Dealing with the Downlight: Australian Residential Lighting Discoveries, Challenges and Future Directions

Jack Brown and Lloyd Harrington, Energy Efficient Strategies
Steven Beletich, Beletich Associates
David Boughey, Australian Department of Industry

ABSTRACT

Historically, Australia's lighting energy consumption was estimated at between 8% and 15% of the average household electricity budget. Whilst tungsten-incandescent bulbs have been largely eliminated as a result of the introduction of MEPS, Australians have a love affair with 12V halogen downlights - hardly better in efficiency terms. Unfortunately, the extent of this obsession was unknown until recently.

In 2010, to fill this knowledge gap, the Australian Government completed two studies:

- For the first time, a residential study comprehensively audited Australian home lighting stock. Completed for 150 homes nationally, data on room characteristics, lamp input power, and technology attributes were recorded.
- The REMP Pilot covered five Melbourne homes. This monitored a representative cross-section of lights for each house every minute, and the total lighting energy at each switchboard. A rich dataset was generated, allowing for analysis of lighting user interactions, and illuminating the holy grail – lighting hours of use.

In the 2000's, 50 Watt downlights began to dominate the lighting makeup of Australian homes. Due to their narrow beam angle, many are required to light a space, producing increases in lighting energy consumption and cost. In 2011, the Australian lighting industry suggested a lamp power limit be introduced – 37 Watts per lamp, and in 2012, a MEPS was altered to enact this change.

The makeup of Australian residential lighting is again changing. LED technologies are rapidly transforming the marketplace and our homes, particularly for downlights, which is reducing overall energy consumption, but generating new policy challenges for lighting in Australia.

Introduction

Lighting is used by different users for different reasons, and while at the most basic level, the utility of illumination is the primary purpose of any lamp, in practice it is never that simple. A lamp in a house could be fixed or plug in, it could be installed for tasks, general illumination or mood lighting, it may have a fitting that is made for only one technology type. Different colours, shapes, Wattages, caps, fittings and technologies – all play a part in how the lighting in a home is selected, used and performs. While in the past, householder choice was limited to incandescent or linear fluorescent lamps, in more recent times the increased penetration of compact fluorescent bulbs, halogen types and LED lamps have made lighting a sometimes confusing topic.

Decisions made at the construction stage of a home can mean it is difficult for the lighting in a house to be easily changed, this is especially true for flush mounted fittings or fittings that are made for a lamp of a certain technology. In Australia, while there are still many general service lighting (GLS) fittings installed in homes which can accept either a bayonet or Edison screw type cap, there seems to be an increasing prevalence of flush mounted downlight and high intensity halogen lamp types. The increasing penetration of halogen lamps in homes is causing concern amongst policy makers, as these latter types of lighting tend to have a higher power consumption than alternatives, and interchangeability is restricted by voltage and installation characteristics.

Lighting Efficiency

Lighting can be a difficult medium to understand and put into an efficiency context. The term ‘efficiency’ (power output ÷ power input) is misleading in a lighting sense, rather ‘efficacy’ is the correct term (light output ÷ power input). *The higher the efficacy (Lumens/Watt), the more effective the lighting source is at converting energy into light*. Lumens are a measure of the visible light emitted from a light source.

It has been known for a long time that the incandescent technology is a relatively inefficient way to create light - light is produced using a simple tungsten filament, along with a lot of heat. Policy makers were aware of this, and in 2007 in an attempt to increase the efficiency of lighting in Australia, the introduction of Minimum Energy Performance Standards (MEPS) for a range of incandescent globes was announced by the Australian Government (DI 2014). Implemented in 2009 and coupled with MEPS on the efficacy and quality of replacement compact fluorescent lamps (CFLs), this move was found to be extremely successful at lowering the general lighting energy profile of Australian homes. Alongside this, however, the popularity of low voltage downlights (many of which remained compliant with MEPS at this time) continued to increase.

Flush mounted low voltage (12 volt) halogen lamps or ‘downlights’ give a warm, sparkling, intense light that interior designers love. Like incandescent lamps, they use a tungsten filament, although the capsule also contains a small amount of halogen gas to increase lifetime and operating temperature. Anecdotally seen by users as a form of general room lighting, downlights actually perform better as a task light, as the comparably narrow beam angle means large quantities of lamps are needed in a space if used for room lighting. Houses have been found with over 200 downlights installed, an effective load of almost 13kW (50W lamp + 13W transformer losses) (E3 2012).

The most common form of downlight historically employed a 50 Watt lamp and transformer – either ferromagnetic or electronic. Ferromagnetic transformers can consume up to 15 Watts, meaning the whole installation may use 65 Watts. For a single lamp this wouldn’t be problematic, but when this technology is normally installed in at least banks of two (using one switch) and commonly installed as banks of four (again with a single switch and often in high use areas), household lighting power consumption can increase markedly. The emerging trend of mass downlight installation was known of by policy makers, however at the time of the introduction of the MEPS in 2009, an effective and efficient alternative was not yet readily available at an affordable price that would allow these lamps to be phased out. The associated use of transformers, not always compatible with alternative lighting and often hidden in ceilings, also made transition to energy efficient more difficult for the average consumer.

2010 Residential Lighting Study

Commissioned by the Australian Department of Industry, the 2010 Residential Lighting Report[1] was the first comprehensive lighting audit of the Australian residential sector. Prior to this study, not a great deal was known about Australia's lighting energy consumption or the lighting technologies that made up the stock of lights. Estimates had put lighting at 8% to 15% of the average household electricity budget, depending on the makeup of installed technologies and user behaviour (EES 2008).

The achieved objectives of the study were to:

- Document the characteristics (lamp type and technology, lamp shape, fitting type, motion sensor function, dimmer function, cap type, transformer type, power) of all lamps in found in a house;
- Identify behavioural trends in the use of each lamp found;
- Measure and document the lighting for each room type in the house;
- Identify forms of lighting that are of particular concern (now and into the future) when considering potential usage patterns, lamp power and ownership trends; and
- Provide a solid benchmark of residential lighting characteristics and a sound basis from which to evaluate the impact of future proposed lighting regulations.

Coupled with a standby survey of all the appliances in each house audited, a general goal of the audit was to obtain as much information as possible concerning lighting.

The survey covered 150 houses in the three most populous cities in Australia – Brisbane, Melbourne and Sydney. The key results of the study were:

- A total of around 7,200 individual lamps were documented;
- An average of 48 lamps were found per house, of which 12 were low voltage halogens;
- An average of 30 switches were found per house;
- An average rated power of 42 Watts was found per lamp;
- An average of 15.4 rooms (defined areas) was found per house, making a total average floor area of 140 m^2 (indoor spaces) per house;
- The number of lamps per m^2 was 0.3, with a lamp power density of 10 Watts/m^2 for indoor rooms[2];
- An estimate of the overall lighting level (if all lamps were on) was found to be 230 Lumens/m^2 (Lux).

Figure 1 below shows the distribution of the total lamps per house, for all houses in the study. Although the majority of houses had between 30 and 60 lamps, it can be seen that the spread of total lamps goes well into the hundreds of lamps per house.

[1] This section draws heavily from reference (E3 2013), including all figures and tables. *Please note – the authors of this ACEEE paper were also heavily involved in the production of this reference.*
[2] The latest upgrade to the Building Code of Australia (2010) now includes a light power density requirement for new builds of 5 Watts/m^2 (ABCB 2010).

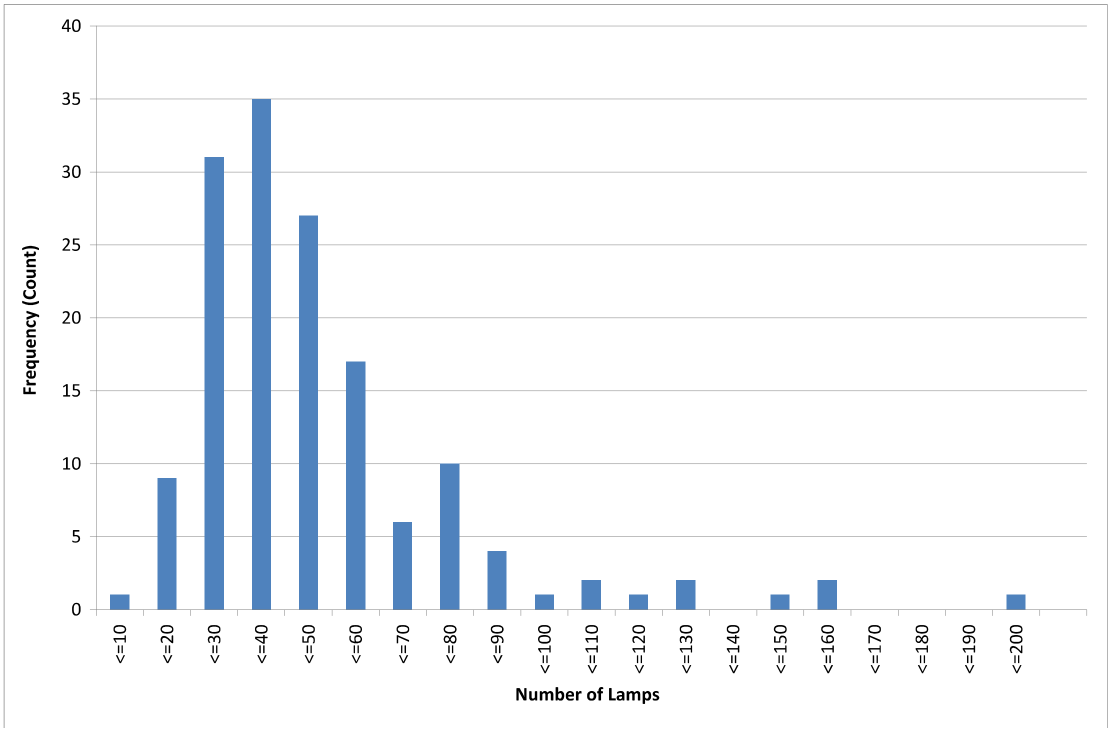

Figure 1.Distribution of total lamps per house, for all houses. *Source*: E3 2013.

Figure 2 shows the floor area versus the total lighting Watts for all houses in the study as a scatterplot, and includes a linear trendline to show any correlation. Quite obviously, as floor area increases, so do the total Watts found for houses. This would seem logical, as more rooms would require a greater number of lights, as stated earlier though, just considering power for lighting doesn't give the full picture. Figure 3 shows the floor area versus the total lighting efficacy (Lumens per Watt) for all houses in the study. In contrast to Figure 2, there doesn't seem to be a correlation between floor area and lighting efficacy.

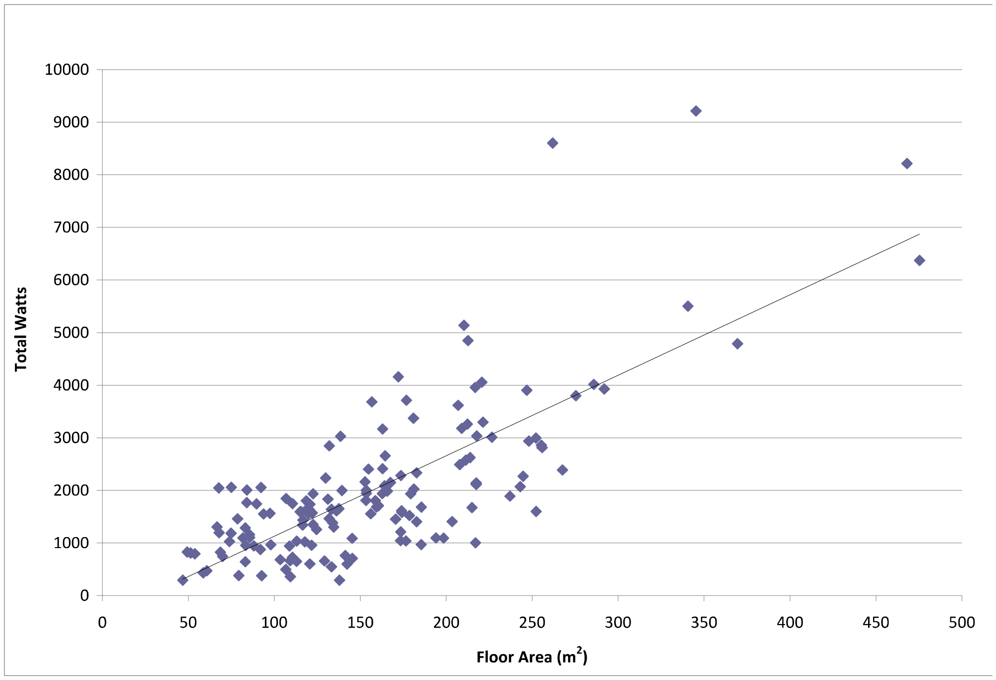

Figure 2. Floor area versus total lighting Watts, for all houses. *Source*: E3 2013.

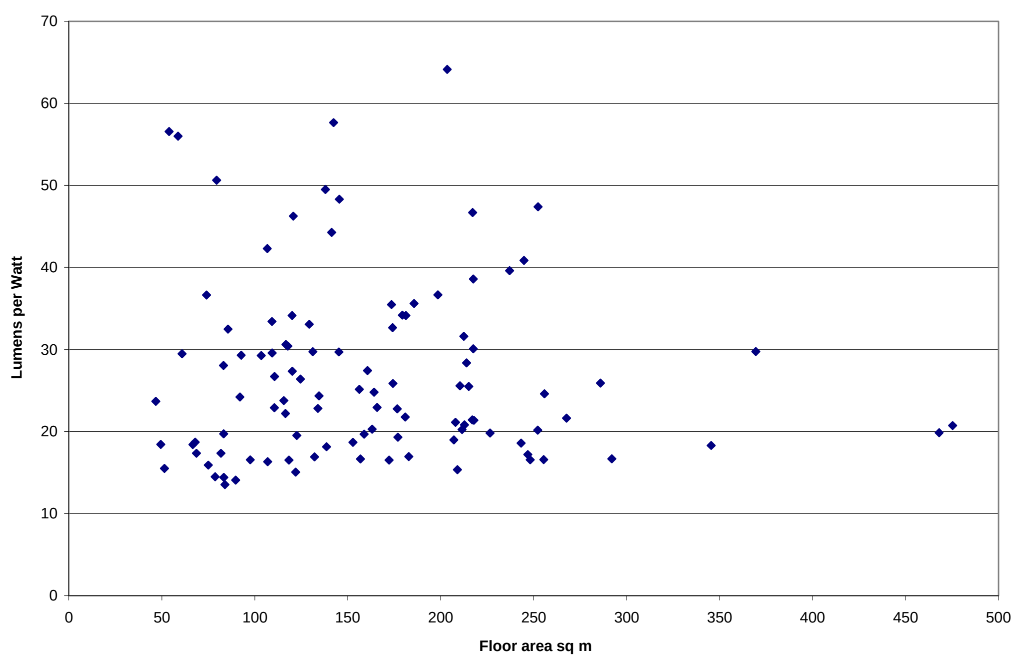

Figure 3. Floor area versus total lighting efficacy, for all houses. *Source*: E3 2013.

The survey findings for each lamp technology is shown in Table 1. The point of interest that should be drawn from these results is that a quarter of all lamps were low voltage halogen downlights. They are clearly the problematic technology in terms of power usage, given that most of the tungsten filament incandescent technology had been banned, with this slowly working through the installed stock as time passes.

Table 1. Survey findings by lamp technology

Lamp Technology	Share of All Lamps*	Average Power	Share of Total House Watts*	Share of Total House Lumens*	Assumed Lumens/Watt
Compact fluorescent	30%	14 Watts	10%	23%	55
Low voltage halogen	25%	44 Watts	28%	19%	17
Incandescent	22%	73 Watts	38%	19%	12
Mains voltage halogen	9%	75 Watts	15%	10%	16
Linear fluorescent	9%	33 Watts	7%	27%	90
LED	1.5%	5 Watts	0.2%	0.5%	60

* Not shown are the share of unknown or missing lamps. *Source*: E3 2013

As an audit was conducted, each room or space that lights were found in were categorised into a usage type. The detailed room results for low voltage halogen downlights are given in Table 2. Note that installed stock is highest in the most used areas of the house (Living Areas), with the Watts share for this technology almost 50% of all Watts used in these areas.

Table 2. Detailed room results for low voltage halogen lamps

Average per House	Whole House	Living Areas	Sleeping Areas	Indoor-Other Areas	Outdoor Areas
Number of lamps	11.9	5.9	2.7	2.4	0.9
Number share*	24.8%	36.2%	24.7%	22.0%	8.9%
Watts total	558.0	281.0	120.0	115.0	42.0
Watts share*	27.8%	45.7%	34.0%	27.7%	6.7%
Watts per lamp	44.0	47.1	37.8	48.0	47.4

* This is a share of all technologies. *Source*: E3 2013

Another factor that plays a large role in the power usage of household lighting is the number of lamps controlled by a single switch. Generally, GLS lighting (ie a ceiling mounted Edison screw fitting) has a 1:1 ratio, or one switch to each lamp. For downlights, it was found that only 40% of lamps had a 1:1 ratio. Almost 30% of switches controlled two downlights, while perhaps 30% controlled 3 or more downlights (up to 8 on a single switch!). Multiple lamps per switch effectively limits the user's lighting energy consumption control.

As interesting and important as the Residential Lighting Study is, it can only give a snapshot in time. It also doesn't provide a key characteristic – lighting use behaviour.

Residential End-Use Monitoring Program (REMP) Pilot Project

The Residential End-Use Monitoring Program (REMP) pilot project[3] was undertaken over a continuous period of around 12 months between 2010 and 2011. It involved installing metering equipment on the switchboard and important end uses in five houses in Melbourne. Like the Australian Residential Lighting Study, it was commissioned by the Australian Department of Industry.

While a lot is known and understood about the energy consumption of appliances through laboratory testing, very little is known about how they are used once installed in real homes. The REMP pilot study was implemented as a scoping project to understand the complexities involved in any future larger study, as well as to assess methodologies and equipment. The end uses of interest for this pilot project included gas and cooking appliances, whitegoods, home entertainment and IT equipment, and lighting.

For the lighting aspect of REMP, a number of outputs were investigated:

- Hours of use and power (daily, seasonal pattern);
- Time of day 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 lights left on when the room is not occupied);
- Prevalence and proportion of plug load lighting.

After undertaking a lighting audit for all lamps in a house, usage questions were asked of the householders to understand a very general usage profile, which was used to aid in the allocation of lamp loggers. These answers were compared against a circuit map of the house to allow as complete coverage as possible of the lighting use of a house. Three types of data logging was used to understand lighting usage:

- Lighting circuits were identified at the switchboard and circuit transformers were installed. These allowed power usage to be recorded for these circuits at a 1 min interval;
- For fixed lamps, a photosensitive threshold sensor was installed on the 10 most used lamps. When a lamp was turned on and a minimum light level was exceeded, the logger recorded the 'on' time until this condition changed;
- For regularly used plug lamps, a power logger was installed. This recorded the Wattage at a 1 minute interval.

The annual energy consumption used for lighting in the REMP pilot homes is in Figure 4. It should be noted that none of the five pilot houses could be called 'average', the average house annual lighting energy consumption could possibly sit somewhere between House 3 and House 5.

[3] This section draws heavily from reference (E3 2012), including all figures and tables. *Please note – the authors of this ACEEE paper were also heavily involved in the production of this reference.*

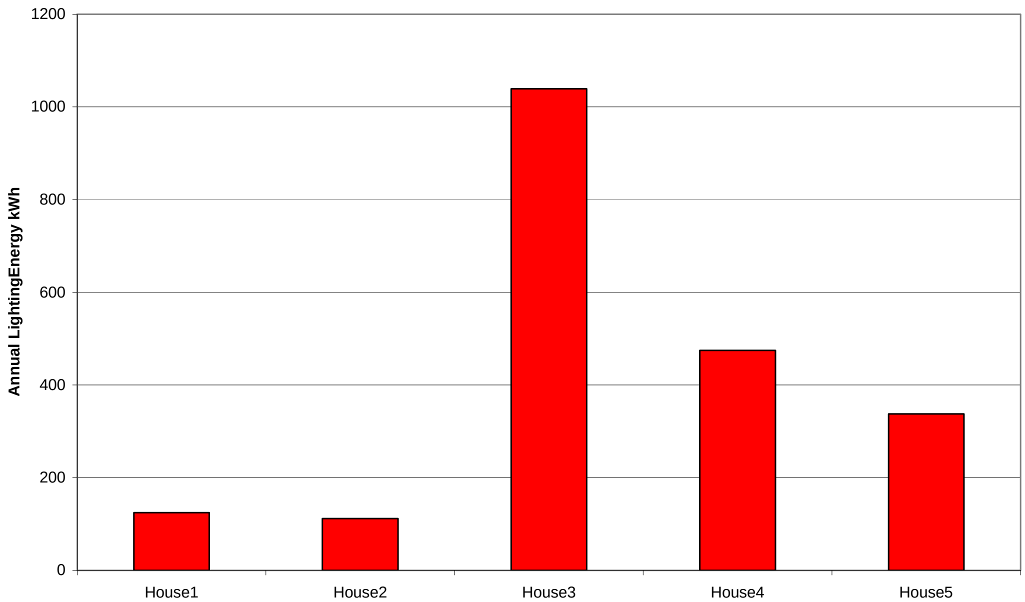

Figure 4. REMP home annual lighting energy consumption. *Source*: E3 2012.

Table 3 gives the demographic, construction and lighting characteristics of the five REMP pilot homes versus the Australian average (as found in the 2010 Residential Lighting Study – E3 2013) - note that these are real monitored numbers.

Table 3. REMP home characteristics

REMP House ID	No. of People	No. of Rooms	Floor Area	No. of 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	1039.0
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
Aust.*	2.84	15.8	157.6	47.8	0.30	3.0	12.7	23.4	??

* Australian average as found by the 2010 Residential Lighting Report (E3 2013). *Source*: E3 2012

In Table 4 below the lighting mix for the five REMP pilot homes versus the Australian average is given. As can be seen, House 3 seems to be outlier. House 3 does show what impact large numbers of installed halogen lamps can have, with this better illustrated in the following figures.

Table 4. REMP home lighting technology mix

REMP House ID	No. of Incand.	No. of Halogen**	No. of CFL	No. of LFL	No. of LED	No. of Unknown	No. of 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
Aust.*	10.5	16.1	14.4	4.2	0.7	1.1	0.8	47.8

* Australian average as found by the 2010 Residential Lighting Report (E3 2013). ** This includes both low (12V) and mains voltage (240V) halogen lamps. *Source*: E3 2012

To expand on the above table, Figure 5 gives the time of day (ToD) lighting breakdown for House 5 for July (Australian Winter). It should be noted that lighting power consumption is affected by seasonal factors – in summer, longer daylight hours mean artificial lights are unneeded, conversely the winter months tend to have the highest usage profiles. The three colours that base the area chart (blue, red and green) correspond to the average power consumption across the three lighting circuits of the house.

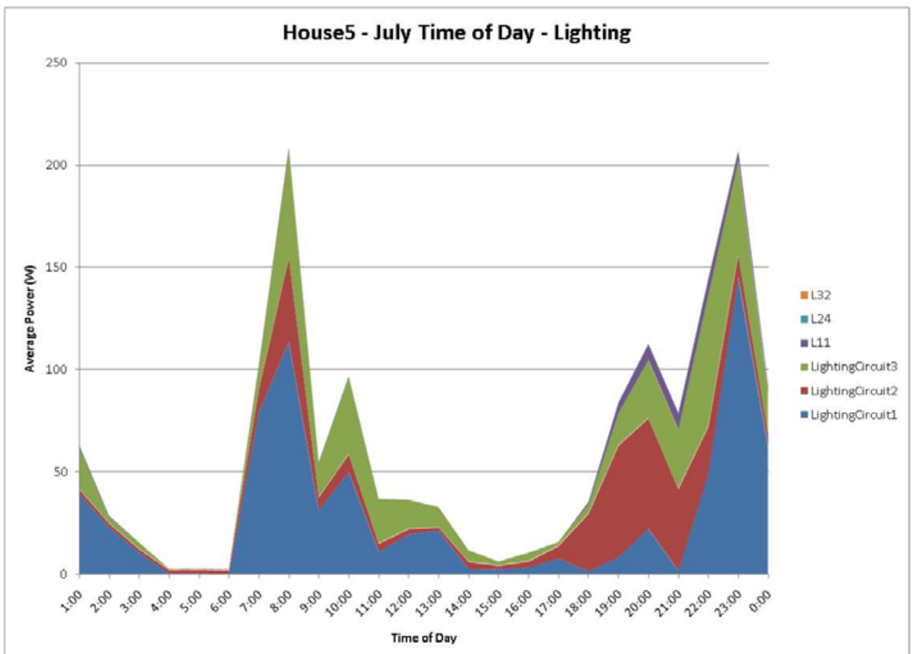

Figure 5. REMP House 5 July time of day lighting usage. *Source*: E3 2012.

Contrasting the time of day lighting breakdown for House 5, Figure 6 shows the House 3 usage for July. Again there are peak usage periods in morning and during the evening. But in spite of more occupants and a greater number of lights compared to House 5, House 3 has a very high average ToD lighting power usage in winter. The number of downlights installed in a house play a large part in this power usage. Again, the four colours that base the area chart (blue, green purple and aqua) correspond to the average power consumption across the four lighting circuits of the house. The higher colours represent the average consumption of sets of lights in the house.

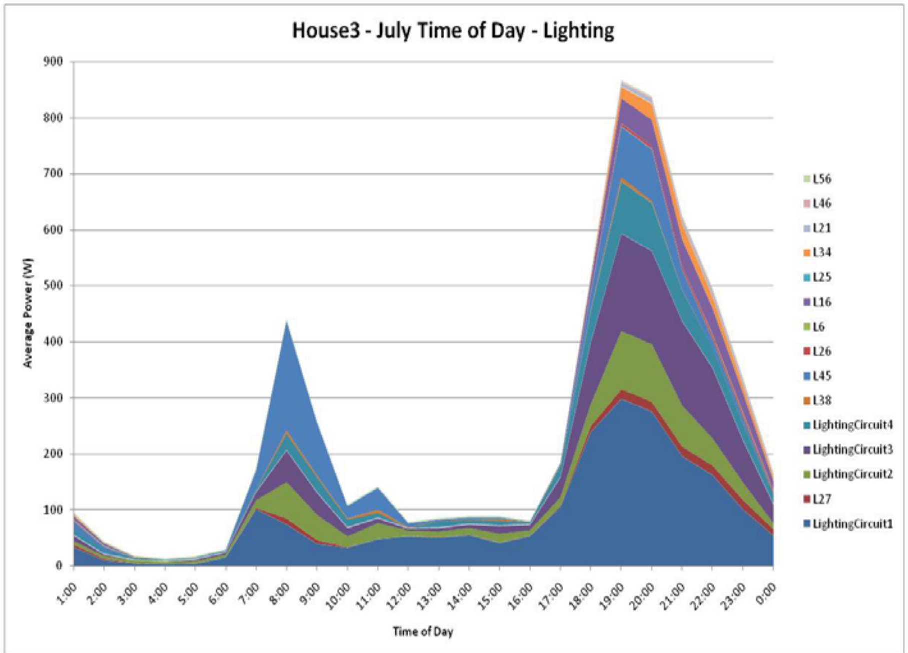

Figure 6. REMP House 3 July time of day lighting usage. *Source*: E3 2012.

Downlight Discussion

These two studies – the 2010 Residential Lighting Study and the REMP Pilot Project have shown that downlights are an issue in terms of installed numbers and usage profiles, as was suspected.

Since 2012, MEPS has limited the Wattage of available 12 volt halogen downlight lamps to 37 Watts. This measure was implemented because a 35 Watt low voltage halogen lamp with an infra-red coating (IRC) can emit a similar light output to a non IRC 50 Watt low voltage halogen lamp (while retaining the existing efficacy requirements) (DI 2014), thus providing the same service for a lower Wattage. Since this action, 50 Watt 12 volt versions have largely disappeared from retail shelves. MEPS has also eliminated ferromagnetic transformers from the market, in favour of electronic equivalents. This means that transformer losses have dropped from around 13 Watts, to around 4 Watts, on average. Combined with 37 Watt lamps, the total circuit power used by these lamp types has dropped from 63 Watts to around 39 Watts, a saving of 38%.

The imports of low voltage halogen lamps have also declined since a peak in 2009-10, as shown in Figure 7 (purple line - low voltage halogen). This figure, constructed from import data sourced from the Australian Bureau of Statistics (ABS 2013), shows the imports of mains voltage incandescent lamps, mains voltage halogen, and CFLs since 2002. Interestingly, mains voltage halogen imports appear to be trending up since 2008. Note that no lamp manufacturing has occurred in Australia since 2001.

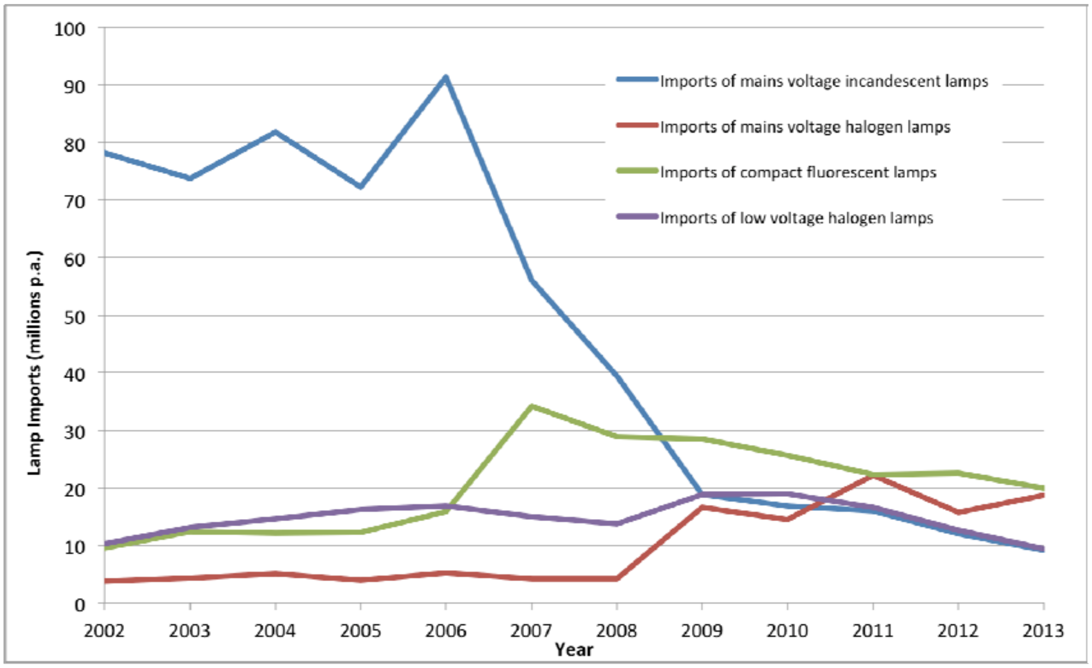

Figure 7. Australian lamp imports. *Source*: ABS 2013.

It is hypothesised that some of the reduction in low voltage halogen lamp sales is due to the growing popularity of LEDs as replacement lamps, which are starting to dominate retail shelf space. In the past two years, replacement LED downlight lamps have evolved to such a point that good quality products are able to emit sufficient light to claim equivalency with halogen downlights, and are becoming more compatible with installed electronic transformers (although the wide range of transformers installed in Australian housing still pose challenges).

Electronic transformers remain a bugbear for LED replacement lamps however, as they produce irregular voltage waveforms (typically at many kHz and with corresponding harmonics which testing has shown can reach hundreds of kHz) (DI 2010). Designing LEDs to cope with the wide variety of waveforms that exist in the installed stock, is a considerable challenge. The upside is that replacement LEDs typically consume around 9 Watts. The total reduction in power from 63 Watts per downlight where it began, to perhaps 13 Watts (including the transformer) and lower, is a worthy goal.

It is uncertain as to whether the current quality of available LED lighting alternatives will be sufficient to ensure the consumer transition is permanent, as the previous experience with the introduction of CFL lighting showed a consumer backlash against poor quality products. To alleviate this possible outcome, international efforts are underway concerning testing, quality assurance and performance criteria. Australia, along with other countries, is active in an IEA 4E Solid State Lighting Annex working on these issues (IEA 2009).

Conclusions

Lighting is a complex issue. Differences in householder habits and attitudes, lighting configuration and lamp technology all have a large impact on the potential to reduce lighting energy consumption. Lighting in the home is used for many reasons and purposes, and the requirements and lighting desires vary from user to user. To deal with an issue like the downlight, good quality data is critical to understand the problem at hand. Once this has been gathered, there are measures available to policy makers that increase the efficacy of lighting options. With the rapid and seemly natural movement of the residential lighting stock from downlights dominated to LED dominated, it is possible though these policy changes will not be needed if technology change continues. However, while import data over the last two years indicates a transition from inefficient halogen downlights to LED lighting may be occurring, the market share that will make this transition voluntarily is unknown. Uncertainties also surround LEDs concerning their quality, with international work underway to assure that quality concerns are alleviated. Future challenges for policy makers concerning lighting will remain until these challenges are met and dealt with.

References

ABS (Australian Bureau of Statistics). 2013. *Lighting Import Data*. Australia. http://www.abs.gov.au

ABCB (Australian Building Codes Board). 2010. *Energy Efficiency Provisions for BCA 2010 Volume One, Information Handbook*. Australia. http://www.abcb.gov.au/education-events-resources/publications/~/media/Files/Download%20Documents/Education%20and%20Training/Handbooks/2010_EE-Handbook-BCA-2010-Vol1-web.ashx

E3 (Equipment Energy Efficiency Committee). 2012. *Lighting Data Collection and Analysis*. Australia. http://www.energyrating.gov.au/programs/remp/

E3 (Equipment Energy Efficiency Committee). 2013. *2010 Residential Lighting Report*. Australia. http://www.energyrating.gov.au/products-themes/lighting/documents-and-publications/?viewPublicationID=2596

E3 (Equipment Energy Efficiency Committee). 2013. *Australian Residential Lighting Survey – Pilot*. Australia. http://www.energyrating.gov.au/products-themes/lighting/documents-and-publications/?viewPublicationID=2594

EES (Energy Efficient Strategies). 2008. *Energy Use in the Australian Residential Sector: 1986-2020*. Commissioned by E3. Australia. http://www.energyrating.gov.au/resources/program-publications/?viewPublicationID=2141

DI (Department of Industry). 2010. *Lamp Tests*. Australia. Private, unpublished data

DI (Department of Industry). 2014. *Lighting Phase-out of inefficient incandescent light bulbs*. Australia. http://www.industry.gov.au/Energy/EnergyEfficiency/Lighting/Pages/default.aspx

IEA (International Energy Agency). 2009. *4E Solid State Lighting Annex*. http://ssl.iea-4e.org/