E3 Equipment Energy Efficiency

Lighting Data Collection and Analysis

Residential Energy Monitoring Program (REMP)

February 2012

A joint initiative of Australian, State and Territory and New Zealand Governments.

This Report is available at

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Executive summary

This paper is one in a series of papers on end-use metering methodologies, prepared to assist in the development of end-use metering campaigns. The full suite of papers are:

- Residential End Use Monitoring Program (REMP) – General Introduction and Overview;
- Residential End Use Monitoring Program (REMP) – Water Heating Data Collection and Analysis;
- Residential End Use Monitoring Program (REMP) – Lighting Data Collection and Analysis; (this paper)
- Residential End Use Monitoring Program (REMP) – Heating and Cooling Loads Data Collection and Analysis;
- Residential End Use Monitoring Program (REMP) – General Plug Loads Data Collection and Analysis;
- Residential End Use Monitoring Program (REMP) – Equipment Recommendations;
- Residential End Use Monitoring Program (REMP) – Data Management Strategy: Data Handling and Database Requirements/Specifications.

Each of those papers contains recommendations that are specific to those end uses or elements. This paper contains general information and recommendations that are applicable to lighting.

The Australian Government is considering end-use metering campaigns to fill various gaps in its knowledge, especially relating the important residential end-uses. These papers will be used to set out requirements for a possible future tender.

Residential lighting in Australia consumes more than 700 kWh pa per household (around 10-20%), although data used to estimate this value is considered outdated.

The purpose of the paper is to provide background information and initial recommendations regarding how lighting should be surveyed and monitored in future REMP data collection campaigns.

The main aim of a metering campaign is to provide:

- Time of use energy consumption load curves for lighting;
- Hours of use by lamps (type, location);
- Seasonal variations;
- Allow more detailed analysis to explain lighting usage (eg by other physical variables such as floor area, or occupants).

The overall measurement campaign should include:

- An inventory of lamps installed in monitored homes (for comparison with larger scale surveys);
- A building survey with room number and type, floor area (by room and total);
- An enhancement to the data can also be obtained if an optional socio-economic survey of householders - a survey of lighting behavioural issues is included.

The main outputs from an end use metering campaign should be:

- Hours of use and power (daily, seasonal pattern);
- Time of day of use and power (seasonal pattern);
- Frequency of switching/dimming;
- Energy consumption per home;
- Lighting product or service measure (eg light output or efficacy);
- Room occupancy (and compared with lighting usage (ie are the lights left on when the rooms are not in use);
- Prevalence and proportion of plug load lighting.

When coupled with other variables, more sophisticated analysis can be undertaken, such as understanding energy consumption as functions of variables such as floor area, income, and number of people per household.

Recommendations

For the Residential Energy Monitoring Program (REMP), the following recommendations are made:

1. Survey participants to understand their socio-economic situation (income, household size);
2. Survey the building to understand characteristics (eg size, type, number of rooms);
3. Complete an inventory of participating households to collect data related to lamp types, prevalence of plug load lighting, prevalence of dimmers, rooms by lamps types, etc (this include occupant estimates of usage level by lamp);
4. (Optional) Survey participating residents on their lighting equipment behavior (data such as switching habits, barriers to technology uptake, decision process, etc.);
5. Monitor (meter) households using the following equipment:
    a. Plug in data logger (tracking power);
    b. Light on/off loggers (photosensitive);
    c. Switchboard loggers;
    d. Occupancy sensors.

A brief discussion on the lessons learnt from the REMP pilot project is outlined in this paper as well as an overview of some of the plug load data analysed.

1. Introduction

From the recent Regulatory Impact Statement prepared for the phase-out of low efficacy lamps, the average household consumes around 700kWh p.a. for the purpose of lighting. New homes are estimated to consume considerably more than this, due primarily to the recent popularity of extra low voltage (and comparably high Wattage) halogen lighting systems, and the large floor area of such homes.

Policies and programs aimed at reducing residential lighting energy consumption are informed by detailed knowledge of the lighting stock and typical household usage patterns. To this end, collection of residential end use data is considered important in the development of effective policies and programs.

1.1 Purpose of this Paper

This paper is one of a series of papers on energy end use measurement that have been prepared for the Department of Climate Change and Energy Efficiency (DCCEE) in relation to the Residential Energy Monitoring Program (REMP).

The purpose of the paper is to provide background information and initial recommendations regarding how lighting data should be collected in the REMP. It proposes data collection strategies aimed at maximising the quality and quantity of information on lighting energy usage, including data logging, collection of an inventory, and an occupant survey.

2 What We Know About Light Data (What is Missing?)

Existing Australian lighting data, and data collection strategies, are inadequate. The recent Regulatory Impact Statement prepared for the phase-out of incandescent lamps estimates that the average household consumes around 700kWh pa lighting. However, this estimate is considered outdate for new homes, which consume considerably more lighting energy, due primarily to the relatively recent popularity of extra low voltage halogen lighting systems and the increased size of new homes. It is also known that lighting energy consumption varies significantly between households.

Lighting energy usage is complex for the following reasons:

- There are multiple lighting points per house – often with more than one fitting and lamp per switch circuit;
- Appropriate and actual lighting levels vary from room to room;
- Lighting, when on, is often innocuous to occupants;
- Interior lighting is generally switched manually;
- Lamps may only last as little as 0.5 years before they are replaced;
- Other factors such as floor area (larger homes need more lighting) and the number of occupants also drive the requirements for lighting.

Many of these factors are not well documented or understood.

2.1 Key Issues about Lighting

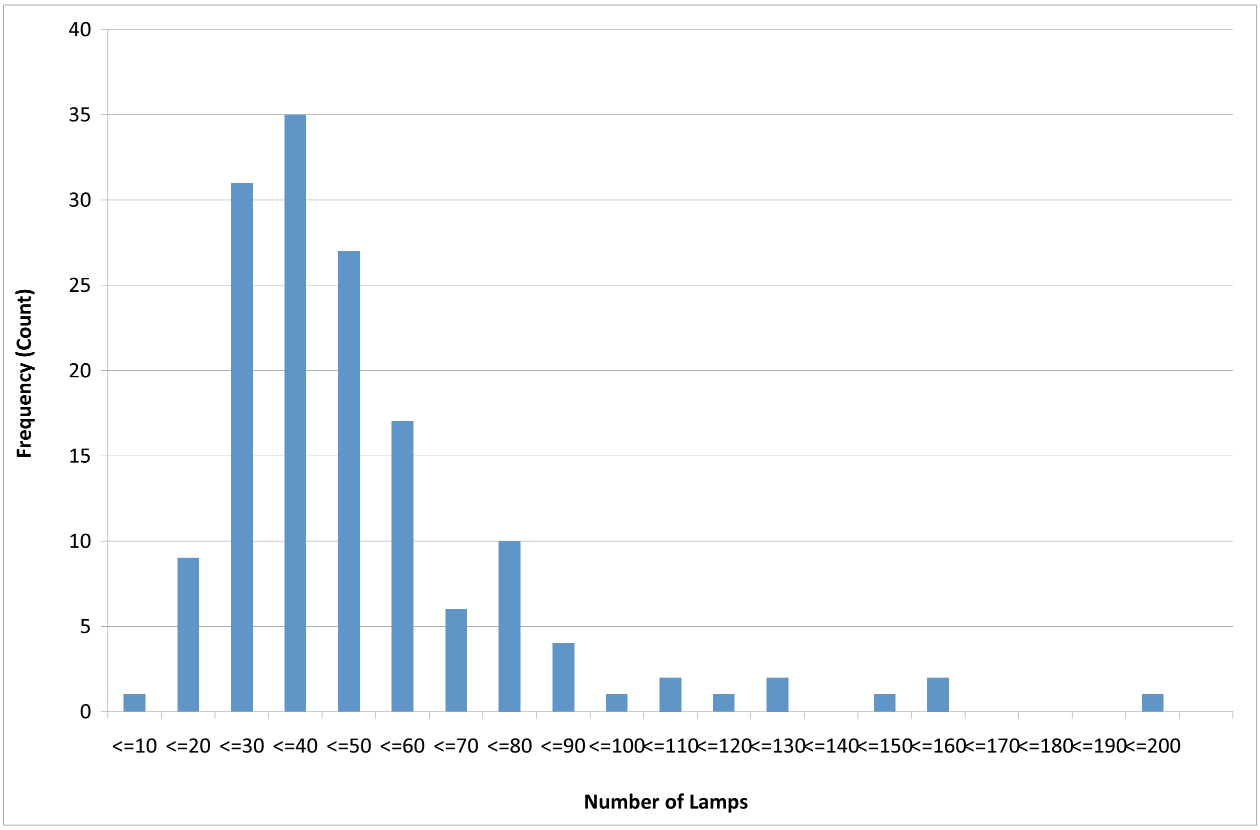
Monitoring lighting presents unique problems. There are large numbers of light fittings found in homes, with many different technology types used. An audit of 150 homes in 2010/2011 found that an average home had 50 lamps (EES 2012), with lamp numbers varying from a low of 10 to a high of 202 lamps per house (see Figure 1).

Whilst it may be technically feasible to separately record usage data for each lighting point (eg using a light sensor and/or data logger), this is not generally practical for a large scale campaign covering many houses.

Most lights in a home are hardwired, which obviates the use of plug in data loggers for individual lighting points. Measurement of total power for lighting circuits (if these are not mixed with power circuits) can give total lighting energy but little information on which lighting points are being used can be gleaned from this data.

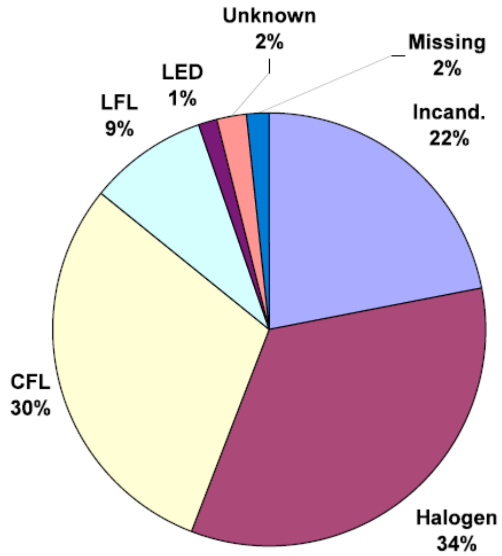
Total lighting energy may be of little value as there are likely to be a range of lighting technologies in service around the home (see Figure 2). Other problems include the use of dimmers and the (possibly slow) replacement of failed lamps during any monitoring period. Task, local or portable lighting powered through normal power outlets can be measured with plug in equipment.

Figure 1: Distribution of lamps per home from household lighting audit 2010



Source, EES 2012

Figure 2: Share of technology for lighting in Australian households 2010



Source, EES 2012

Other issues to consider include:

- Number of occupants in a home;
- Floor area of the house;
- Seasonal and daily variations in lighting usage.

3 Data Collection

For lighting, the main components on an end use measuring strategy should include:

1. Data logging;
2. Collection of a lighting inventory.

These three components are addressed further in the following sub-sections. Wherever possible, physical and occupant surveys should be combined to make data collection activities as cost effective as possible.

3.1 Data Logging

This section describes a potential strategy for logging of lighting parameters during future REMP campaigns.

Table 1 lists the lighting parameters, along with a subjective rating of the importance of the data, likely demographic influence on the trends in the data (suggesting demographic sampling will be required), together with the recommended collection modes and monitoring frequencies.

Table 1: Lighting Parameters for Monitoring

Lighting Parameter	Importance of Lighting Parameter	Has a Demographic Influence?	Modes of Data Collection	Recommended Monitoring Frequency*
Hours of use (daily, seasonal pattern)	High	Yes	Monitor	Event based or 1 min
Time of day of use (seasonal pattern)	High	Possibly	Monitor	Event based or 1 min
Frequency of switching	Medium	No	Monitor	Event based or 1 min
Dimming levels (manual dimmers)	Medium	No	Monitor	10 minutes
Energy consumption	Essential	Yes	Monitor	10 minutes
Total lighting power factor & total residential power factor (all appliances)	Low	Possibly	Monitor	10 minutes
Room occupancy rate while lights are on	Low	No	Monitor	10 minutes
Typical household lamp technology inventory (overall and by room type)	High	Possibly	Audit	

** For lighting, it is recommended to use the shortest possible sampling period (ie one minute) or event based recording. This fine level of data allows more detailed (and useful) analysis to be undertaken.*

Each of the households should have a standard survey of the building shell (eg AccuRate) and the householders (eg socio-economic), which will be used for further analysis (classification and stratification) of the lighting data.

The main goal of lighting in REMP, is to monitor hours of use and energy consumption. As homes typically have many lighting points (average of 50 lamps), it is not possible to monitor or track the use of each lamp. However, in Australia, most lights in a house are usually on a separate lighting circuit (sometimes two or three circuits), which should be separately monitored. The energy used in lighting circuits can capture all the energy associated with the use of hardwired lamps. In order to disaggregate the lighting energy as much as possible, heavily used lamps on lighting circuits should be separately monitored through the use of individual lamp sensors[1]. It is important to note that an average home has 7 plug in lamps that are powered by normal power outlets, so these can be monitored using plug in data loggers. Additional information may also be obtained by the use of occupancy sensors.

[1] Typically, these are photoelectric sensors that allow a data logger to record on time for an individual lamp, or time of switching (event logger). Combined with data on the lamp power, this allows for post processing of data to estimate the energy profile for the lamp.

Placement of loggers should be undertaken as follows:

- Objective is to maximise cover of individual lighting points and usage of lighting;
- Where points are readily identifiable from lighting circuit logging (ie unique loads), there is no need to place individual loggers on these points;
- Where a limited number of lights are included on a single circuit, it is possible to use subtraction or residual power to calculate non-individually logged points(s) where most lights have individual usage loggers;
- It is important to prioritise high use lights to maximise energy coverage.

3.2 Lighting Inventory

To compile a lighting inventory requires trained personnel (ie able to identify lamp types, ballast/transformer types, rated wattages, dimmer and occupancy controls etc) to perform a walk-through of each house.

The inventory should list data on:

- Each light fitting should be identified by the following recorded characteristics:
- Light fitting identifier (number / letter);
- Which lighting circuit the light fitting is wired to (where lighting circuits are to be logged);
- Light fitting type (eg downlight, wall light, desk lamps, etc);
- Lamp type (eg halogen, CFL, etc);
- Lamp rated power;
- Rated current;
- Ballast/ transformer type and rating;
- Existence of dimmer, PIR sensor, timer;
- Room type/location;
- Nominal usage as stated by the occupant[2].

An outline of a survey log is given in Appendix B. In addition, a log will need to be taken of the installed plug in data loggers, occupancy sensors and event recorders and these related to the end uses surveyed. An example of this type of lighting audit can be found in EES (2011). This includes key information on usage, dimmers and other related lighting equipment. It is important that this type of lighting audit be conducted on all houses included in any REMP monitoring so that the data can be more accurately scaled up to a national level[3].

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[2] Initial analysis has found that that nominal usage levels for each lamp provide a good basis for estimating overall lamp usage and hence energy consumption. However, correlation of these responses with actual usage through end use metering is necessary for a reasonable number of homes.

[3] Any REMP campaign will necessarily cover relatively few houses and small samples are subject to significant sampling bias unless the data is correctly weighted against a more representative large scale sample.

4 Lessons from the Pilot

Commencing in February 2010, the REMP pilot project undertook monitoring of five houses. This monitoring continued for over a year and included the installation of loggers on each of the switchboard circuits, the 12 key (most used) lights, and 16 key appliances. Also installed were humidity and temperature sensors (both internal and external), in-line gas and water loggers, occupancy sensors in major living areas and hot water temperature sensors – in all there were around 60 individual channels (loggers) per house. The pilot project ultimately collected over 220 million datapoints, and provided both valuable insights into user behaviour as well as highlighting some of the challenges of end use monitoring project challenges.

Lighting is a relatively small but important end use in the residential sector. It has been the subject of a significant number of energy policies over the past 10 years. Inefficient lighting can represent a significant share of electricity consumption (as much as 20%) and there is significant potential to save energy by employing more efficient technologies.

There is no practical way to measure the total light output of a light fitting during normal use. However, the typical luminous efficacy of different lamp technologies is well established, so energy input can be used as a proxy for light output where the technology used in the lamp is known. There are some limitations to this approach, as individual product efficiency within a technology type does vary somewhat and, more importantly, the effect of luminaries and lamp orientation can be significant (in terms of light transmission, distribution and quality).

The most important end use determinants of energy use are the patterns of use (primarily occupancy driven) and the technology used. Therefore a full audit of lights in each house is a necessary starting point. Given that there are so many lighting points in a typical house (in the range 20 to 200, average 50), measurement of all individual light outlets is not practical. However, most houses have lights wired onto one or more separate circuits, so these can be logged at the switchboard. Light sensors on the most commonly used lamps can provide a good breakdown of lighting energy by circuit. Where there is a mix of different lighting types in use, it is important to place selected light sensors in such a way as to help separate out the use of each technology, as far as possible. Plug in lamps need to be measured with separate plug in data loggers.

Key considerations for lighting equipment are:

- Around 85% of lights are hardwired;
- Around 15% plug in, which can be measured with stand alone plug in data loggers);
- Average of about 50 lights per house, so it is only possible to monitor small proportion of all lights individually – target highest usage lights to get good energy estimates (it is probable that a small number of heavily used lights account for the majority of lighting energy);
- Most houses have separate circuits for lighting so it is possible to assess the total energy consumption of all hard wired lights (avoid recruiting houses with highly mixed lighting and power circuits);
- An electrician is needed to install equipment at switchboard;
- Plug in end use metering must be done together with an integrated lighting survey.

Lighting is another end use that is highly variable at user level, both from day to day and across seasons. Monitoring of the REMP homes has found that lighting is strongly seasonal (as expected), so monitoring over a longer period is usually required in order to correct for this affect. Absences during holiday periods can also strongly skew seasonal effects (again this varies a lot by household). A mixture of lighting circuit energy and usage sensors for high use areas in the home together with a comprehensive physical audit appears to be the best compromise for this complex end use.

4.1 Pilot Study Data

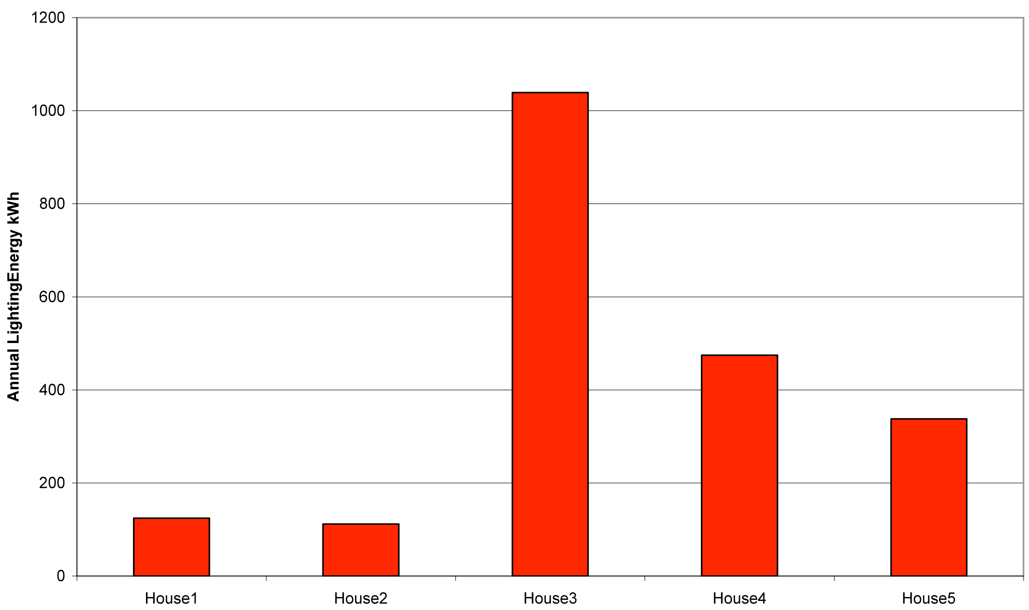
Lighting is an important end use and it is one that is not well understood or documented in Australia. The recent survey of lighting in 150 homes has improved the knowledge of what lighting technologies are installed, but usage factors are still very poorly understood. The REMP end use measurement data set, along with the lighting audit (which intentionally covered the 5 REMP homes) has provided great insight into lighting energy consumption, even if only for a limited number of homes.

Virtually all of the lighting energy can be either measured at the switchboard (where it is in separate lighting circuits, which is common) or via plug in data loggers where the lamplight is plugged into a wall socket. For the REMP pilot, the 12 most commonly used lamps (as reported by the householder) had separate lamp sensors to indicate the on time of those individual lamps – this appeared to provide a good breakdown of energy on the main lighting circuits. It is important to note that dedicated "lighting" circuits usually only have hardwired lights connected to them, but sometimes they may include other hardwired loads like heat lamps (bathrooms), fans and smoke alarms (and possibly some other hard wired loads like security systems). Where a house is being monitored, it is critical to identify all loads on all circuits (not just for lighting, but for all circuits) in a complete audit of appliances and equipment in the home. This includes mapping every light in the house back to the relevant circuit at the switchboard.

Where there is a mix of lighting technologies on a circuit (which is very common), it can be difficult to understand usage patterns without some direct monitoring of the most heavily used lamps. While it is theoretically possible to monitor lighting circuits at high speed (faster than 1 minute intervals) to work out usage of individual lamps from changes in power at the time of switching, this has not been successfully achieved for routine end use measurement campaigns. This technique fails where there are many lamps of about the same power on the same circuit that use different technologies.

As an introduction to the REMP pilot homes, the annual energy consumption for lighting is shown in the following figure for each of the 5 REMP Pilot Homes.

Figure 3: Annual Energy for Lighting – REMP Pilot Homes



The following tables provide some benchmarking of the 5 REMP pilot homes against data from the lighting audit of 150 homes in 2010/2011 (EES 2012).

Table 2: Lighting Characteristics of REMP Pilot Homes vs Australian Average (audit of 150 homes)

REMP House	People	Rooms	Floor Area	Lights	Lights/ sq m	Lights/ room	W/m^2	Lumens/ Watt av	Annual kWh
1	4	12	120.7	30	0.25	2.5	5.0	46.2	124.3
2	4	15	110.6	28	0.25	1.9	6.6	26.7	111.6
3	4	22	210.4	117	0.56	5.3	24.4	25.6	1039
4	1	12	174.3	38	0.22	3.2	9.1	25.9	474.6
5	2	14	116.6	39	0.33	2.8	11.5	22.2	337.8
All (150)	2.84	15.8	157.6	47.8	0.30	3.0	12.7	23.4	??

Table 3: Mix of Lamps in REMP Pilot Homes vs Australian Average (audit of 150 homes)

REMP House	Incand.	Halogen	CFL	LFL	LED	Unknown	Missing	Total
1	4	0	20	4	1	0	1	30
2	4	8	14	0	0	0	2	28
3	15	50	33	15	0	4	0	117
4	9	2	24	2	0	0	1	38
5	7	11	20	1	0	0	0	39
All (150)	10.5	16.1	14.4	4.2	0.7	1.1	0.8	47.8

Comparing the five REMP houses to the 150 audit houses, it can be seen from the above tables that the REMP pilot homes were all quite far from an "average" home in terms of lighting characteristics. This is not surprising as all households are diverse in terms of their lighting systems and their demographic characteristics. So sampling a significant number of homes for end use metering is necessary. But even if 50 homes were covered, there could be significant sample bias.

It is important to note that House 1 was significantly more efficient than average, was smaller than average and had a very low number of lights. This household could be characterised as frugal. House 2 also had very few lights and could also be characterised as relatively frugal. Houses 1 and 2 had quite a low density of lights per square meter and a very low power density in terms of Watts/m^2. Houses 2 to 5 were all similar weighted average efficiency in terms of lighting (average Lumens per Watts of all lights installed). House 3 was larger than average and had more lights than average (a significant number of which were quartz halogen downlights) and had a substantially higher power density in Watt/m^2 than average, so this explains the higher lighting energy use. House 4 is a single person who keeps unusual hours and this probably explains that low lighting energy given the house size and overall efficiency is close to average. House 5 is relatively small with 2 occupants, which explains the lower than average lighting energy. Houses 4 and 5 have about 20% fewer lights than an average home.

All REMP houses (except House 3) had fewer incandescent lamps than average and fewer extra low voltage halogens lamps than average. All REMP houses had substantially more compact fluorescent lamps than average (except House 2 which had an average number of CFLs). This may reflect to some extent participation of these households in efficiency programs offered by Moreland Energy Foundation[4], who recruited the houses for REMP.

[4] Moreland Energy Foundation is not for profit organisation dedicated to developing sustainable energy solutions in the Melbourne area.

Of course the lighting energy consumption depends on the hours of use of each of the lights. During the lighting audit, the householder was asked to rate their use of each light into one of 4 categories – frequent long, frequent short, occasional and rare. Some ex post analysis of the REMP data and the lighting audit data was used to characterise the usage of each of those lamps that were individually tracked as part of the REMP monitoring and compare this to the householder rating for those lamps. Analysis has shown that for the REMP pilot homes at least, this subjective user rating appears to provide a reasonable basis for estimating total household lighting energy (and approximate seasonal energy). So an important focus for any further end use monitoring will be to firm up estimates of usage associated with each of the user based usage ratings (and perhaps to provide more guidance to householders on what these ratings mean in practice).

The following figures illustrate some of the data collected from the REMP pilot homes in 2010/2011. Note that the Y axis scales is the same for each house for summer (January) and winter (July). Each charge is a time of day average for a whole month. However, the scale changes dramatically for each house as the maximum power levels differ dramatically between houses due to the installed lighting stock. As expected, summer lighting is substantially less than winter lighting, which is discussed in more detail later. Note that in some houses the low usage is partly reflective of absences, which have not been corrected. So this data is useful as it shows there is a strong time of day usage pattern for lighting, as well as a strong seasonal pattern for lighting. It also shows that the majority of lighting energy is consumed by fixed lighting circuits (rather than plug in lamps).

Note that these figures only show dedicated lighting circuits in aggregate plus separately monitored plug in lamps in each house (the lighting audit showed an average of 7 plug-in lamps per house). The 12 individual lamp monitors used in each house can provide a more detailed breakdown of energy by lamp within each of these dedicated lighting circuits (and in most cases can allocate the majority of energy use to individual lamps), but this has not been shown in these figures.

Figure 4: Time of Day Lighting Breakdown for January – REMP House 1

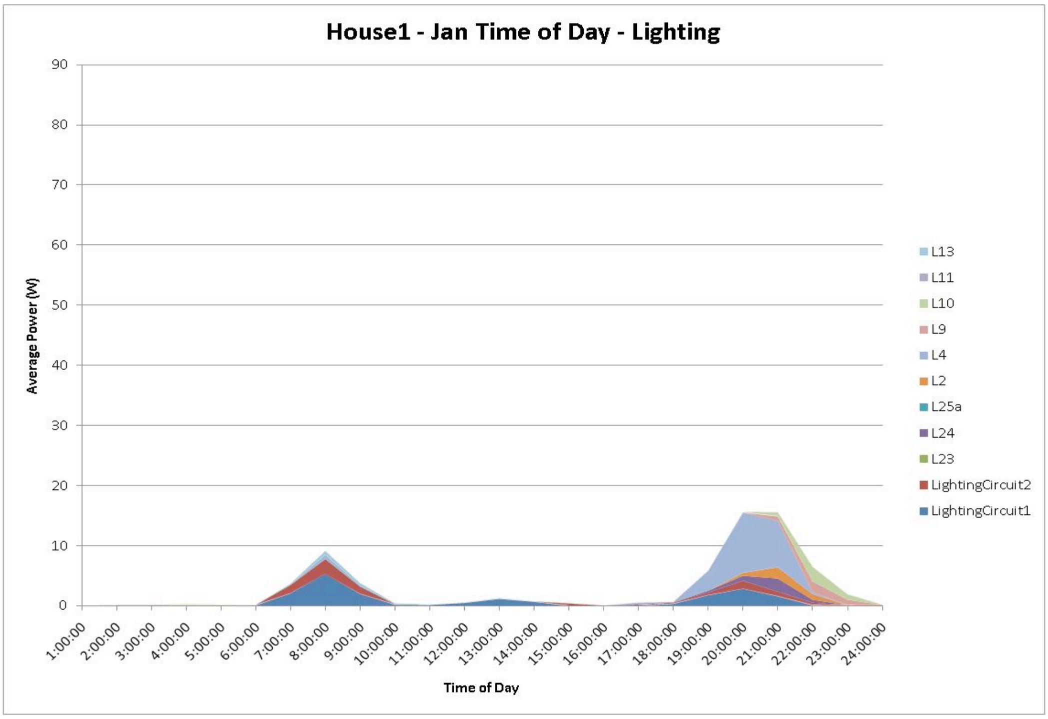


Figure 5: Time of Day Lighting Breakdown for July – REMP House 1

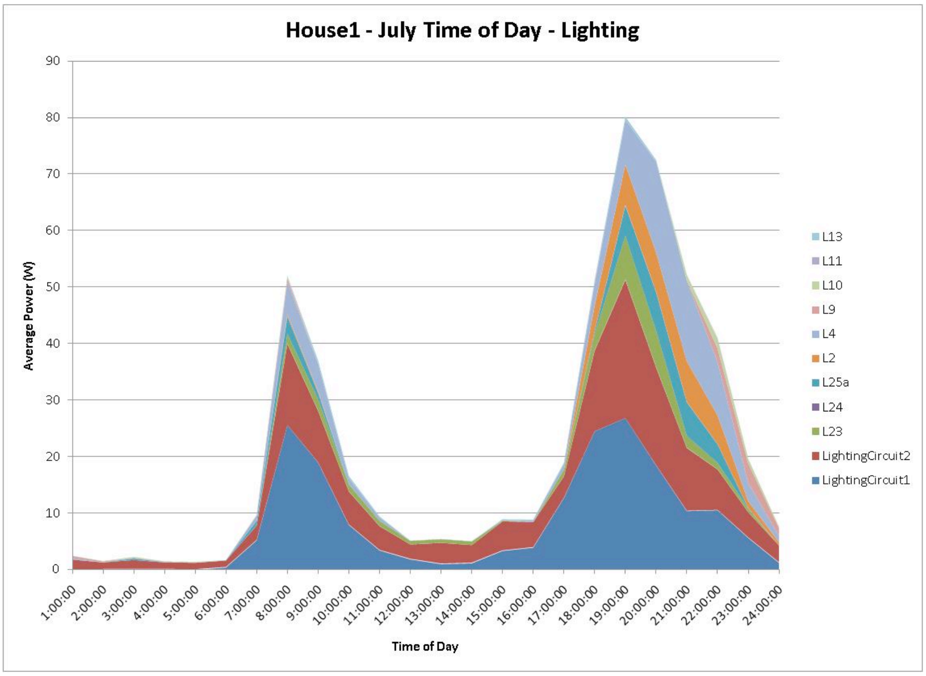


Figure 6: Time of Day Lighting Breakdown for January – REMP House 2

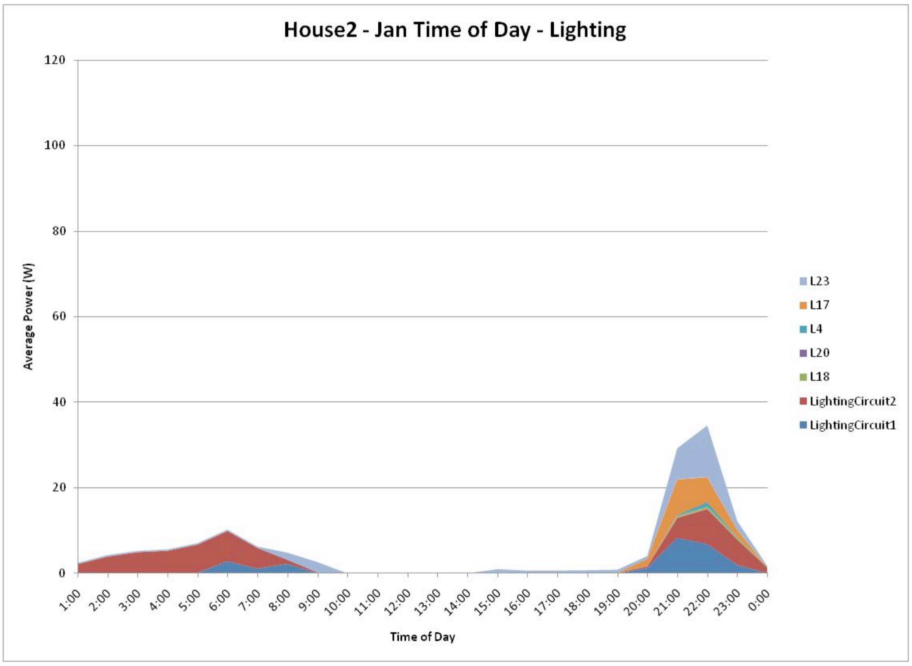


Figure 7: Time of Day Lighting Breakdown for July – REMP House 2

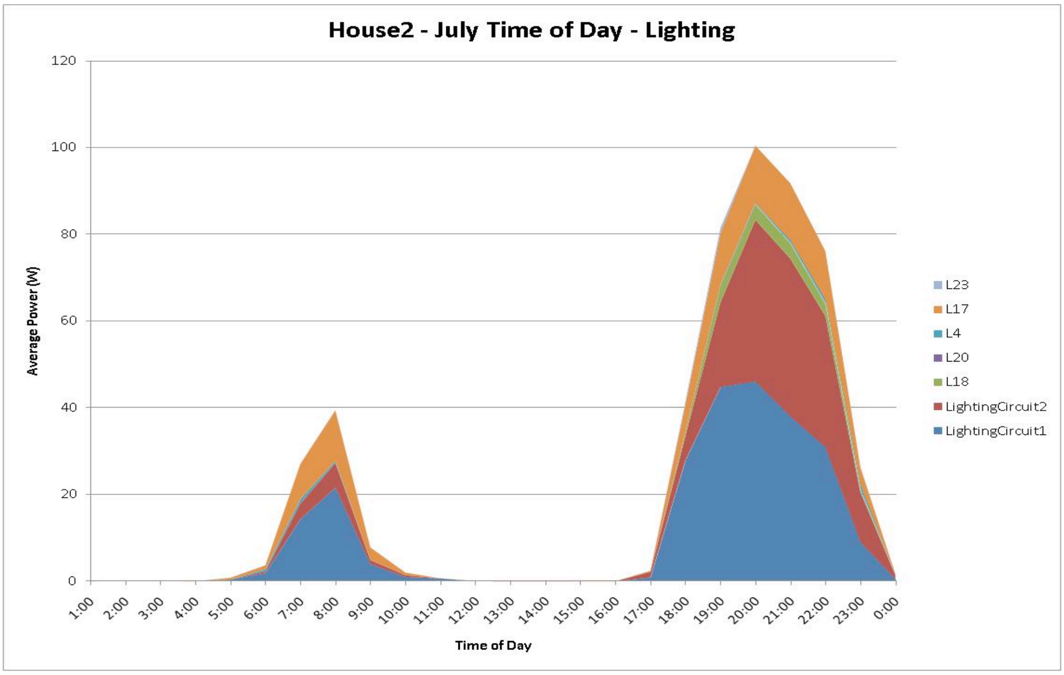


Figure 8: Time of Day Lighting Breakdown for January – REMP House 3

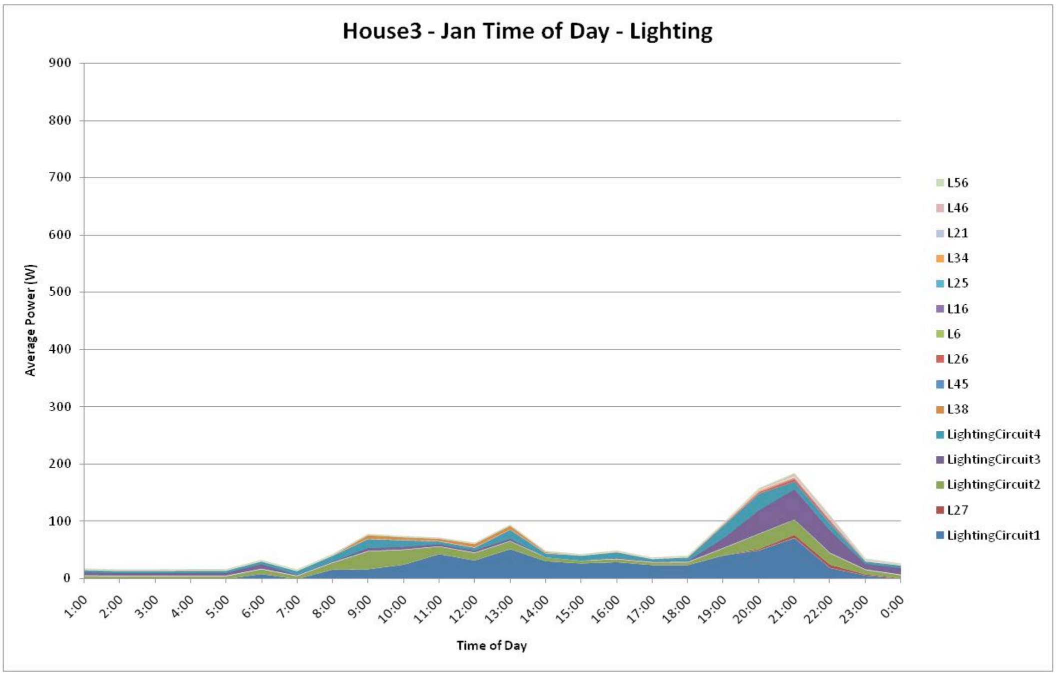


Figure 9: Time of Day Lighting Breakdown for July – REMP House 3

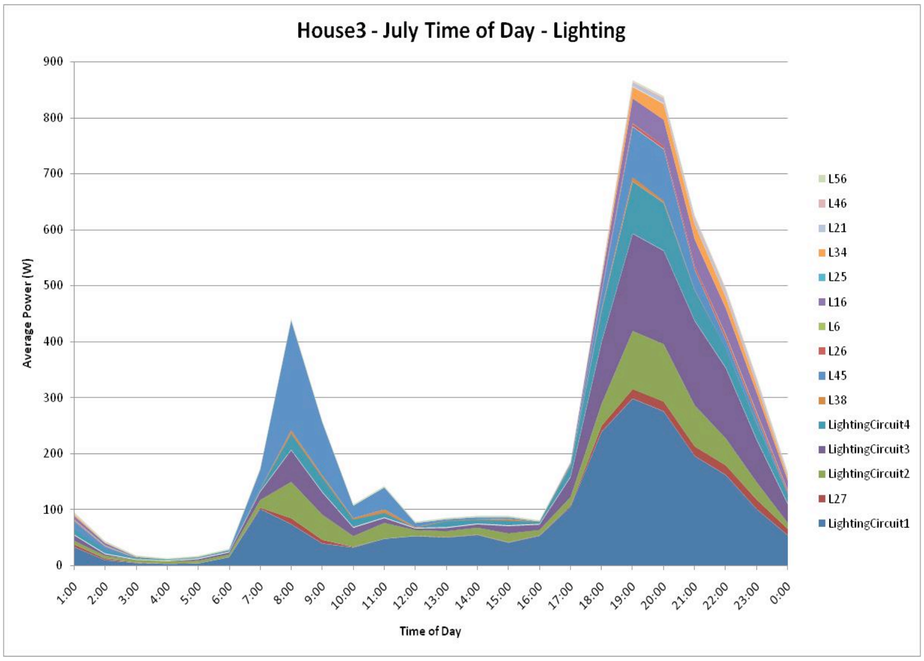


Figure 10: Time of Day Lighting Breakdown for January – REMP House 4

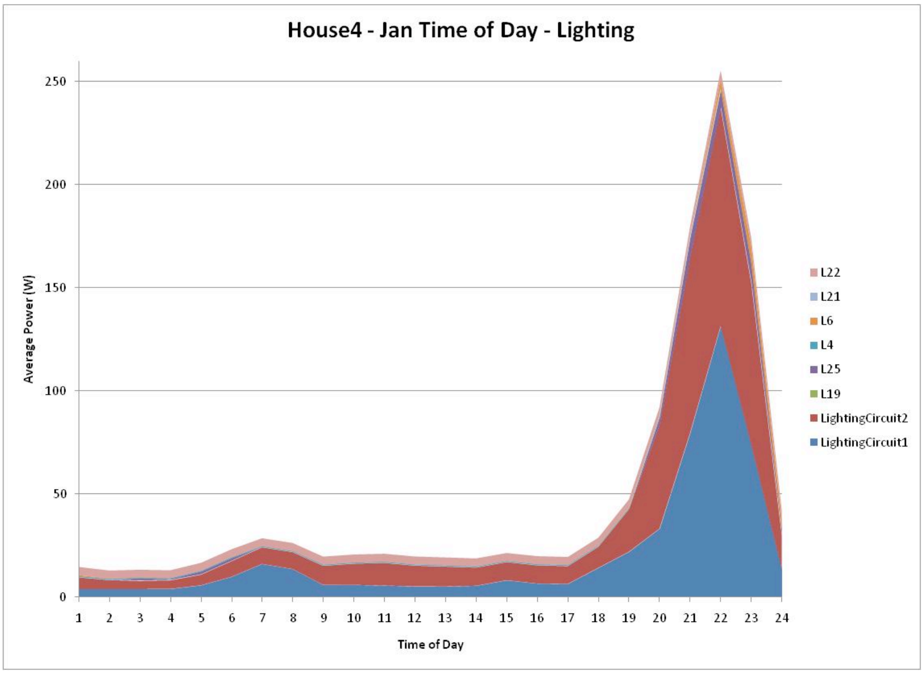


Figure 11: Time of Day Lighting Breakdown for July – REMP House 4

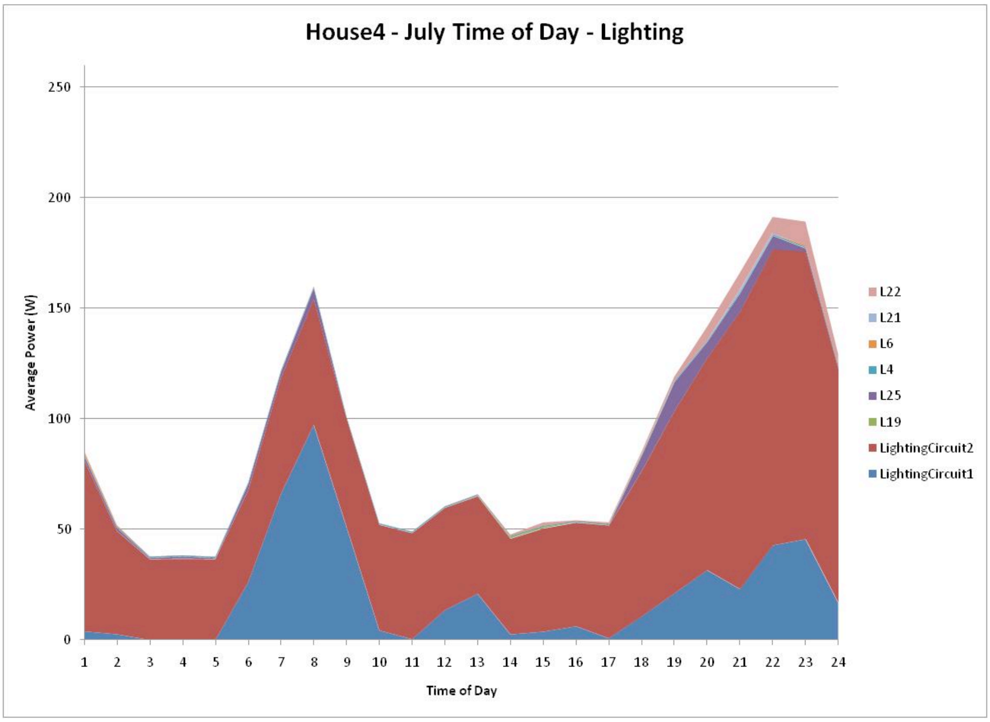


Figure 12: Time of Day Lighting Breakdown for January – REMP House 5

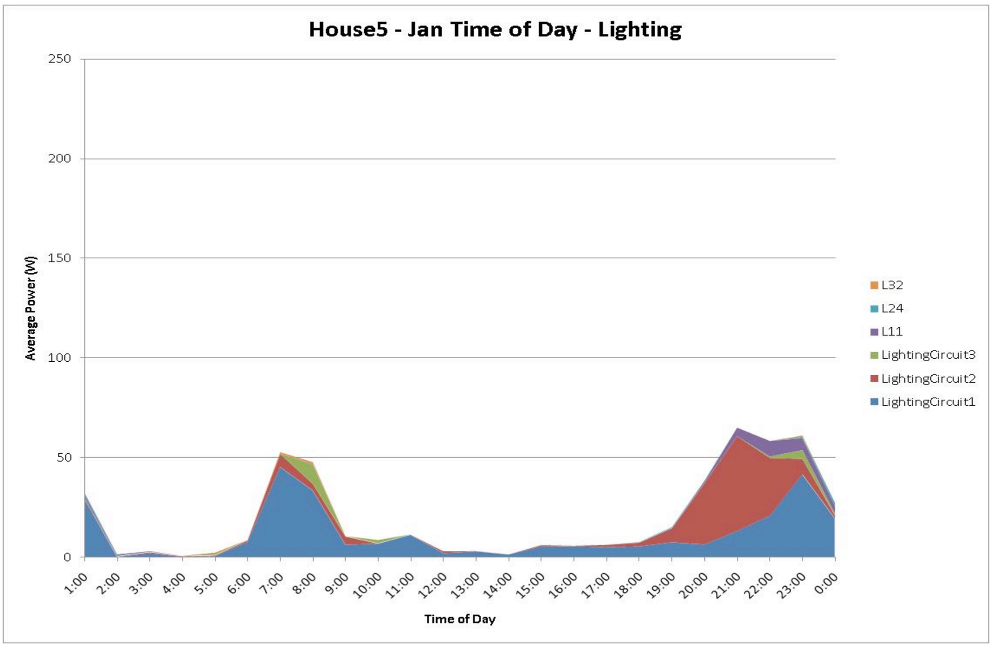
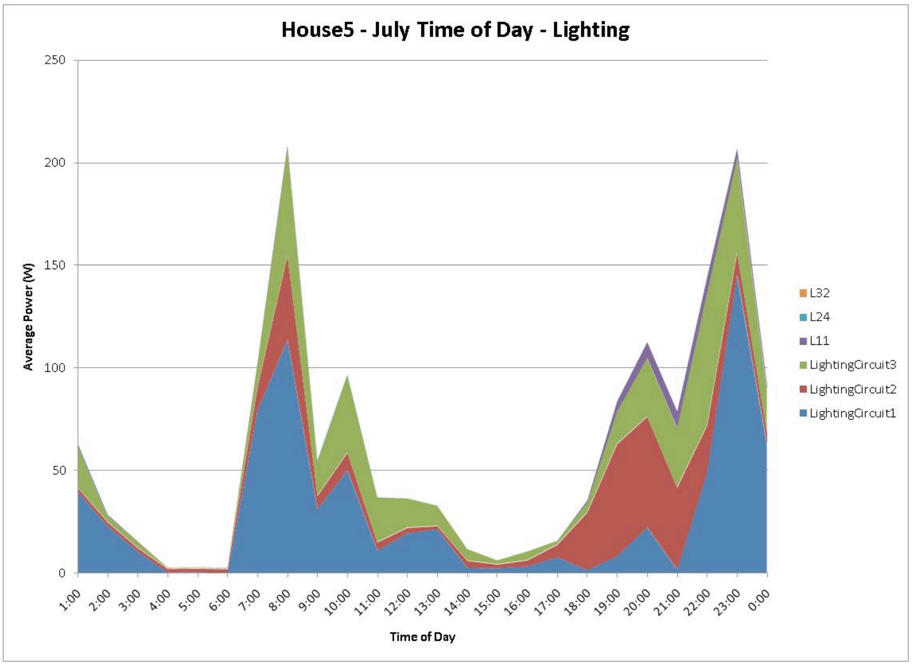


Figure 13: Time of Day Lighting Breakdown for July – REMP House 5



The following figures show daily total lighting energy (in Wh) for the REMP Pilot Homes. These figures are useful as they illustrate the variability from day to day of total lighting energy under typical usage conditions. They also show (in general terms) the strong seasonal effects on lighting energy (although there are many random daily variations overlaid onto this season pattern). The strong effect of absences is also obvious if these were included in usage patterns. Note that all Y axis scales are different due to the large differences between houses.

Figure 14: Daily Lighting Energy Consumption for 1 Year – House 1

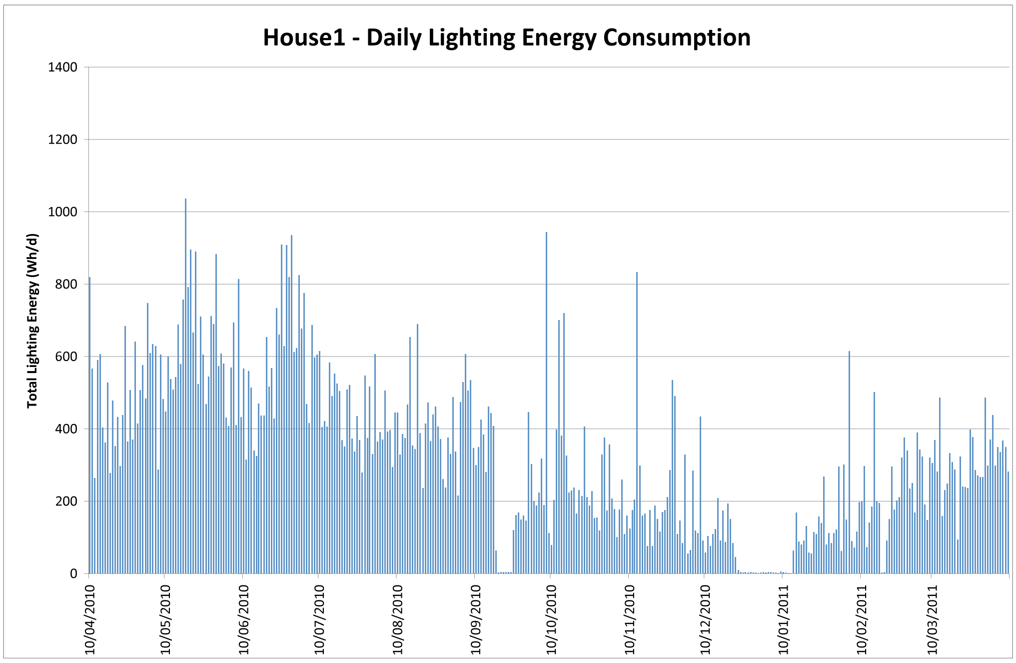


Figure 15: Daily Lighting Energy Consumption for 1 Year – House 2

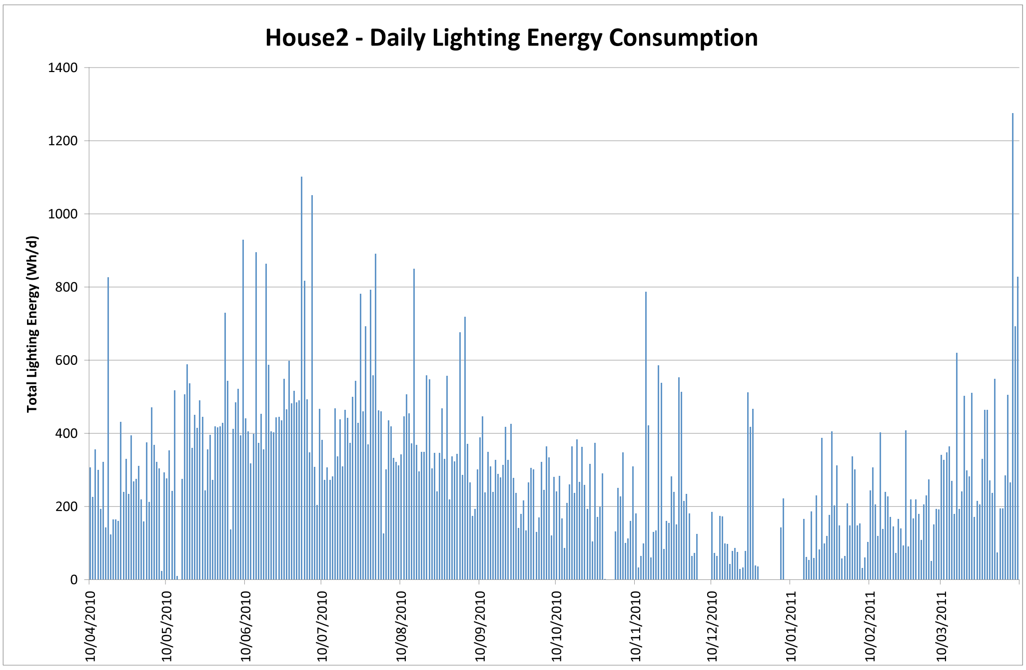


Figure 16: Daily Lighting Energy Consumption for 1 Year – House 3

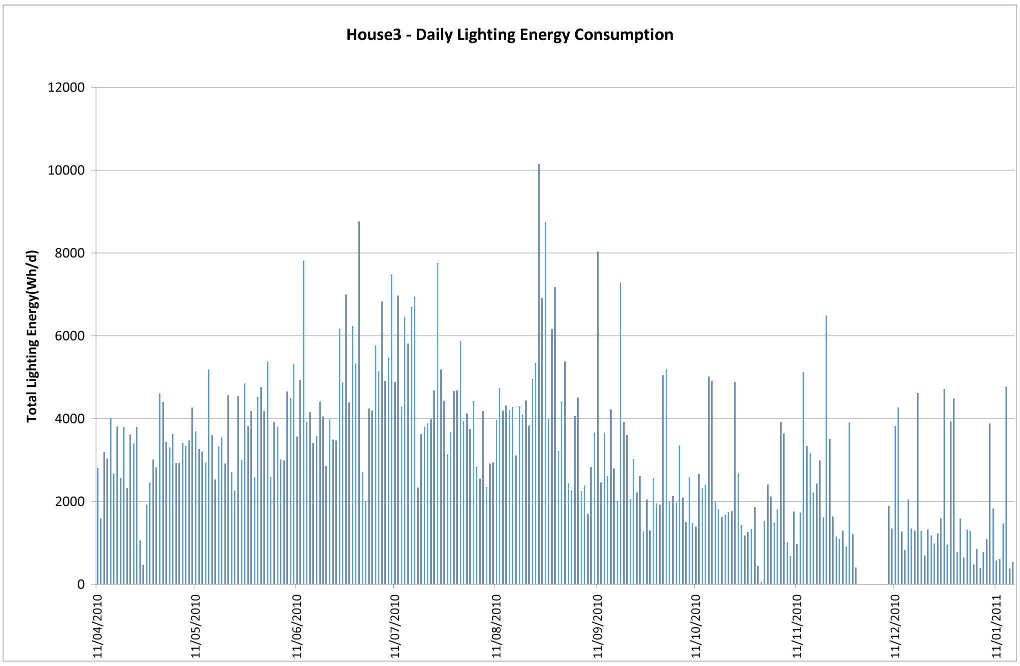


Figure 17: Daily Lighting Energy Consumption for 1 Year – House 4

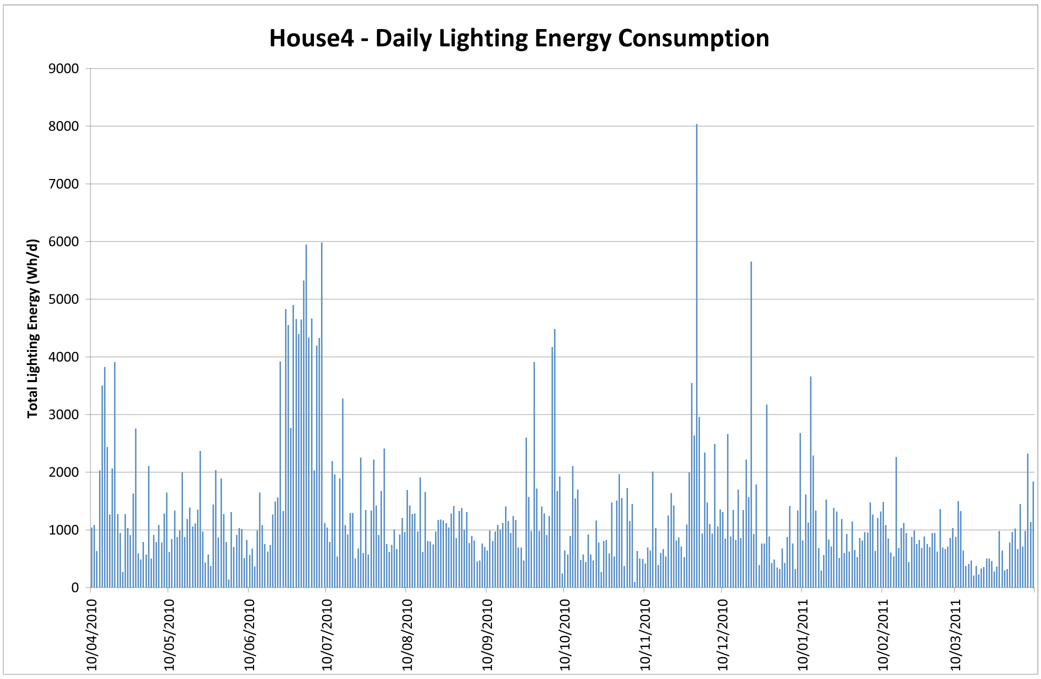
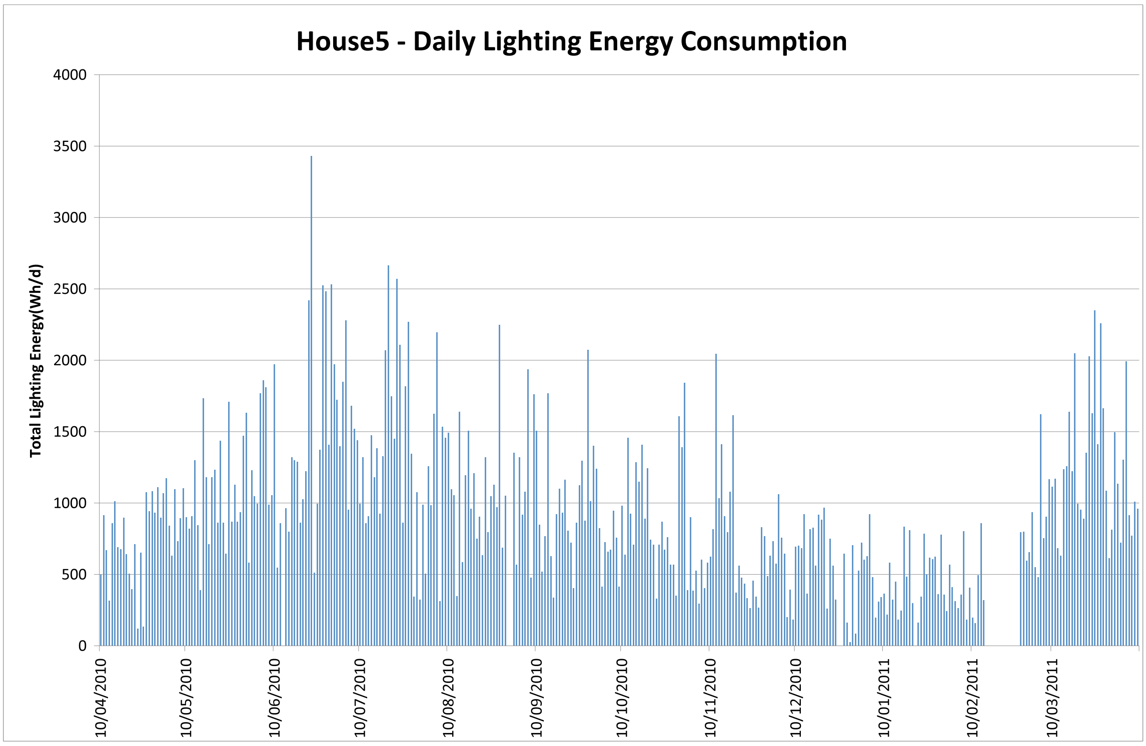


Figure 18: Daily Lighting Energy Consumption for 1 Year – House 5



Further analysis on the annual energy showed that there was a very strong seasonal effect (as expected). This is also evident in the time of day figures above for July and January shown previously. Monthly lighting energy was examined and the relative monthly energy was plotted against the month with the highest lighting energy (shown as a ratio of 100%).

Figure 19: Relative Monthly Lighting Energy for All REMP Pilot Homes

All houses had their peak lighting load in July (except for House 1 which occurred in May). The month with the lowest lighting energy was generally from December to February, but the minimum was less distinct and regular. All houses showed a substantial decline in lighting energy from winter to summer, with typical energy summer energy consumption at 30% of the winter peak. This has important implications for any end use measurement program that does not include the summer and winter period in each house. If only short periods are to be monitored (eg short periods for a larger number of homes), there needs to be careful consideration on how to characterise and normalise for the seasonal effects. A simplistic approach would be to fit a sine wave function to 1.0 in winter in July and 0.3 in summer in January. Of course individual houses may vary from this "shape" considerably (House 4 is a good example above) so a larger annual sample would be necessary (noting this is based on a sample of 5 houses only).

The other important consideration is that absences have a substantial impact on the lighting energy and usage patterns. Generally, when occupants are away on holidays, no lights are used (an exception may be some plug lights on time clocks, but this is not common and the energy would be small). This would not be of great concern of a sample size of several hundred was being examined – but it would mean that the usage levels for lights had holiday absences "built in" to the monitored values (ie usage in January is often very low because people often go away for several weeks and because the days are long and lighting requirements are low). For a smaller sample size, it may be more robust to determine that seasonal usage patterns correcting for actual absences (determining usage patterns assuming that someone is present for 365 days a year) and then apply absences more consistently to the whole sample on the known frequency from a larger sample. For example, if there were 30 houses in a monitoring sample and 3 households happen to be away for July (which may be uncharacteristically high), this would depress the usage factors for July unless there was a correction for these absences.

Some initial review of the data did not reveal a strong effect from daylight saving, but this is partly because the day to day variation in energy has a large random component and partly because the REMP monitoring started and ended near the autumn time change (so only one time change was clearly included). It would appear that the effect of daylight saving is also hard to detect as this occurs at a time of the year where the change in day length is fastest and the background change in lighting use is also rapid. Another consideration for an expanded REMP program is that the variation of day length (and hence lighting demand) will be different in different cities (eg Brisbane has no daylight saving and the variation in day length through the year is much less than in Melbourne, where the REMP pilot homes were located).

Substantial data from the REMP pilot for electrical appliances, including some plug lighting, can be found in the paper titled *REMP – General Introduction and Overview*. Information on the audit of lighting in Australian homes can be found in EES (2011).

5 References

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Appendix A– Policy Discussion

Policy Background

Lighting is unique amongst the electrical appliances in a household when it comes to regulatory control of energy use. There are two levels of regulatory control: one is the efficiency of the individual lighting products (lamps, ballasts, etc) and the other is the design efficiency of lighting installations. The Minimum Energy Performance Standards process covers the individual lighting products and the Building Code of Australia covers the efficiency of lighting installations in new buildings.

It is important to note that at this stage no information has been or is currently being gathered on the *lamp technology mix* and transformation progress. This information, as well as any perceived barriers to lamp technology transformation, is critical to the development of information dissemination programs for the general public in order to achieve optimal lamp replacement solutions. Projects such as household lighting audits and REMP campaigns provide an opportunity to collect this type of data and to more fully support regulatory and advisory programs on lighting.

Minimum Energy Performance Standards

MEPS for lighting is a program which is removing the lowest performing products/technologies (in terms of efficacy) where there is an acceptable alternative technology with which to replace it.

The most recent lighting MEPS eliminates some types of incandescent lamps. The alternative products utilise three main technologies: tungsten halogen (nominally 30% more efficient), compact fluorescent (nominally 3-4 times more efficient) and LED (nominally 3-4 times more efficient).

Building Code of Australia – Efficiency of Lighting Installation

The Building Code of Australia energy efficiency changes will now capture all residential buildings (ie including Volume 2) in terms of regulating installed lighting. The BCA 2010 requirements have been progressively introduced in various states from May 2010, with completion from May 2011.

The BCA is a performance based code which regulates lighting energy use by limiting *installed* (ie circuit connected) lighting power. This then becomes a de-facto regulation of residential lighting design. Portable lighting, such as floor based standard lamps and furniture based desk or task lamps, collectively known as plug load lighting is not captured within the BCA regulation. This is due to it being virtually impossible to regulate and the general premise that *plug load lighting is deemed insignificant* in the lighting energy consumption of a house. With the 2010 BCA lighting provisions encompassing residential lighting where there is currently no recommended minimum illumination levels, there is the potential for installed lighting in residences to be minimised to achieve the prescribed energy levels, and a corresponding greater reliance placed on (unregulated) plug load lighting to meet the lighting needs and preferences of the occupants.

Energy use is influenced by two factors; appliance power and hours of operation. Since there is no "standard" time of operation (incorporating "*hours of use*" and "*time of day of use*") and therefore predictor of energy use for lighting in residential buildings, due to the factors outlined in Section 2 (of this paper), installed lamp power density (LPD) and illumination power density (IPD) in W/m^2 are specified as the regulated metrics in the BCA.

Lamp Power Density is a metric which includes only the power of the lamps whereas Illumination Power Density covers the entire lighting system power which includes ballasts, transformers etc.

Illumination Power Density allows for adjustment factors which effectively give concessions to the allowable power density due to control devices (eg manual dimmer, occupancy sensor) being installed which are broadly recognised as reducing the energy consumption of the light when compared to the same scenario without the control device installed.

The value of the individual adjustment factors are the estimated probable energy savings based on the use of a particular type of lighting control technology. For example an occupancy sensor's adjustment factor is based on the *estimated "wasted" energy* of an unoccupied room which has the lights remaining on. All of these adjustment factors are based on the "best estimate" by the Australian Building Codes Committee. {As examples, for non residential buildings, the BCA has adjustment factors for manual dimmers of 0.95 (ie saves 5% of the energy consumed by the same lighting circuit without the dimmer installed), and for occupancy sensors a value of 0.80.}

It is assumed that these values for the adjustment factors would have been used in the regulatory impact assessment to determine the cost benefit of introducing the particular regulation in the BCA.

These kinds of regulatory frameworks would benefit from hard defendable data as a basis for justification.

Building Code of Australia – House Energy Rating

The upcoming mandatory disclosure of house energy performance by way of a star rating (ANZHERS) will also include lighting. The development of the algorithm to determine the contribution of lighting to the house energy performance required an assignment of hours of use of lighting for each type of room. Currently, the hours of use of lighting in key rooms (eg kitchen, living, bedrooms) has been estimated from overseas studies

Appendix B - Data Discussion for Lighting

(Refer to separate paper for overall data management strategy)

Standard Processing and Outputs

Once the data has been collected it will need to be checked, processed and saved to a database, which will be described in a separate REMP data management strategy document. Checking should involve the following tasks:

- Ensure data present for all time stamps and value fields;
- Identify unusual zero values;
- Identify outliers;
- Visual check of graphed data to identify unusual data points.

One challenge of this analysis will be to turn monitoring data, survey results and audit information into the required lighting parameters, given that not all lighting points in the home will be monitored. Overall lighting load will be monitored at the switchboard, and this provides an opportunity to adopt a top-down / bottom-up approach to constructing the lighting energy profile for the house and all its lighting points.

The objective of data analysis is to convert raw data into the parameters listed earlier. The raw monitoring data will take the following form:

- Time-based electrical data points for power, current, VA, volts, etc. for various lighting points (plug-in and lighting circuits);
- On/off event times for various light fittings;
- Time-based binary information for room occupancy (under investigation).

Post processing for event logger readings, the data will require the on/off events readings to be transformed using a time-based series of “lamp on” and “lamp off” multiplying by the power value for the corresponding lamp power (or lamp + ballast power) from the lighting audit (inventory) to generate the energy consumption over time.

The first standard output analysis that will be most useful will be to create an “average household profile”. This should be based primarily on switchboard data, and some breaking down of this into individual rooms may be possible, depending on which rooms are monitored and how lighting is wired.

Various average profiles can then be generated, eg a typical day, typical week day, or weekend day. This and other standard outputs are listed in the table below.

Table 4: Standard Lighting Analysis Outputs

Input	Analysis	Output Parameter
Time profile		Hours of use (daily, seasonal pattern)
Time profile		Time of day of use (seasonal pattern)
Time profile	Build algorithms to look for changes in state. Easy to get from on/off loggers.	Frequency of switching
Time profile (post-dimmer voltage)	Build algorithm to look at post-dimmer voltage readings to determine dimming percentages (time-based).	Dimming levels (manual dimmers)
Time profile	Integrate over time	Energy consumption
Time profile	Multiply by efficacy (from typical efficacy values)	Lighting service (eg light output or efficacy)
Time profile (VA, power)	Compare VA and power, where possible	Total lighting power factor & total residential power factor (all appliances)
Time profile (room occupancy)	Build algorithms to look for changes in state. Easy to get from on/off loggers.	Room occupancy
Lighting audit		Typical household lamp technology inventory (overall and by room type)
Lighting audit		Prevalence and proportion of plug load lighting

Enhanced analysis

Once a detailed and consistent dataset has been assembled (ie to incorporate physical measurements and social information) it is relatively simple to undertake a statistical investigation to explain lighting energy consumption.

Such an examination can include looking at explanatory variables and indicators such as:

- Energy consumption per floor area;
- Energy consumption per number of occupants.

This type of analysis, though relatively simple, can be very useful and has been used as the basis for energy modelling in some countries, eg UK such an approach for its BREDEM modelling.

However, this type of analysis can be as detailed as the amount of data collected, so it will be possible to investigate the influence of other factors on consumption and lamp technology installation levels, eg household income, education. For such an analysis, the approach will be to download a consistent dataset from the REMP database and perform a multivariate analysis. The analysis opportunities are endless once a harmonised and integrated database has been established (and the process of collecting, cleaning and uploading the data to the database).

Note that EES (2008) models lighting energy consumption using the following parameters (many of which are assumed):

- Technology efficacy (from product specifications);
- Typical lighting levels (lux);
- Resulting power density for each lighting type (calculated);
- Technology share by floor area for living and non-living areas;
- Average floor area per house (from building stock model);
- Usage (assumed).

REMP – Lighting Data Collection and Analysis

www.energyrating.gov.au

A joint initiative of Australian, State and Territory and New Zealand Governments