star house is a mixed (gas and electric) house with much reduced reliance on electricity compared to the former. However, the use of electricity for cooling will increase its summer peak demand ratio.

The space heating and cooling energy consumption for the three homes reflects both the thermal performance of the houses' envelopes and the heating/cooling appliances installed in each home. For space heating, a combined increase of star rating from 2.5 to 5 and from 2.5 to 7.5 and the energy rating of the heating appliance used results in about 33% and 70% reductions in heating energy consumption, respectively. Likewise, for space cooling, an increase of star rating from 2.5 to 5 and from 2.5 to 7.5 results in 30% and 50% reductions in cooling energy consumption, respectively.

Table 5 –Annual Energy (**E**lectricity and **G**as) Consumption and greenhouse gas emissions for 2, 5 and 7.5 Star Homes (in MJ)

Star Rating	2.5		5		7.5	
Energy source	E	G	E	G	E	G
Water Heating	21240			22830		8640
Space Heating	4693		3137		1411	
Space Cooling	5172		3608		2567	
Cooking		2527		2246		1872
Lighting	1130		848		269	
Other Appliances	11113		10883		10653	
Standby Energy	2167		924		745	
Total energy consumption	45516	2527	19399	25076	15645	10512
Total energy generated					15552	
Total electricity consumption	45516		19399		93	
Total gas energy consumption		2527		25076		10512
Emissions - electrical, kg-$_{CO2-e}$	13200		5626		27	
Emissions - gas, kg-$_{CO2-e}$		186.5		1850.6		775.8
Total emissions	13386		7476		803	

*) Based on local electrical emission factor of 290 kg-$_{CO2-e}$/GJ and gas emission factor 73.8 kg-$_{CO2-e}$/GJ.

The rest of the energy consumption items listed in Table 3 also reflect the efficiency levels of appliances used in each of the three houses.

The combined effect of high energy performance of the house, high efficiency appliances and the installation of the 2.4 kW PV system on the roof of the 7.5 star house results in very low greenhouse gas emissions. The household can also stake the claim of being a net zero energy and zero emission home.

It is worth comparing some of the results of the above calculations with the results of earlier data reported in Oliphant (2003) for base line energy use in South Australian homes. The data for “all electric homes” in 1989/90 shows that a 3 member family home consumes about 32000 MJ annually whilst a 4 member family home consumes about 35834 MJ annually. The figures for 1997/1999 are: 30304 MJ and 34808 MJ, respectively. Keeping in mind the increased air conditioning and appliance use over the last ten years, these are comparable with the figures for the 2.5 star home listed in Table 5 which represents the homes built in early nineties.

Figures 1 – 3 show the composition of energy consumption in each of the houses. When considering these charts, the energy source type (natural gas for cooking for all houses and for water heating in the 5 and 7.5 star homes and electricity for all other purposes) must be taken into consideration. As shown, the main energy consumer for the 2.5 and 5 star houses is water heating which consumes 44% and 51%, respectively, of the total energy. The installation of a solar hot water heating system in the 7.5 star house reduces the water heating energy consumption (in this case gas) to 33% of the total. In terms of their contribution to total energy consumption, space heating and cooling consumes 21% of the total for the 2.5 star house and 15% for the 5 and 7.5 star houses. Reduced share of space heating and cooling to the total energy consumption for higher star houses is expected due to improved thermal performance of these houses. As the provision of hot water, heating and cooling becomes more energy efficient, the dominant components which assume higher significance are those for cooking and other appliances.

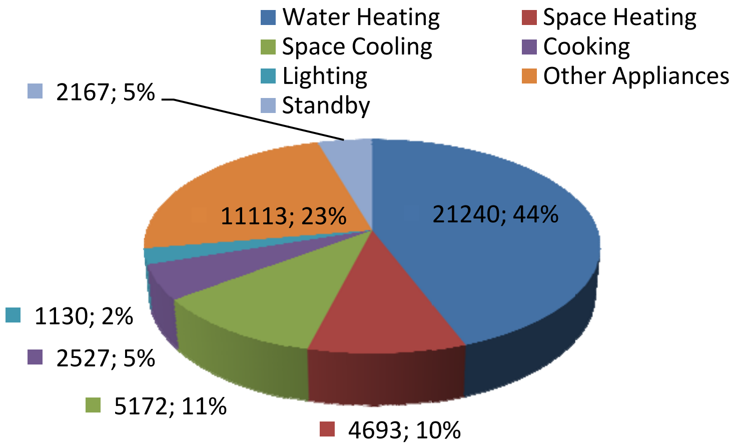

Figure 1 – Composition of energy use in the 2.5 star house

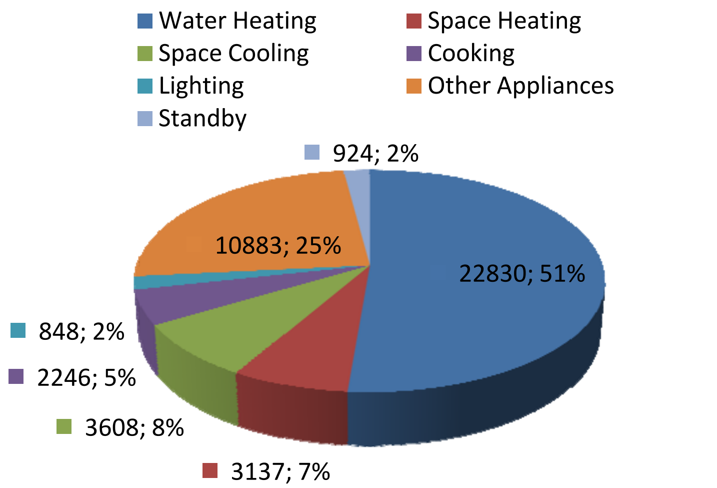

Figure 2 – Composition of energy use in the 5 star house

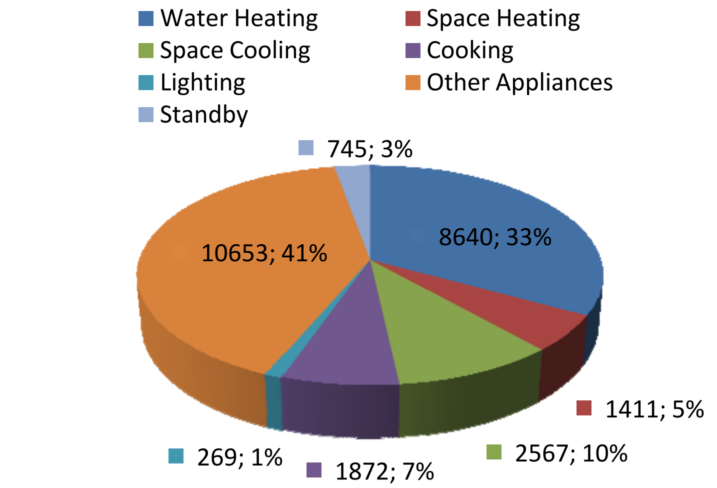

Figure 3 – Composition of energy use in the 7.5 star house

4.2 Peak Demand Ratio

Based on the information given in Table 4 and the method described in Section 3.3, the average power demand, the peak portion of load due to space conditioning and the peak demand ratios of the three houses are presented in Table 6.

It is worth nothing that in estimating the impacts of passive design and solar energy use on the improved performance of the 7.5 house in terms of its contribution to the utility peak load, most of the electrical appliances used in the three houses are assumed to have the same operating hours. The main impacts are due to energy efficient lighting, solar hot water and the space heating and cooling.

Table 6 – Peak Load Performance of the 2.5, 5 and 7.5 star houses

House Star Rating	2.5	5	7.5
Average Power Demand, W	1062	372	349
Load contribution from air conditioning, W	6700	3660	1430
Locally Generated Power during peak period, W	0	0	600
Peak Power Demand without LGP*), W	7762	4032	1779

Peak Power Demand with LGP, W	7762	4032	1179
Peak Demand Ratio without LGP	7.3	10.8	5.1
Peak Demand Ratio with LGP	7.3	10.8	3.4

*) LGP = Locally generated electrical power

Based on the method mentioned in Section 3.3, the peak cooling requirements for the three houses are: 17.5 kW, 10.33 kW and 7.44 kW, respectively. For an EER of 2.61, 2.82 and 5.2 the electrical input power of cooling systems are: 6.7 kW, 3.66 kW, 1.43 kW. These values significantly impact on the peak load.

As discussed previously, the installation of the 2.4 kW PV system on the roof of the 7.5 star house helps to reduce the annual energy consumption of the 7.5 star house. The same system also contributes to reducing the electrical peak demand of the house despite its diminished power generation capacity during the peak demand period. For an equator facing PV system, the peak power of 2.4 kW_p is attained at noon when solar radiation reaches its maximum intensity. The peak electricity demand in South Australia, on the other hand, occurs at about 16.00 – 16.30 hrs in the afternoon (ESCOSA (2007 & 2008), Saman & Halawa (2009)). Based on daily performance monitoring results, a conservative estimate of 25% of the peak power output of 2.4 kW is deemed appropriate as the PV system contribution to reducing the peak demand (Table 6).

The reduced peak power demand and peak demand ratio for the 7.5 star house comes from the combined effect of much improved thermal performance of the house, the use of more efficient appliances and the installation of PV system and gas boosted solar hot water system.

5. CONCLUSIONS AND RECOMMENDATIONS

The study demonstrates the effectiveness of combined passive design, energy efficient appliances and solar energy use in realising self-sufficient energy homes and consequent reduction of greenhouse gas emissions and in reducing the peak load of dwellings. Widespread construction/renovation of dwellings approaching the specifications similar to those of the 7.5 star home described in this paper will lead to a considerable reduction of the greenhouse gas emissions from the housing sector and will help reverse the recent trend of increasing load factors due to domestic air conditioning use.

Compared with the 2.5 star rated home, the 5 star home has reduced energy consumption, reduced peak load but higher peak demand ratio. This demonstrates that in designing houses and selecting their appliances, both the total energy and peak demand aspects must be considered. In order to reduce the peak demand ratio, houses need to have low heating and cooling requirement, efficient heating and cooling appliances as well as local energy generation. The previous trends in some Australian housing development in reducing heating and cooling requirements and switching to gas powered hot water provision has resulted in reductions of their overall greenhouse gas emission but has raised their peak demand ratio. This paper has demonstrated the causes of this trend and offered some solutions in reversing the trend and thus reducing the need for upgrading the electricity supply and distribution infrastructure.

REFERENCES

AS/NZS 4234-2008 - Heated water systems - Calculation of energy consumption.

EES, 2004: Electrical Peak Load Analysis – Victoria 1999 – 2003, Energy Efficient Strategies, prepared for VENCORP.

ER, 2009: The Energy Rating website: www.energyrating.gov.au – accessed 30 July 2009.

ESCOSA, 2007: ETSA Utilities Demand Management Program – Progress Report, June. The Essential Services Commission of South Australia.

ESCOSA, 2008: ETSA Utilities Demand Management Program – Progress Report, October. The Essential Services Commission of South Australia.

ETSA Utilities, 2009: Load Shedding Hits 83 Suburbs, ETSA Utilities Media Release, 30 January 2009 - http://www.etsautilities.com.au/centric/news_information/media_releases/load_shedding_hits_83_suburbs.jsp

Fung, A.S., Aulenback, A., Ferguson, A. & Ugursal, V.I., 2003: Standby power requirements of household appliances in Canada, Energy and Buildings, vol. 35, pp. 217 – 228.

Koomey, J. & Brown, R.E., 2002: *The role of building technologies in reducing and controlling peak electricity demand*, Energy Analysis Dept. – Environmental Energy. Technologies Division – Ernest Orlando Lawrence Berkeley National Laboratory – University of California – Berkeley, CA 94720, September – http://enduse.lbl.gov/Info/LBNL-49947.pdf.

NatHERS Website, 2009: www.nathers.com.au – accesses 15 July 2009.

NEMMCO, 2009a: NEMMCO Media Release, Friday 30 January 2009.

NEMMCO, 2009b: **Pricing Event Reports - January 2009,** http://www.nemmco.com.au/opreports/pricing_jan.html

News.com.au, 2009 - *Increase in sudden deaths of elderly in Adelaide appear to be due to the heatwave* – 7 February:

http://www.theaustralian.news.com.au/story/0,25197,25019866-5006787,00.html

ORER, 2008: REC calculation methodology for solar water heaters and heat pump water heaters with a volumetric capacity of up to and including 700 liters – Version 13, The Office of Renewable Energy Regulator (ORER), January 2008.

Poore, W.P., Stovall, T.K., Kirby, B.J., Rizy, D.T., Kueck, J.D., Sotavl, J.P., *Connecting distributed energy resources to the grid: their benefits to the DER owner/customer, the utility, and society*, Oak Ridge National Laboratory, ORNL/TM-2001/290

TEPCO, 2004: Electricity Market in Japan – Tokyo Electric Power Company website:

http://www.tepco.co.jp/en/news/presen/pdf-1/0406-e.pdf - accessed 27 March 2009

Saman, W. & Mudge, L., 2002: Development, implementation and promotion of a scoresheet for household greenhouse gas reduction in South Australia, Submitted to Partnerships Group, Australian Greenhouse Office, Canberra.

Saman, W., Mudge, L., Cheng, T.Y., Halawa, E., Bruno, F., 2009: ANZHERS - Space Cooling Rating Tool - Final Report, submitted to Residential Building Efficiency Team, Department of the Environment, Water, Heritage And the Arts, Canberra.

Saman, W., Halawa, E., 2009: NATHERS – Peak Load Performance Module Research – Final Report, submitted Residential Building Efficiency Team, Department of the Environment, Water, Heritage And the Arts, Canberra.

Wan, K.S.Y. & Yik, F.W.H., 2004: Building design and energy use characteristics of high-rise buildings in Hong Kong, Applied Energy, vol. 78, pp. 19 – 36.

ACKNOWLEDGEMENT

This study is part of a CSIRO funded three year project on the investigation of the impact of the intelligent grid in a new housing development. The authors acknowledge the financial support from CSIRO Energy Transformed Flagship and Land Management Corporation, South Australia.

APPENDIX 4 – PAPER PRESENTED THE WORLD RENEWABLE ENERGY CONGRESS XI, 25-30 SEPTEMBER 2010, ABU DHABI, UAE

TOWARDS ZERO ENERGY HOMES DOWN UNDER

Wasim Saman
Sustainable Energy Centre, Institute for Sustainable Systems and Technologies
University of South Australia
Mawson Lakes Campus, Mawson Lakes SA5095, Australia
Corresponding author: Wasim.Saman@unisa.edu.au

Abstract
The concept of net zero energy and zero emission home has been a goal for those involved in the sustainable building industry. It is now becoming a reality in many parts of the world with an integrated approach of passive design, energy efficient appliances and local renewable generation. The paper describes the activities in Australia focussing on reducing energy use from the housing sector. It describes the regulatory approach of energy performance for housing which involves developing a house energy rating tool covering the building envelope as well as major energy consuming appliances. It also describes the implementation process which comprises gradually more stringent regulations coupled with financial inducements. The paper describes a world leading new Australian housing development where net zero energy homes are being built and enjoyed. It tells the story of how this outcome is being achieved starting with the planning process and developing environmental guidelines. The paper describes the innovations being used in order to achieve net zero energy homes and reports on energy monitoring results and feedback from householders.

Keywords: Zero energy home; Domestic energy consumption; Energy efficiency; Energy rating tool

1. Introduction and Background

The energy consumption of Australian commercial and residential buildings has been escalating throughout the last 2 decades. The energy used by Australian buildings accounts for approximately 20 per cent of Australia's greenhouse gas emissions. On average, space heating and cooling represents 41% and domestic water heating about 30% of the energy demand of residential buildings with heating and cooling of buildings directly responsible for 11% of Australia's national greenhouse gas emissions despite the temperate climate of major Australian cities [1, 2]. The number of residential dwellings will be around 10 million in 2020 compared to 6 million in 1990. The energy consumption of the residential sector was about 402 PJ in 2008 and is projected to increase to 467 PJ by 2020, showing a 56% increase in residential sector energy consumption over the period 1990 to 2020 [3]. Extreme heat waves that hit southern Australia in recent years have resulted in a dramatic increase of the use of air conditioners and a consequent rise in the peak electricity demand. Australia has to adapt to increasing frequency of heat waves. As examples, the number of days over 35°C will increase to 19-25 by 2030 and to 20-32 by2050 from a current value of 17 for Adelaide. The corresponding figures for Perth are 29-38 and 31-48 from 27 respectively [4]

Due to the abundance of cheap energy, housing designs and constructions have not considered energy efficiency as a high priority. Aesthetics, larger built area at minimum construction costs have been the key elements in marketing both new and existing dwellings. A typical traditional Australian home is detached, around 200m² in area and has 3-4 bedrooms. It is constructed of brick veneer walls with single glazed, mostly unshaded windows. Roof and wall insulation is becoming the normal practice to comply with building regulations. In 2008, 77% of Australian dwellings had one or more space heaters and two thirds had space coolers [1].

Figure 1 shows the energy consumption of a typical home built ten years ago. The results are based on a detailed monitoring program of individual homes and a housing cluster [5]. Table 1 shows a breakdown of energy use and emissions for 3 houses of similar size and basic design. The first is built ten years ago; the second house represents currently built houses which comply with the minimum energy rating requirements (5 star); while the third represents a recently built near net zero energy home having a 7.5 star rating[6].

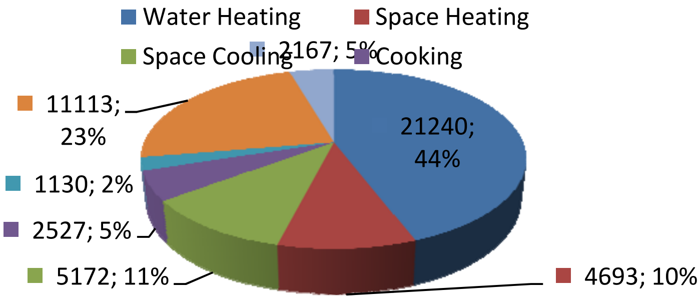

Figure 1 – Breakdown (in MJ) of annual energy use in a typical 10 year old Australian house

Table 1 –Annual Electricity (E) and Gas (G) Consumption and greenhouse gas emissions for 2, 5 and 7.5 Star Homes (in MJ)

Star Rating	2.5		5		7.5	
Energy source	E	G	E	G	E	G
Water Heating	21240			22830		8640
Space Heating	4693		3137		1411	
Space Cooling	5172		3608		2567	
Cooking		2527		2246		1872
Lighting	1130		848		269	
Other Appliances	11113		10883		10653	
Standby Energy	2167		924		745	
Total energy consumption	45516	2527	19399	25076	15645	10512
Total solar energy generated					15552	
Total energy consumption	45516	2527	19399	25076	93	10512
Emissions, kg-CO_{2-e}	13200	186.5	5626	1850.6	27	775.8
Total emissions, kg-CO_{2-e}	13387		7477		803	

2. Energy Consumption Regulations and Rating for Australian Housing

The annual energy use for maintaining thermal comfort in dwellings is determined using various computer based simulation tools. One of the most widely used tools is the Nationwide House Energy Rating Scheme (NatHERS). It was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in conjunction with some states and territories as a nationally accepted energy rating tool [7]. It estimates the heating and cooling energy requirements of a dwelling by performing hourly calculations for heating and cooling requirements over a typical year, based on specific information (eg. dwelling design, dimensions, construction materials, orientation and climate zone for a standardised occupant pattern). The simulated results allow the ranking of a dwelling in terms of performance. NatHERS rates the building envelope of dwellings on a scale of 1 to 10 stars according to their total energy performance (i.e. heat required in winter and extracted in summer without considering appliance performance) in satisfying occupants' thermal comfort. Dwellings with more stars require less heating or cooling to deliver thermal comfort to occupants with a 10 star home requiring no heating and cooling. [7]

This and other simplified tools based on the NatHERS package (e.g. FirstRate, BERS) do not account for other energy consuming appliances nor do they predict environmental impact. Table 2 shows the heating and cooling energy levels associated with different star ratings for selected Australian locations. The star rating tools have been used in mandating minimum energy performance standards for housing in the last few years. New Australian homesd must have a minimum rating of 5 stars. Some Australian States are raising the requirements to 6 stars later this year.

In order to allow for the overall energy and emission performance of housing, approximate methodologies have been developed such as the energy scoresheet [5] and Basix[8]. The second generation energy rating tools currently under development go a long way in determining the overall energy consumption. The second generation AccuRate tool is a replacement of NatHERS. Most of the NatHERS disadvantages were addressed in AccuRate including improved natural ventilation modelling, user-defined constructions, improved modelling of roof-spaces, sub-floor spaces, skylights and horizontal reflective air gaps and improving the indoor comfort temperature settings [9]. The second generation tools will also consider other major energy components including heating and cooling appliance performance, hot water, lighting and local solar energy generation. The Australian Ministerial Council on Energy has approved the use of rating tools to mandate the disclosure of the energy star rating of dwellings when advertised for sale or rent.

TABLE 2 - Star rating criteria for heating and cooling loads in MJ/m² conditioned floor area per year

Climate Region	Location	Star Energy Rating									
		1.0	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**
1	Darwin	773	648	555	480	413	349	285	222	164	119
5	Townsville	309	259	218	183	153	127	103	81	61	44
6	Alice Springs	562	385	269	196	148	113	84	56	29	7
7	Rockhampton	295	222	171	136	110	90	71	54	38	24
10	Brisbane	203	139	97	71	55	43	34	25	17	10
13	Perth	387	251	167	118	89	70	52	34	17	4
16	Adelaide	480	325	227	165	125	96	70	46	22	3
17	Sydney	230	148	98	68	50	39	30	22	13	6
21	Melbourne	559	384	271	198	149	114	83	54	25	2
24	Canberra	792	547	387	284	216	165	120	77	35	2
26	Hobart	723	498	354	262	202	155	113	71	31	0
69	Thredbo	1238	888	655	499	387	298	216	136	61	1

A good example of the regulatory approach for appliances is the phase-out of incandescent lights in February 2009. Minimum Energy Performance Standards and Energy Star Rating of appliances has produced consistent improvements in the last 10 years [10]. Table 1 above shows a breakdown of the energy use in a typical, recently built 5 star home. With improved building envelope, more use of natural gas for water heating, energy efficient appliances and improved building envelope, it can be seen that the annual emission is reduced from over 13 tonnes to around 7.5 tonnes of CO_2 equivalent.

3. Government Incentives for households

The current move to set minimum energy performance standards for both the dwellings and appliances is being countered by a reduction of number of occupants per home (the current average is 2.5) and an increase of the floor area of dwellings. In order to limit the energy use and consequent greenhouse gas emission, a number of government driven schemes have been implemented to educate builders and households and to provide financial incentives for using energy more efficiently or installing solar systems. Below are examples of national and state government incentive programs targeting new homes as well as Australia's existing 8 million households [10].

The Australian Government offers an incentive of A$1000 for households replacing electrical resistance heaters with solar hot water systems. It also provides a rebate to all households installing solar water heaters for the value of renewable energy certificates (RECS) associated with replacement of conventional energy. A REC is the equivalent of 1 MWh of renewable energy produced, or non-renewable energy displaced over ten years. The performance of systems in various climatic regions is analysed and their REC values are published for the purpose of incentive determination. The current value of a REC for a hot water system is fixed at A$40. Many Australian state governments offer additional incentives of up to AS600 with additional rebates to low income families. (More details are in http://www.hotwaterrebate.com.au/). A REC multiplier for photovoltaic home systems provides an incentive of A$7200 for installing a 1.5kW system, making it an attractive proposition.

The government has also facilitated several hundred thousands of free energy home assessments through accredited assessors. Home assessment results are presented in a report listing the major items for reducing energy consumption, costs and associated emissions. The most ambitious program which was implemented for a short period aimed at providing free roof thermal insulation to all uninsulated Australian homes. However, the program was discontinued in February due to fire and safety risks associated with improper installation of insulation material in older roofs.

4. New Housing Developments: a Case Study

The Lochiel Park Green Village is a world leading exemplar sustainable housing development. It has the objective of "building ecologically sustainable homes within a natural bush and parkland settings" [11] The Green Village master plan was finalised in 2005 and released to market in November 2006. Upon completion at the end of 2011 it will have 106 homes including social housing. The homes being built in the Green Village have many sustainability features which include optimised allotment design for maximum benefits from environmental elements, passive design with high envelope energy rating, mandatory use of best available energy efficient appliances in each home, use of solar electricity (1kW per 100m^2 of floor area), installation of electrical load limiting devices, and gas boosted solar hot water systems. Each dwelling has a smart meter and energy usage display screen. There is an arrangement with the utility for special bundled tariff incorporating green power. The development has many other sustainability features for water usage, waste management and community development. The development was planned and implemented through collaboration between the South Australian Government, selected building companies with support from the University of South Australia in developing the building sustainability guidelines, assisting in home energy and appliance ratings as well as installing detailed monitoring systems for energy and water consumption. It is planned to record and analyse the vast data emerging from the monitoring program for 9 years.

4. Performance of Net Zero Energy Housing

The anticipated energy performance at the design stage of an example home built at Lochiel Park is given as a case study. The home has 7.5 star energy rating. Table 3 shows the design and appliance specifications.

TABLE 3 – Specifications of the example home

Area-adjusted heating requirement	15 MJ/m^2-annum
Area-adjusted cooling requirement	37.5 MJ/m^2-annum
Number of floors	2
Habitable floor area, m^2	197.1
Conditioned floor area, m^2	156
Number of bedrooms	4
Roof/ceiling insulation/construction	R 4.0/ Corrugated steel with air gap
External wall insulation/construction	R 3.5/Reverse brick veneer
Floor	Standard concrete with carpet and felt underlay
Windows	Double glazed 4 mm clear with 12 mm and low E film.
Doors	Solid construction

Cooling / heating system	Reverse cycle (6 star)
Hot water system	Solar / gas boost, 300 litre tank
Installed PV system capacity, kW_P	2.4

4.1 Appliance specifications

The choice of energy consuming appliances was based on the best available on the Australian market. The appliance use patterns were based on long term monitored consumption results reported in Saman & Mudge [12] and Fung et al. [13]. The house uses reverse-cycle air conditioners with the cooling mode energy efficiency ratio (EER) of 5.2 and heating coefficient of performance (COP) of 4.8. The systems represent Australia's current 6 star energy rating for space conditioning appliances. The system is correctly sized to satisfy the house energy requirement for cooling and heating. The home has a gas boosted solar hot water system. A 300 L system exposed to Adelaide weather data is used with a REC value of 35. All houses being built at Lochiel Park Green Village are required to have a minimum of 1 kW solar PV system per 100 m^2 of the roof area. The example house has an installed PV system of 2.4 kW. The assumed PV system coefficient of annual energy production is 0.6 and the system is estimated to operate for 3000 hours annually.

4.2 Energy consumption and greenhouse gas emissions profiles

Table 1 shows the estimated total energy consumption of the example houses which include energy for water heating, space heating and cooling, cooking, lighting, and others including standby energy. The space heating and cooling energy consumption for the homes allows for the appliance performance. For space heating, the increase of star rating from 2.5 to 7.5 and improving the energy rating of the heating appliance result in about 70% reduction in heating energy consumption. Likewise, for space cooling, a 50% reduction is made possible.

Figure 2 shows the various energy consumption components in the example house. When considering the chart, the energy source (natural gas for cooking and for supplementing the solar water heating in the home and electricity for all other purposes) must be taken into consideration. Contrasting with typical existing homes as shown in Figure 1, the main energy consumer for the 2.5 star house is water heating which consumes 44% of the total energy; the installation of a solar water heater in the 7.5 star house reduces the water heating energy consumption (in this case gas) to 33% of the total. In terms of their contribution to total energy consumption, space heating and cooling consume 21% of the total for the 2.5 star house and 15% for the 7.5 star house. As the provision of hot water, heating and cooling becomes more energy efficient, the dominant components which assume higher significance are those for cooking and other appliances.

The overall energy consumption and emissions of a typical 10 year old home and the example house having the same design, floor area and number of occupants is shown in Table 1. . The combined effect of high energy performance of the house, high efficiency appliances and the installation of the 2.4 kW PV system on the roof of the 7.5 star house results in very low net annual electricity consumption (26kWh compared with 12643kwh for the 10 year old home). The greenhouse gas emissions associated with electricity and gas consumption is 0.8 tonnes per annum compared to 13.4 tonnes for the older house.

Consequently, the occupants of the new house can stake the claim of living in a net zero energy and zero emission home.

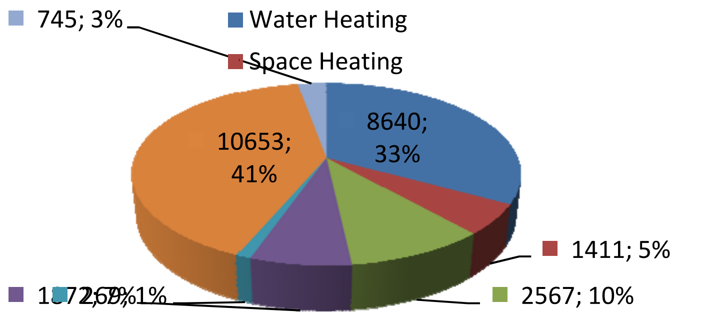

Figure 2 – Composition of energy use in the example house (in MJ/m²)

4.3 Sample monitoring results

A long term monitoring program for all homes is underway including detailed monitoring of all appliances, indoor temperatures and household surveys for some of the Lochiel Park homes. Figures 3 and 4 are sample results which show that on many days, the energy consumption is well below the local generation. Figure 4 shows how despite the relatively modest consumption, air conditioning still dominates electricity use on hot days. The maximum temperature on the day shown was 35.6°C. As occupants were at work during daytime, cooling was used for most of the night hours.

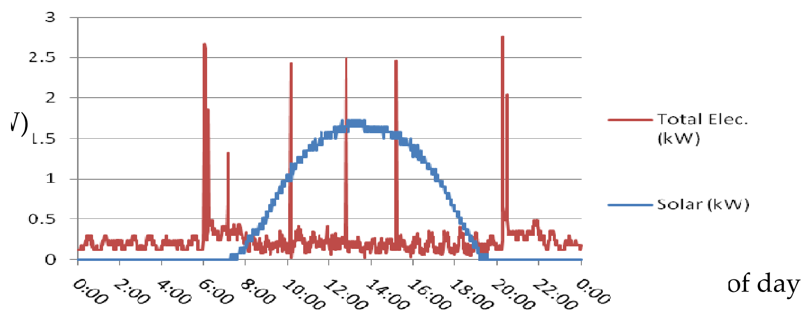

Figure 3 – Typical daily energy use and generation (1 March 2010)

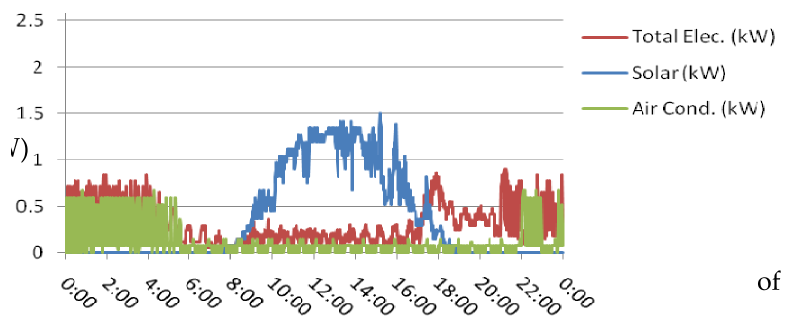

Figure 4 – Contribution of air conditioning on a hot day (18 March, 2010)

4. Conclusions

The study demonstrates the effectiveness of combined passive design, energy efficient appliances and solar energy use in reaching the goal of energy self-sufficient homes. Widespread construction/renovation of dwellings approaching the specifications similar to those of the example home described in this paper will lead to a considerable reduction of the greenhouse gas emissions from the housing sector and will help reverse the trend of increasing energy demand from the domestic sector.

Current surveys of households at Lochiel Park indicate how the occupants enjoy the notion that they are not contributing to damaging the environment, the low or negative energy bills they pay and the thermal comfort for long periods of the year when their homes require no heating or cooling. The housing developer has received many unsolicited messages from occupants reflecting these sentiments. The fact that the energy bill is very low or in credit has been used by the developer in advertising the new vacant blocks.

The University of South Australia is embarking on a detailed monitoring program of energy and water use in all homes including monitoring individual appliances every minute for 10 homes. Surveying the household attitude and behaviour is also continuing with emphasis on interaction with new energy saving features and appliances.

The monitoring results are also demonstrating that behaviour is a key factor in determining the level and pattern of energy use. The provision of adequate information on the need to operate the house components and appliances correctly will produce further energy reductions. Examples are windows and shading devices, air conditioning and entertainment systems. A potential also exists for better integration of the solar systems into the building and roof design.

5. References

[1] ABS, (2010), *Energy in Focus; Energy Efficiency in Australian Homes*, Australian Bureau of Statistics

[2] Wilkenfeld, G. and Associates (2002), *Australia's National Greenhouse Gas Inventory, 1990, 1995 And 1999, End Use Allocation*, Department of Climate Change, Canberra.

[3] Department of the Environment, Water, Heritage and the Arts (2008) *Energy Use in the Australian Residential Sector 1986 – 2020,* Commonwealth of Australia

[4] Suppiah, R. Hennessy, K.J. Whetton, P.H. McInnes, K. Macadam, I. Bathols, J. Ricketts J. Page, C.M. (2007) *Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report,* Aust. Met. Mag. 56, 131-152

[5] Saman, W. & Mudge, L., (2003), *Development, implementation and promotion of a scoresheet for household greenhouse gas reduction in South Australia*, Final Report to the Australian Greenhouse Office, Commonwealth of Australia, Canberra, June, 2003.

[6] Saman, W. & Halawa, E., (2009), *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.

[7] Nationwide House Energy Rating Scheme (NatHERS), (2010), www.nathers.gov.au

[8] Building and Sustainability Index (BASIX), www.basix.nsw.gov.au

[9] Saman, W., Oliphant, M., Mudge L. and Halawa, E. *Study of the effect of temperature settings on AccuRate cooling energy requirements and comparison with monitored data*, Final Report to the Department of the Environment, Water, Heritage and the Art, Commonwealth of Australia, Canberra, June, 2008.

[10] Australian Government Energy Efficiency Programs (2010) http://www.environment.gov.au/sustainability/energyefficiency/index.html

[11] Lochiel Park – Australia's Model Green Village, (2010), http://www.lochielpark.com.au/lochielpark/home.htm

[12] Saman, W. & Mudge, L., (2006), *Validation of a scoresheet for household energy reduction in South Australia,* Proc. Second International Solar Cities Congress, Oxford, UK.

[13] Fung, A.S., Aulenback, A., Ferguson, A. & Ugursal, V.I., (2003), *Standby power requirements of household appliances in Canada,* Energy and Buildings, vol. 35, pp. 217 – 228.

Acknowledgement

The study is part of a CSIRO funded three year project on the investigation of the impact of the intelligent grid in a new housing development. The author acknowledges the financial support from CSIRO Energy Transformed Flagship and Land Management Corporation, South Australia. The work described is being carried out by a team including Edward Halawa, David Whaley, Lachlan Mudge and many others. The team member contributions are duly acknowledged.