Residential Lighting Overview Report

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FINAL REPORT

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GLOSSARY AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
Ballast	Device connected between the power supply and one or more discharge lamps primarily to limit the current of the lamp(s)
BCA	Building Code of Australia
CFL	Compact fluorescent lamp
Efficacy	A measure of efficiency, in lumens of light per Watt of electricity
GLS	General lighting service (typical incandescent non-reflector lamp)
Halogen	Filament lamp utilising halogen gas fill
Incandescent	Filament lamp utilising argon gas fill
Lamp	Source of artificial optical radiation
Lm	Lumen, the international measure of light output (luminous flux)
ELV	Extra low voltage (typically 12 V)
GLS	General Lighting Service (light bulb)
kWh	Kilowatt-hour – the total energy used over a period of time. There are 277777.8 kWh in a TJ
LED	Light emitting diode
Luminaire	Apparatus which distributes, filters or transforms the light transmitted from a light source, including lamp(s), control gear and all components necessary for fixing and protecting the lamps
Lux	The international measure of illuminance, or light falling on a surface (lm/m^2)
MEPS	Minimum energy performance standards
MV	Mains voltage (230/240 V)
Nominal	The manufacturer's rated value for a lighting product
PAR	Parabolic aluminised reflector (lamp)
PJ	Petajoule, a measure of energy which is equal to 1000 TJ
ReLAMP	Residential Lighting Australasian Model Project
TJ	Terrajoule, a measure of energy which is equal to 277777.88 kWh
W	Watt

1. Introduction and Key Findings

In Australia and New Zealand, there is a lack of comprehensive data related to residential lighting technologies and their usage, and existing data sources are disaggregated. There are several reasons for this:

- Lighting is a complex area – each dwelling typically incorporates more than 30 lamps of various technologies.
- Use of lighting is complex – lights in homes can be subject to hundreds of user interactions (switchings) per day.
- Lighting technologies are changing rapidly, particularly with the increasing popularity of compact fluorescent lamps (CFLs) and light emitting diodes (LEDs).

In order to better inform the development of efficient lighting policy and evaluate previous policies, a more complete picture of residential lighting in Australia and New Zealand is desirable. The objective of this study is to evaluate and summarise the findings of a number of recent reports and other available data sources pertaining to residential lighting in these two countries, in order to provide an insight into:

- Types, applications, designs and usage of household lighting.
- Past/present trends and future projections of lighting technologies.
- Consumer knowledge and awareness of lighting energy efficiency.
- Limitations of, and gaps in, data.
- Likely trends in energy consumption associated with lighting and opportunities for further government initiatives to derive energy savings from household lighting.

This study seeks to meet these objectives by undertaking the following sequential tasks:

1. Summarise, assess and categorise relevant existing data sources.
2. Based on this assessment, conceptually design an energy model for residential lighting in Australia and New Zealand – the "Residential Lighting Australasian Model Project" (ReLAMP). Identify how each of the available data sources might be incorporated into the ReLAMP model on an ongoing basis.
3. Construct a "first pass" of the ReLAMP model and attempt to derive the insights listed above (trends, opportunities, limitations, etc.).

The first pass of ReLAMP model is unlikely to yield accurate results. Rather, it seeks to encapsulate the "best available" data into a market snapshot, and derive recommendations into how data collection and modelling can be better organised in the future.

This report was undertaken by Beletich Associates, with the assistance of Energy Efficient Strategies for the Equipment Energy Efficiency Program.

Please note that the quantitative results of this report, whilst considered to be the best achievable with current data sources, remain subject to considerable uncertainty.

The key findings of this study are summarised below.

- For both Australia and New Zealand there is a lack of data prior to the mid-2000s.
- The lighting policies of the late 2000s appear to have had a significant impact in both Australia and New Zealand markets – filament lamp imports fell around 62% in Australia and around 32% in New Zealand over the period 2002/06 to 2013
- A trend of increasing sales and penetration of halogen downlights has also been experienced in both countries (more so in Australia).

- Both countries undertook physical audits of residential lighting in recent years. For Australia this was the 2010 Residential Lighting Report (E3 2013a), and for New Zealand the 2012 EECA/IPSOS Lighting Report (an update of a 2009 study). Both studies had a sample of around 150 houses, and included a complementary data collection on householder behaviour and attitudes. The average Australian household was found to have 48 lamps, while in New Zealand this number was found to be 35. The technology mix for each country was:
  - Australia: 30% CFL, 25% extra-low voltage (ELV) halogen, 22% incandescent, 9% mains voltage (MV) halogen, 9% linear fluorescent, 1% LED.
  - New Zealand: 24% CFL, 10% halogen, 57% general lighting service (GLS) incandescent, 3% linear fluorescent, less than 1% LED.
- Time-of-use monitoring data is extremely important for successfully assessing the energy consumption characteristics of lighting in houses.
- For paper, online or telephone questionnaires, it can be difficult to fully assess the accuracy of householder responses – bias, question format and psychological factors can all play a part in the answers that are given.
- In Australia, lamps are reportedly purchased from supermarkets (64%), hardware stores (47%), specialty lighting store (18%), online (3%) and other (5%). In New Zealand, this has been reported as supermarkets (71%), hardware stores (19%), lighting specialty stores (12%) and other outlets.
- In Australia, several reasons were given for changing lamp types. These were all of approximately equal influence and include: room renovation, energy efficiency and dissatisfaction with the existing lights. When selecting lamps, the primary influencing factors were reported to be energy efficiency, purchase cost, wattage, brightness, colour and lamp lifetime. Of lesser influence were the type of lamp used previously, brand and lamp warm-up. Around a third of households reported being interested in changing remaining incandescent/halogen lamps to CFLs.
- In New Zealand, the primary reasons for changing to energy efficient lamps were given as aesthetics, energy efficiency, light quality and initial cost. Around 20% of householders reported being unhappy with their energy efficient lighting – 59% of those dissatisfied said it wasn't bright enough, 16% because it was the wrong colour, 11% didn't like the look of the bulb, 11% said it took too long to reach full brightness, 8% said it didn't last long enough, 4% said it was too bright, and 19% had another reason.
- The ReLAMP model for Australia and New Zealand was developed to enable identification of the data needs required to accurately describe and make projections about the lighting market in Australia and New Zealand, and to identify current and potential future trends in lighting energy consumption.
- The quantitative results of this model, whilst considered to be the best achievable with current data sources, remain subject to considerable uncertainty.
- Based on results from the ReLAMP model, Australia was experiencing a gradual reduction in residential lighting energy (power density in W/m^2) from 1990 onwards, due to the increasing popularity of CFLs. In the mid-1990s, this began to reverse due to the introduction of ELV halogen lighting, which caused lighting power density to increase until around 2007, when the phase-out of incandescent lamps was announced and state-based CFL giveaway programs were taking effect.
- New Zealand appeared to experience a decline in residential lighting power density commencing in 2005 (potentially due to CFL giveaway programs).
- The ReLAMP model estimates average stock lighting power densities of 11-14 W/m^2 in 2010 for Australia and New Zealand. In both countries, there is a current trend towards the installation of more efficient lighting. LEDs are expected to play a key role in enhancing this trend, particularly as replacements for ELV halogen downlights. Currently, it is possible for a room lit with LED downlights to have a lighting power density of 4 W/m^2 or better – in fact a recently built Australian house with predominantly LEDs had a power density of 2.6 W/m^2.
- Commercially available LEDs are currently capable of achieving around 50-100 lm/W. If LEDs universally reach 200 lm/W by 2020 (as is predicted by some experts) then lighting a house to an average of 200 lux (lux = lumens/m2) would require just 1 Watt of lighting power per square meter, or 1 W/m^2.
- Although these may be achievable figures, the ReLAMP model needs to consider the average dwelling (the stock average of installed equipment). For this purpose, 4 W/m2 has been used as the ultimate average lighting

power density for Australia and New Zealand by 2030, although it is quite feasible that aggressive policy measures and faster technology changes could achieve even more positive outcomes.

- Note however that this significant downturn in lighting energy is essentially an educated guess, based on the recent improvements in LED quality and reductions in price continuing, to the point that these become a viable mass-market product in the medium term (as is predicted by many experts). Other scenarios are also possible, such as occurred with CFLs – these were subject to some uptake, then a stall due to product quality and a market not inclined to make a transition from familiar products. From this aspect it is still unclear as to what portion of the market will make the transition from MV and ELV halogen to LED, without any government interventions such as Minimum Energy Performance Standards (MEPS).
- If the aggressive LED trend were to eventuate, the annual energy consumption of lighting per home in Australia and New Zealand would decrease to around 400 kWh by 2030. This may be even lower if LED efficacies continue to improve and be taken up by the market. In more radical scenarios, where LED efficacy climbs to 200 lm/W, lighting energy consumption could be half this value.
- The emergence of remote controlled 'smart' lighting with standby modes and/or networked lighting has the potential to work against the optimum savings scenarios depending upon the configuration and functionality of these products.
- Once calibrated with the best available data, ReLAMP is a powerful tool to examine the impacts of changes in policy, technology and user behaviour into the future under a range of assumed conditions.
- Lighting operating hours are extremely difficult to quantify. There is high variability between houses, a highly seasonal pattern, and individual lamps are highly variable from day to day.
- Average lamp operating hours in this report and model are derived from a very small sample size. These operating hours need to be carefully calibrated and correlated with related sources (which are also scarce) or further hours of use data collected.
- Data related to technology penetration, by room type, is scarce, particularly historically.

2. Household Lighting - Design and Applications

2.1 Household Lighting

Lighting is used by different users for many different purposes. Whilst at the most basic level illumination is the primary purpose of any lamp, in practice there are many nuances involved in fulfilling that purpose. Lamps have a wide range of installation options such as indoor or outdoor, hard wired or plug-in and can be fitted in a range of fitting types. Lighting is used for a wide range of applications including specific tasks, general purpose illumination, flood lighting and mood lighting.

Lamps come in many different colours, shapes, wattages, caps, fittings and technologies – all play a part in how the lighting in a home is selected, used and ultimately how it performs. In the (distant) past, householder choice was essentially limited to incandescent or linear (including circular) fluorescent lamps. In more recent times there has been increased penetration of CFLs and halogen lamps (primarily ELV, but also recently MV). In the past few years LED lamps have become widely available as a new technology and are predicted to become predominant in terms of cost, light output and efficiency in coming years. Given the vast number of lighting types and the recent rapid changes underway, lighting can be a confusing topic for householders (and policy makers). Decisions regarding light fittings made during building design and construction can lock a household into particular technologies and specific lighting points in the home, and often these decisions are not made by the householder. For example, luminaires (light fittings) such as embedded or flush-mounted fittings can be difficult to change and may restrict householders to certain lighting technologies.

In the construction phase of a new house, there may be varying degrees of householder input into a lighting design. If the house is purchased 'off the plan' then it is probable that the building designer will select the lamp types and placement. For new houses where there is more householder and builder interaction in the decision making process, then lighting design can be influenced by a range of inputs, which may or may not take lamp efficacy into consideration. In order to minimise capital costs, builders will often provide a base template of batten holder fittings in all rooms, that meet Building Code of Australia (BCA) regulations, with householders then deciding if they want to 'upgrade' the lighting in certain rooms to other lamp types such as downlights or suspended fittings.

Lighting changes during renovation of existing houses may allow for a wide range of options, at the discretion of the householder. Advice from professionals such as architects and interior designers, or specialist lighting retailers, is sometimes sought, different forms of media used, and the houses of friends and family or display homes can play a role. It comes down to personal preference, and may also have other factors involved like budget or energy considerations. Often, however, lighting efficacy is a lower order consideration, if it is considered at all. In recent years project homes have been built with ELV downlights fitted, in large numbers, in every room of the home. Note however that this is now transitioning to LED downlights.

Different rooms require different forms of lighting – a bedroom will not typically require the same type of task lighting required in the food preparation areas of a kitchen. Similarly, an outdoor area may require a higher intensity light compared to a lounge room. The type of room also plays a large role in the decision whether to use a plug-in lamp – this type of fitting may be used to boost light levels in a room, reduce the need to use fixed lamps, to provide task lighting or to set a mood.

Light colour preference can vary by room type. For utility areas like bathrooms or studies, a whiter light may be beneficial whereas for living areas a warmer yellowish light feels more natural. Residential LED lighting is now starting to be developed that can be programed to change colour.

There seems also to be a convention for installing certain types of lights in certain rooms. The intense, sparkling, warm light given by ELV halogen downlights is popular in living areas (open plan living areas, kitchens and lounge rooms) whereas the practical and long lasting linear fluorescent lamps seem to be used more in garages, utility areas, kitchens and outdoors. These trends will probably change as technologies and fashions change, although the practicalities of moving with the times are not always straightforward for a discerning householder.

The types of fittings installed in a room can constrain the type of lamp technology that is used. General lighting service (GLS) fittings (pendant, oyster, bare baton, etc.) have the ability to accept a range of technologies (MV halogen, incandescent, CFL, LED), while a flush mounted downlight might only accept one or two technologies – low voltage halogen and possibly LED. A fitting may constrain a technology where an ELV transformer is used to convert mains voltage to 12 V. The "cap" used by the lamp / fitting (bayonet, Edison screw, GU10, bi-pin, etc.) may also constrain lamp choice. There may also be space limitations (e.g. in some "oyster" fittings) which can impact on the lamp size and shape that will fit. Certain luminaires have a limit on the rated lamp power (in terms of the heat dissipation). Some light fittings rely on specific light output geometry to operate correctly. All these factors can constrain a householder in changing the setup of the lighting in their house, especially if they are unhappy with the current configuration.

Different technologies have a range of available cap types and shapes to choose from, and not every technology will be available in every cap or shape. CFLs that come in a stick or spiral shape have different light output distributions. Filament based technologies (halogen and incandescent) are easier to design into different lamp shapes, as the light emitted can be simply directed. LED and fluorescent technologies require a greater complexity in the globe structure to provide a comparable type of light in comparable situations. This impacts on lamp purchase cost, which may influence householders at the time of purchase. The expected lifetime of the lamp and the efficacy (together with the expected hours of use) dictate the overall cost effectiveness of different technology options. Educating purchasers to take these factors into account can be a challenge. Where tradespeople supply lamps and luminaires (which is common), these factors may be given little consideration.

Different technologies also vary in their ability to be compatible with dimmers and other controllers, an advantage that filament style lamps (and some LEDs) have over fluorescent lamps. Whilst a relatively small proportion of all lamps in homes have dimmers fitted, the 2010 lighting survey (E3 2013a) found that, in Australia, most houses have at least one dimmer. Dimmers can be very useful in changing the lighting dynamics of a space, but the presence of a dimmer may limit lamp and luminaire replacement options.

2.2 Lamps and Applications

2.2.1 Incandescent lamps

Incandescent lamps (Figure 1) are defined as filament lamps which utilise a tungsten or carbon filament suspended in a vacuum or inert gas. For the purpose of this report, incandescent lamps do not include lamps with a halogen gas fill.

Incandescent lamps were invented in the late 1800s and are the least efficient type of lamp available. For residential applications they are typically mains voltage (240 V in Australia and 230 V in New Zealand). Incandescent lamps are available as omni-directional (non-reflector) and directional (reflector) lamps (Figure 1).

Figure 1 – Examples of incandescent lamps

Omni-directional (non-reflector) incandescent lamp

Directional (reflector) incandescent lamp

Reflector lamps will always be less efficient than equivalent non-reflector lamps, as some light is absorbed by the reflector. In a residential context, incandescent reflector lamps are typically used in downlights (older style can-type downlights), for spotlighting (e.g. works of art), bathrooms (in heat-light fittings) or outdoors (PAR lamps).

Australia was one of the first countries in the world to announce regulations aimed at eliminating inefficient incandescent lamps from its market. This announcement occurred in February 2007 and was followed by the development of a minimum energy performance standard (MEPS) program for incandescent, halogen and compact fluorescent lamps.

The program was implemented in a staged fashion, commencing with an Australian import restriction on tungsten filament incandescent lamps used for general lighting service (GLS; traditional A-shaped (pear shaped) “light bulbs”) lamps on 1 February 2009. In November 2009 GLS tungsten filament and extra-low voltage halogen non-reflector lamps were subject to the more traditional “point of sale” MEPS in Australia. The scope of MEPS for incandescent and halogen lamps was then broadened regularly until October 2012.

2.3 Halogen lamps

Halogen lamps (Figure 2) have a tungsten filament suspended in a mixture of an inert gas (usually argon, krypton or xenon) together with a small amount of halogen gas (usually bromine or iodine). The halogen gas suppresses degradation of the filament by a chemical regeneration process known as the halogen cycle. During lamp operation, the halogen gas combines with the tungsten molecules that have evaporated from the filament. The lamp envelope is too hot to allow the tungsten-halogen compound to be deposited on it, hence the tungsten is deposited back onto the filament and the halogen released to start the cycle again. Depositing tungsten back onto the filament in this way helps to maintain the lumen output of the lamp and increases lamp lifetime.

The lamp envelope inner surface needs to be greater than 250°C for the halogen cycle to occur so bulbs must be made from heat resistant glass or quartz. Therefore these lamps are sometimes referred to as quartz halogen lamps.

Halogen lamps achieve better efficacy, have a longer operating life and produce a whiter, brighter light than incandescent lamps. In Australia and New Zealand they are designed for either 240 V operation (MV) or 12 V operation (ELV, sometimes referred to simply as “low voltage”). The latter requires a transformer or voltage converter (subject to MEPS). ELV lamps run at higher current, which allows for a shorter filament and thus a smaller light source which is suitable for focusing light into a tight, directional beam. As the filament is shorter, it also runs hotter and as a result ELV halogen lamps are a little more efficient than MV lamps (but still significantly less efficient than CFL or LED lamps).

A subset of halogen lamps are infrared coated (IRC) lamps. These lamps incorporate a coating on the filament capsule which redirects infra-red radiation (heat) back onto the filament. This allows the filament to run even hotter and therefore produce more light for the same electrical power. Note however, that IRC technology is not viable at 220-240 V and is better suited to 12 V halogen lamps.

Halogen lamps are available in both omni-directional (non-reflector) and directional (reflector) format (Figure 2).

Figure 2 – Examples of halogen lamps

Halogen GLS lamp (non-reflector MV)	Halogen capsule lamp (non-reflector MV or ELV)	Halogen MR16 reflector lamp (ELV)	Halogen GU10 reflector lamp (MV)

MV halogen non-reflector lamps are used in the same fashion as their incandescent equivalent – for general purpose lighting (note that candle and decorative shapes are also available). ELV halogen capsule lamps are typically used for task lighting such as a desk lamp. MR16 lamps are very commonly used in downlights for general purpose lighting, as are MV GU10 reflector lamps and other MV halogen reflector lamps with Edison screw and bayonet caps.

2.4 Compact fluorescent lamps

CFLs (Figure 3) are defined as single-capped lamps with a compact (e.g. folded or spiral) gas discharge tube, with integrated ballast circuitry for controlling the lamp (i.e. the ballast is part of the lamp).

CFLs are amongst the most efficient lamps available, employing a gas discharge technology together with a phosphor coating to produce visible light. An electronic ballast, required to operate the gas discharge at the correct current, is incorporated into the base of the lamp. CFLs in the typical lighting context are mains voltage and are generally a direct replacement for incandescent and halogen lamps. They are available in both reflector and non-reflector formats (Figure 3).

Figure 3 – Examples of CFLs (RH image courtesy Sylvania Lighting Australasia)

Spiral-shape omnidirectional CFL | Stick-shape omnidirectional CFL | Covered CFL | CFL reflector lamp

CFLs are available to replace almost every type of mains voltage incandescent or halogen lamp. They are less suitable as reflector lamps as there large light source (tube) does not provide the point source of light desired by a reflector – the result is a large beam spread rather than a tight, focussed beam.

2.5 Light emitting diode lamps

LEDs, or Solid State Lighting (SSL) use one or more semiconductor diodes (solid state chip) to emit non-coherent optical radiation (light) in the visible spectrum, which is produced by the recombination of conduction electrons and photons, when excited by an electric current. LEDs are currently available to replace many types of lamps and continue to evolve rapidly to cover many different lighting applications. The performance of LED lamps is variable, although in the last 2-3 years significant improvements in performance have been observed. Figure 4 shows examples of LED integral lamps (with integral power supply electronics).

Figure 4 – Examples of LED integral lamps (images courtesy Barryjoosen and Lee, E.G. via Wikimedia Commons)

Omnidirectional-replacement LED | LED MR16 | Directional LED lamp

LEDs are now available (although not always widely) for almost every conceivable lighting application. In Australia over the past few years, MR16 LEDs have become popular to replace halogen lamps in downlight fittings.

3. Existing Reports and Data

This section of the study seeks to analyse and briefly summarise the findings of a number of household lighting reports and other available data used for this study. The reports and data are listed in Table 1.

Table 1 – List of reports and data

Ref	Responsible Agency	Report / Data
1	Department of Industry, Australia	E3 2010 Residential Lighting Report
2		E3 Australian Residential Lighting Survey Pilot, 2013
3		E3 Proof of Concept Residential Energy Monitoring Program (REMP), 2012
18		GEMS (Department of Industry) Store Survey, 2013
5	Australian Bureau of Statistics (ABS)	ABS Environmental Issues (4602): Energy Use and Conservation Survey, 2008
13a		ABS Lamp import data
16		ABS Household Energy Consumption Survey, 2012
19		ABS Population Survey Monitor for Selected Months (Nov 97, Feb 98, May 99, Aug 99)
4	BIS Shrapnel, Australia	BIS - Lighting Installed in New Dwellings, 2009
12	Energy Efficiency and Conservation Authority (EECA), New Zealand	EECA Energy End Use Database
14		EECA / IPSOS Lighting Report 2012 (survey)
15		EECA / RightLight sales data
13b	Statistics New Zealand	New Zealand Lamp import data
10	BRANZ, New Zealand	BRANZ Energy Use in New Zealand Households
11		BRANZ Home Lighting Survey, 2009
17		BRANZ Lighting in New Zealand Homes, 2009 (survey)
8	Sustainability Victoria (SV)	SV Green Light Reports, 2008, 2009 and 2010
21		SV Victorian Residential Energy Monitoring Program (REMP), 2012
7	Department of Human Services (DHS), Victoria	DHS Victorian Utility Consumption Household Survey, 2008
6	Department for Manufacturing, Innovation, Trade, Resources and Energy, South Australia	SA Department for Transport, Energy and Infrastructure – Results from household survey on the use of energy appliances and products in the home
9	Queensland electricity utilities	Queensland Household Energy Survey 2009, 2011 and 2012
22	Ausgrid	Ausgrid SHAPE Data Analysis Final Report

3.1 Brief Synopsis of Existing Reports and Data

3.1.1 E3 2010 Residential Lighting Report (data source #1)

The 2010 Residential Lighting Report (E3 2013a) represents a comprehensive in-home study of residential lighting in Australia, undertaken in 2010 and 2011. As part of the survey, 150 houses in Brisbane, Newcastle, Sydney, Melbourne and Gippsland (Victoria) were visually surveyed by trained personnel. The key output data relates to stocks of lamps and the primary conclusions were:

- On average, each house contained 48 lamps (including "plug lamps" and outdoor areas).
- The lamp penetrations were – 25% ELV halogen, 9% MV halogen, 30% CFL, 22% incandescent and 9% linear fluorescent.
- The average lamp power was 42 Watts (W).
- The average house size was 140 m².
- On average, there were 0.3 lamps per m².
- The average lamp power density was 9.9 W/m² (indoor).

Other results from the study can be seen in Table 2.

Table 2 – Key outputs from the E3 2010 Residential Lighting Report

Average House	Average Per House
Number of Lamps	47.8
Number of Switches	29.8
Total Watts	2008
Number of Rooms	15.4 (12.4)
Floor Area (m²)	157.6 (139.2)
Lamps per m²	(0.27)
Lamps per Room	(3.1)
Watts per Lamp	42.0
Power density (Watts/m²)	(9.9)
Power density (Watts/m²) – Fixed	(8.3)
Power density (Watts/m²) – Plug	(1.6)
Lumens	47083
Lighting Levels (Lux)	(230)
Lighting Levels (Lux) – Fixed	(201)
Lighting Levels (Lux) – Plug	(29)
Note – brackets indicate indoor only.	

The sample houses are skewed towards higher incomes, with under-representation of single-member and one-parent households. The sample has an increased proportion of 25–34 year old occupants and a bias towards larger size houses. The study only contains data from 2010/2011 – no time series data is available from this study. While the raw data is slightly skewed, the demographic information for each house is available and the sample results can be re-weighted to provide a more representative population weighted average result (although this was not done for the project report).

Other data collected as part of the study include the connection of lamps to light switches and lighting usage (householder questionnaire). Householders were asked a general usage question for each lamp in the house during the audit and could only provide the qualitative responses frequent long, frequent short, occasionally or rarely. ELV halogen lamps had a generally even spread across usage levels (26–29%), with the exception of "occasionally (16%). CFLs also had a generally even spread of 21–25% with the exception of frequent long (32%). Incandescent and mains voltage halogen lamps tended to be in lower usage areas, as were linear fluorescent (linear fluorescents are more prevalent in garages, for example). The usage patterns for incandescent and compact fluorescent lamps suggest that the weighted energy consumption for lighting may not be as poor as the count by lamp type would initially suggest.

This study is considered the most comprehensive of its kind undertaken in Australia, and its results are extremely useful as key inputs to the ReLAMP model (for the year 2010). The outputs from this study and report were used extensively as a baseline for the Australian section of the ReLAMP model. As the data is from 2010, it is useful in capturing the shift from incandescent lamps to CFLs, which accelerated after the announcement of MEPS for incandescent, halogen and compact fluorescent lamps in 2007 and the commencement of state-based incentive schemes. It also shows the prevalence of ELV halogen lamps.

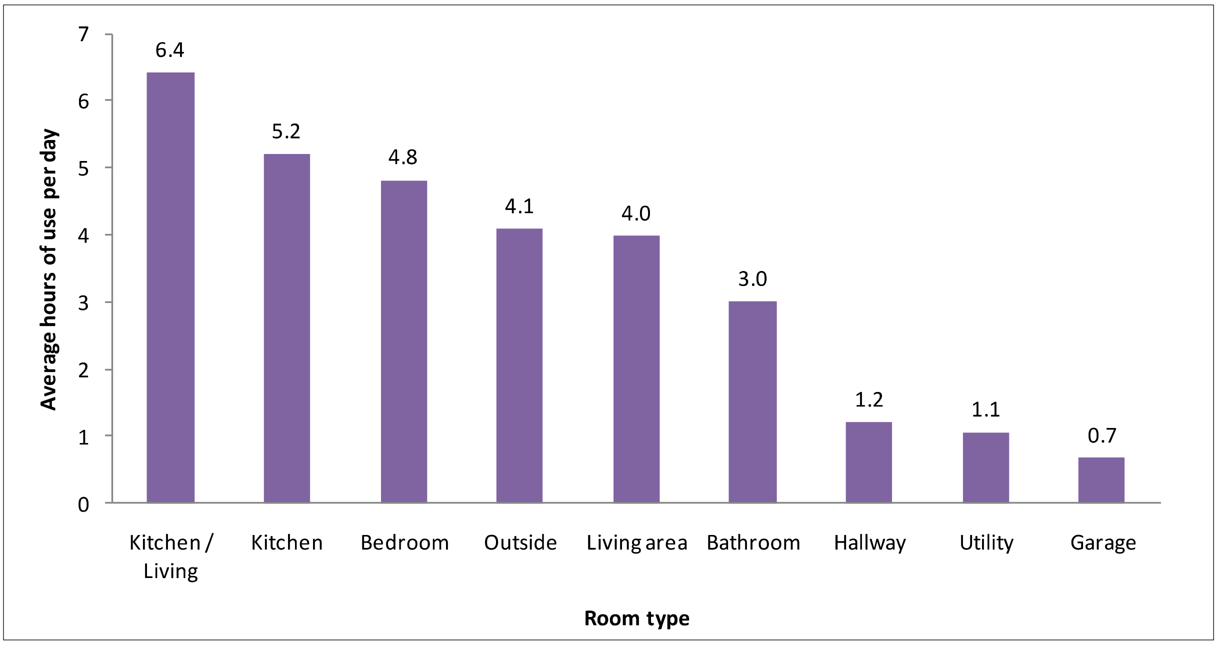
The key data from the study, which are incorporated into the ReLAMP model are lamp stock and house/room details.

3.1.2 E3 Australian Residential Lighting Survey – Pilot, 2013 (data source #2)

The Australian Residential Lighting Survey – Pilot (E3 2013b) was undertaken by Databuild for E3. It is a survey of residential lighting usage characteristics, and was undertaken as part of the E3 2010 Residential Lighting Report in 2010 and 2011 (see section 3.1.1). The same 150 houses as the Residential Lighting Report were surveyed in Brisbane, Newcastle, Sydney, Melbourne and Gippsland (Victoria). The survey comprised a written questionnaire which was completed by householders, unaided by survey personnel, relating to lighting usage.

The key outputs from the survey are lighting usage (as reported by householders), split by room type, including average hours of use per day, usage by time of day, dimmer usage, estimated load profiles and estimated average lighting energy consumption. One of the key outputs is reproduced in Figure 5 and indicates the highest lighting usage is in open plan kitchen/living areas, followed by discrete kitchen areas, bedrooms and outside areas.

Figure 5 – Average hours of use per weekday, from the E3 Australian Residential Lighting Survey Pilot, 2013



As each household was only surveyed once (i.e. only one time of the year) there is likely to be some uncertainty related to seasonality of lighting usage. In addition, it is currently unclear if average lighting usage was surveyed "per lamp" or "per room".

This data is considered moderately useful to ReLAMP, although the accuracy of householder answers carries some unavoidable uncertainty. The sample houses are skewed towards higher incomes, with under-representation of single-member and one-parent households. It has an increased proportion of 25–34 year old occupants and a bias towards larger size houses.

The survey also collected answers relating to consumer attitudes towards various lighting technologies (see section 3.2.1).

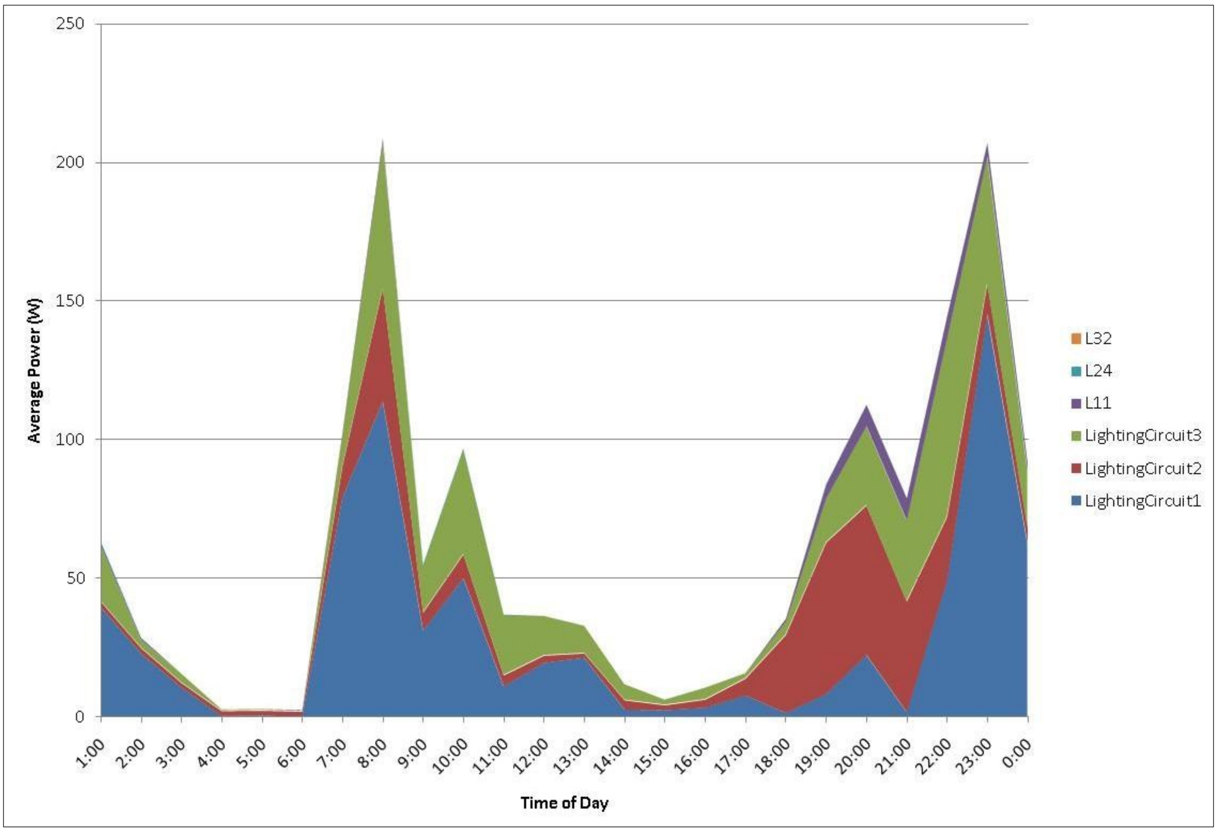
For the ReLAMP model, this data source was used as a reference point for hours of use for lamps, but not used directly due to the availability of better data – the end use monitoring data (discussed in section 3.1.3).

3.1.3 E3 Proof of Concept Residential Energy Monitoring Program (REMP), 2012 (data source #3)

The E3 Proof of Concept Residential Energy Monitoring Program (REMP; E3 2012) was undertaken in 5 houses in north east metropolitan Melbourne in 2010 and 2011. This pilot monitoring study recorded all aspects of energy consumption for each house, which included time of day usage for the monitored lamps. Also recorded were the consumption of all lighting circuits, on/off usage data for 12 individual hardwired lamps, and the consumption of all plug lamps, all over a 15-month period. The study found that lighting use in households is very seasonal in nature and difficult to pigeonhole into a demographic type. Technology types and the numbers of lamps connected to each switch played a large role in total lighting energy consumption.

The key outputs from the study are lamp stock, room details, usage details and time of use data. A complete circuit and lighting audit was undertaken, and usage questions were asked (using the same format as in the E3 2010 Residential Lighting Survey Pilot). An attempt was made to test the four usage responses (freq-long, freq-short, occasionally, rarely) against the actual recorded usage data, to see if a correlation could be made. This was further documented in an analysis report that was released at the end of the REMP study, with a reasonable correlation between user responses and monitored usage. Usage monitoring for a single house in July can be seen in Figure 6, indicating that for this particular household peak lighting use was in the morning at around 8am and peaked again in the evening at about 8pm and then 11pm (note the latter peak is not typical of an average household).

Figure 6 – Time of day lighting breakdown for July (House 5), from E3 Proof of Concept REMP Program, 2012



The data from REMP is useful to ReLAMP, although the study has a very small sample size. The sample of households is not considered representative of the general population and thus the data should be treated with some caution.

The data, usage responses and analysis from this study may be used to better equate actual use with householder responses. The hours of use data from this study, combined with those from the Sustainability Victoria (SV) Victorian Residential Energy Monitoring Program (data source #21) were used in the ReLAMP model.

3.1.4 GEMS Store Survey, 2013 (data source #18)

The GEMS Store Survey (E3 2013c) incorporated a store audit that was undertaken on lighting products in Tasmania, Victoria, South Australia and New South Wales. The audit was completed in 2013, with the goal of ascertaining the compliance of stores with MEPS registration requirements for lighting products. The survey comprised of a physical store visit, comparing shelf product details with the MEPS registration database. A total of 1,269 products were audited.

The key outputs of the study are lamp details (brand, model, technology, power, light output, etc.). Note that the data does not contain price information.

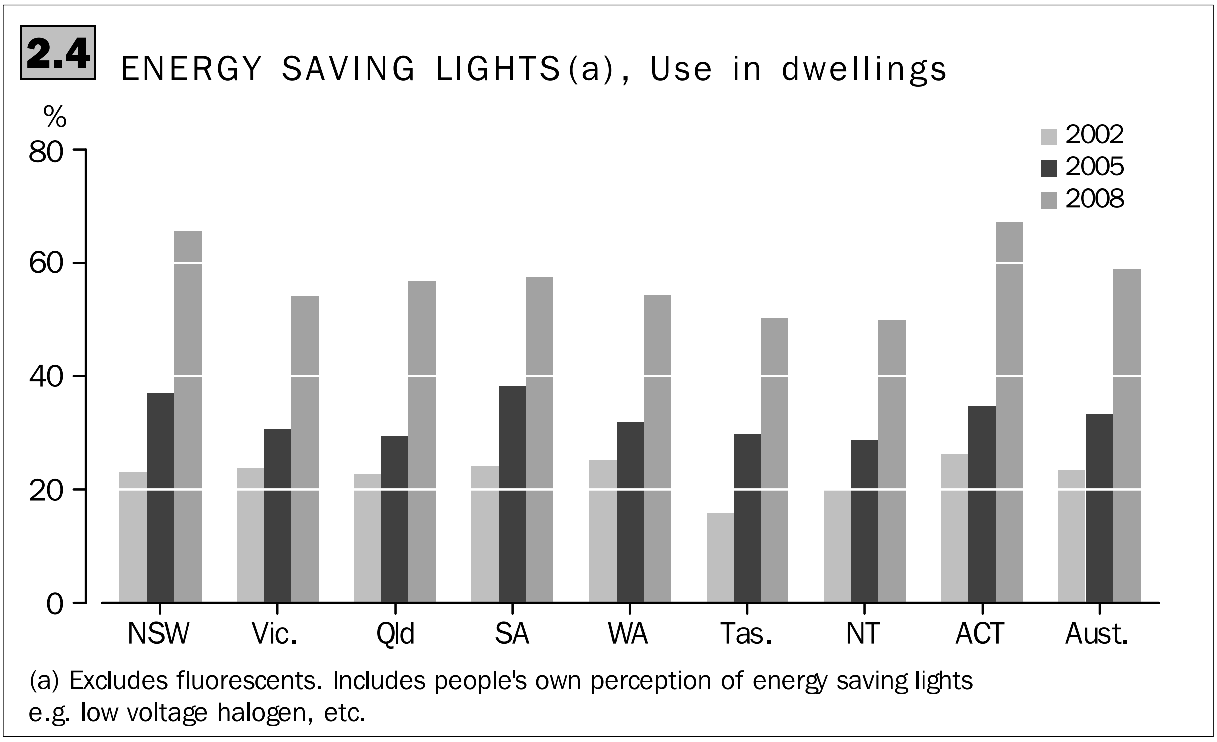
There were no assumptions used in the data collection, although auditor experience is critical to data accuracy. There are some uncertainties in how stores were selected to be part of the audit, as well as some details on how the study was conducted. The representativeness of the study is also unknown. The data is not currently directly useful for the ReLAMP model, although in future the lamp price information may be used, if available.

3.1.5 ABS Environmental Issues: Energy Use and Conservation Survey, 2008 (data source #5)

The Australian Bureau of Statistics (ABS) Energy Use and Conservation Survey (ABS reference 4602; ABS 2008) is conducted every three years. It concentrates on aspects of residential dwellings, energy sources, heaters, coolers, appliances and attitudes. Also included is information regarding numbers of fluorescent lamps and CFLs, and these data are included in the 1999, 2002, 2005 and 2008 studies. The survey findings are weighted to the total Australian housing stock, and split by State. Responses are gathered by surveying households.

The key output of this study is the fluorescent, compact fluorescent and 'energy saving' lamp stock. The study found that the proportion of houses fitted with fluorescent lamps has remained stable overall, at around 58% (for the survey years). The number of houses fitted with energy saving lamps increased from 23% in 2002 to 59% in 2008 (Figure 7). Note, the 'energy saving' lamps category includes those which people perceive as energy saving, e.g. ELV halogen downlights – it was found that only 76% of the households which reported having 'energy saving' lamps actually had CFLs.

Figure 7 – Proportion of Australian houses fitted with 'energy saving' lights, from ABS Environmental Issues: Energy Use and Conservation Survey, 2008



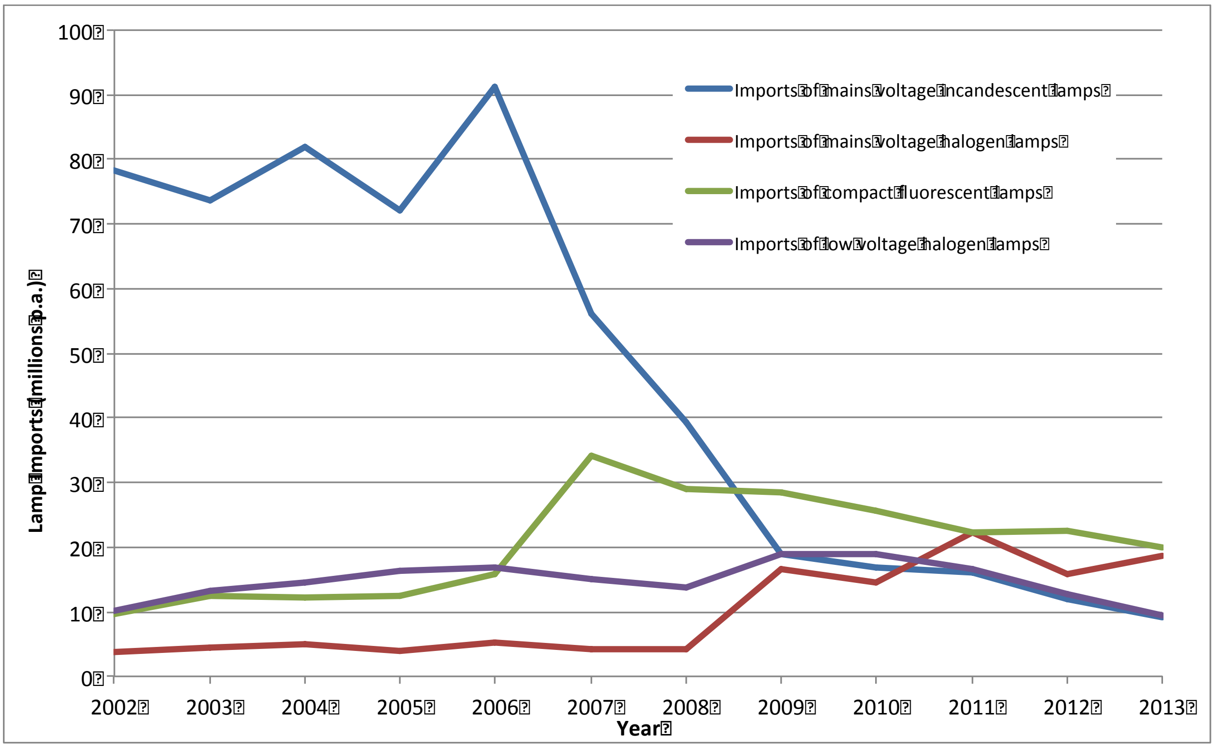
These data are useful to ReLAMP, in that it shows the trends for fluorescent and CFL stock for Australia. ABS survey results are considered representative, although there may be some uncertainties associated with householder survey responses. This time series is useful as it tracks the prevalence of "energy saving lamps" prior to the wider availability of LED lamps, which has only occurred since about 2010.

The trends in the numbers of fluorescent and CFL lamps from 1999 to 2008 were used as a guide for entries in the ReLAMP model.

3.1.6 ABS lamp import data (data source #13a)

The ABS Australian Lamp Import data provides an invaluable time-series for lamp imports to Australia. Import statistics represent a good proxy for lamp sales in Australia, as the sole Australian lamp manufacturing plant closed in April 2002. One caveat to this is that CFL imports include those used in early "giveaway" programs, where some of the CFLs distributed may not have been installed – recent state-based incentive schemes include the installation of CFLs. In addition, the CFL import statistics include non-ballasted lamps which are primarily used in commercial premises. Figure 8 graphs aggregated import data for lamps from 2002. Imports of MV incandescent lamps have decreased since the announcement of the phase-out of GLS incandescent lamps. CFL imports peaked initially around the announcement of the phase-out and have since decreased.

Figure 8 – Imports of lamps in Australia, from ABS lamp import data



This data is considered very useful as an input to the ReLAMP model, as it contains a continuous time-series of lamp imports from 2002 to the present. There may, however, be some uncertainty related to the accuracy of lamp category reporting by lamp importers. The main parameter of interest in a stock model is sales (new products entering the stock) which are generally not available. Import data is a proxy for the types of lamps that are flowing into the stock of lamps over a longer period. Sales and import statistics are somewhat disconnected as the inventory in warehouses can fluctuate over time. The other limitation of import data is that there is significant uncertainty regarding the share of sales into the residential sector and non-residential sector, although certain lamps types are assumed to be predominantly supplied to the residential sector. It should also be noted that, when comparing lamp sales and lamp stocks, lamps with longer lifetimes (e.g. CFLs) will be under-represented in sales (as compared to stock) as they are required to be replaced less often.

3.1.7 ABS Household Energy Consumption Survey, 2012 (data source #16)

This 2012 survey used phone and web-based surveys to ask around 12,000 Australian householders a large number of questions regarding their energy use. 80% of respondents reported using energy efficient light bulbs (such as CFLs) for the majority of lights. Around half of respondents reported using halogen lights. 5% reportedly had LEDs installed. ABS survey results are considered representative, although there may be some uncertainties associated with householder survey responses. The results from this study were used as a guide for entries in the ReLAMP model.

3.1.8 ABS Population Survey Monitor for Selected Months (November 97, February 98, May 99, August 99) (data source #19)

The ABS Population Survey Monitor (ABS reference 4103) was a study that covered a wide range of topics, including lighting data. The number of rooms lit by fluorescent lights (expected to be linear fluorescents) were recorded in November 1997, February 1998, May 1999 and August 1999. The survey findings were weighted to the total Australian housing stock, and are split by State. Responses were gathered by surveying households through a telephone or online questionnaire.

The key output of this study is the fluorescent stock, and results from survey to survey appear constant, which is expected for this time period. This data is moderately useful to ReLAMP, in that it provides a base line trend for changes in fluorescent lamp stock for Australia (albeit over a brief period) prior to the wider introduction of CFLs. The data also includes room numbers, which may also be useful to ReLAMP. ABS survey results are considered representative, although there may be some uncertainties associated with householder survey responses. The trends in the numbers of fluorescent lamps from 1997 to 1999 were used as a guide for entries in the ReLAMP model.

3.1.9 BIS Shrapnel – Lighting Installed in New Dwellings, 2009 (data source #4)

The report Lighting Installed in New Dwellings (BIS Shrapnel 2009), concerns a 2007 survey documenting the lighting installed in new dwellings in Australia. The results relate to luminaires, lamp technology types and lighting control systems. The survey covers 17,444 detached houses. The data was gathered from online interviews with 101 residential builders.

The study found that around 5 million lamps were installed in new houses in 2007 (the data is weighted for all new dwelling stock), with 57% of these being downlights, and 29% being batten holders (regular Edison/bayonet lamp holders). There were on average 49 fittings per house, comprised of 52% ELV halogen downlights, 27% incandescent lamps, and 10% CFLs. This data, while focusing on new dwellings (which are on average larger than the existing stock), appears to be quite consistent with the data obtained from the 2010 Residential Lighting Report (E3 2013a; data source #1).

The data is useful to ReLAMP, as it provides an insight into the types of lighting technologies being installed in new dwellings in Australia. The data also includes lighting control systems (e.g. dimmers, motion sensors) which may be useful. The BIS Shrapnel survey results are considered reliable, although there may be some uncertainty related to builder survey responses. The proportion of lamp technologies installed in new dwellings in 2007 was used as a guide for entries in the ReLAMP model.

3.1.10 EECA Energy End Use Database (data source #12)

The Energy Efficiency and Conservation Authority (EECA) of New Zealand has a publically accessible energy end use database (www.enduse.eeca.govt.nz). The database shows the energy delivered/used (in terrajoules – TJ), by end use and sector.

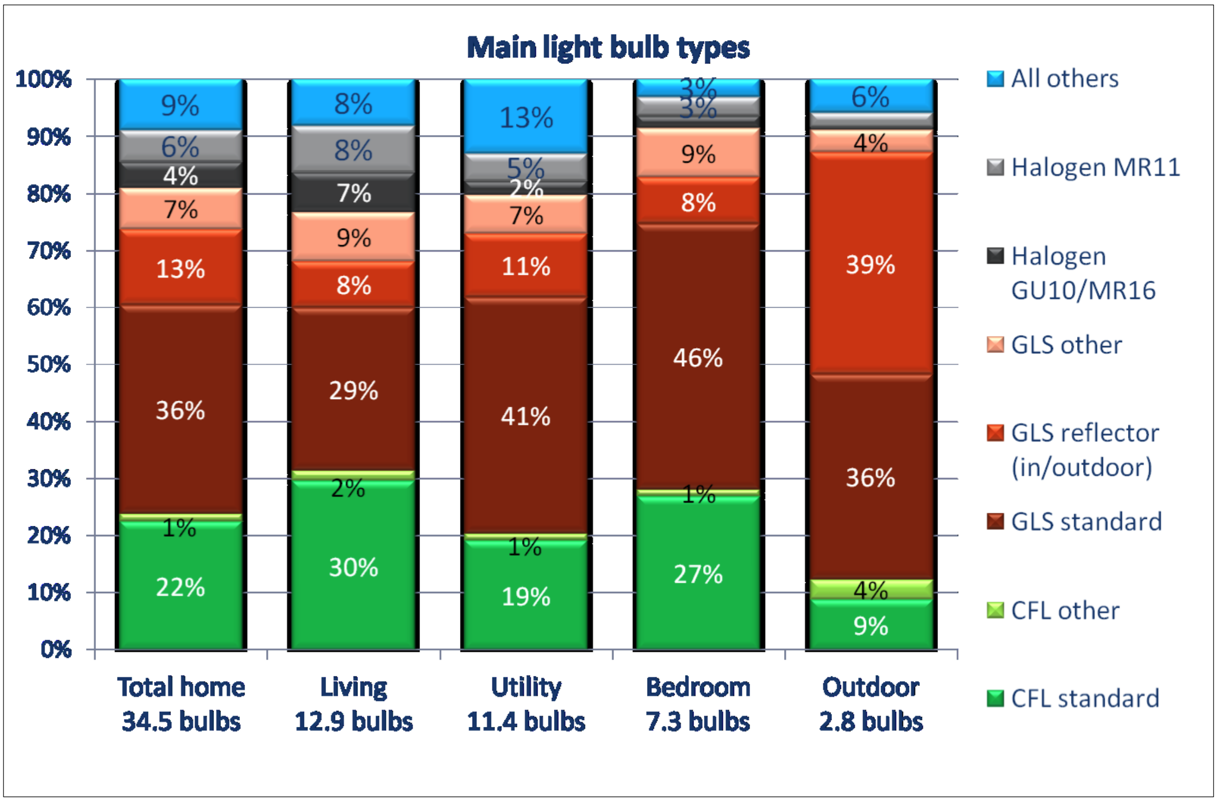
For New Zealand in 2007, the total energy used by residential lighting was reported as 5379 TJ. This reportedly increased to 5523 TJ in 2012. This data was used as a reference point for the energy results of the ReLAMP model.

3.1.11 New Zealand EECA / IPSOS Lighting Report 2012 (survey) (data source #14)

In 2011-2012, EECA and IPSOS surveyed 149 New Zealand homes. This was a comprehensive in-home survey of residential lighting in New Zealand, complemented by a survey to understand demographics and behaviour. The study comprised an in-home visual survey by trained personnel, as well as paper-based survey. This was an update of an EECA survey on lighting undertaken in 2009.

The study found an average of 34.5 lamps per New Zealand home, of which 9.5 were efficient types, and 25 inefficient types. On average 8.3 lamps were CFLs (an increase of 38% since 2009) and 1 fitting was fluorescent. 19.7 GLS incandescent lamps and 3.5 halogen lamps were present. On average, LEDs were less than 1% of total lamps found. A breakdown of lamp types found can be seen in Figure 9.

Figure 9 – Main lamp types in New Zealand homes, from EECA / IPSOS Lighting Report 2012 (survey)



The data is useful for ReLAMP, as it provides an update to an earlier EECA study, and a comprehensive snapshot of the lamp stock and type, room details and usage details for lighting in homes in New Zealand. The study is weighted to the 2006 New Zealand Census, and can be regarded as representative. The data also includes demographics and dwelling characteristics, which are useful. The survey does carry some uncertainty as it is based on an online survey completed by householders.

The outputs from this study and report were used extensively as a baseline for the New Zealand portion of the ReLAMP model. As the data is from 2012, it allows the lighting stock and usage trends from the 2009 EECA study to be updated.

3.1.12 EECA / RightLight sales data (data source #15)

The following are the total sales numbers (and number of registered suppliers) of MEPS-registered lamps in New Zealand for 2013:

- Ballasts: 147,761 from 7 suppliers
- CFLs: 2,612,134 from 5 suppliers
- Linear fluorescent lamps: 2,484,454 from 12 suppliers.

Sales data is collected annually with regulated products. Linear fluorescent lamp and ballast sales data has been collected since 2004, and CFL sales data has only been collected since 2013. These data are also discussed in the following section 3.1.13.

3.1.13 Statistics New Zealand – New Zealand Lamp import data (data source #13b)

Similar to Australia, the imports of lamps into New Zealand is considered a good proxy for lamp sales, and time-series data for lamp imports is readily available. The New Zealand import data is however likely to be subject to limitations similar to the Australian import data (see section 3.1.6).

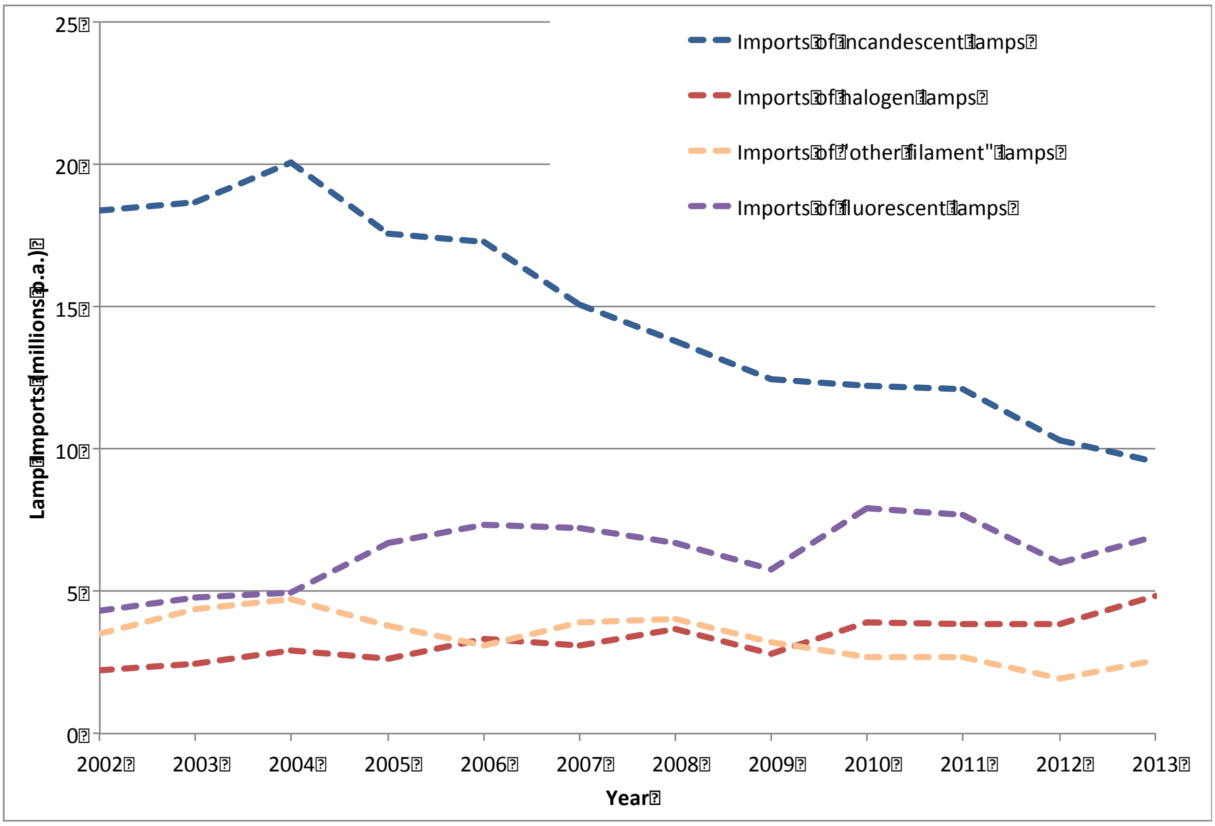
The categorisation of lamps imported to New Zealand is less detailed than for Australia, which creates some difficulty in identifying lamps and the likely destination when installed (residential or non-residential).

Figure 10 graphs imports of lamps into New Zealand. The import data incorporates four relevant categories:

- incandescent lamps;
- halogen lamps;
- other filament lamps; and
- fluorescent lamps.

It is possible that "other filament" lamps contains both incandescent and halogen lamps, as these lamps both incorporate a filament. Therefore it is possible that there is overlap between the categories graphed – incandescent, halogen and other filament. Note also that these may be of any voltage and may be either reflector or non-reflector. In addition, it is expected that "fluorescent lamps" contains both linear fluorescent lamps and CFLs (integrated ballast and non-integrated ballast, the latter of which is predominantly used in commercial buildings).

Figure 10 – Imports of lamps, from Statistics New Zealand import data



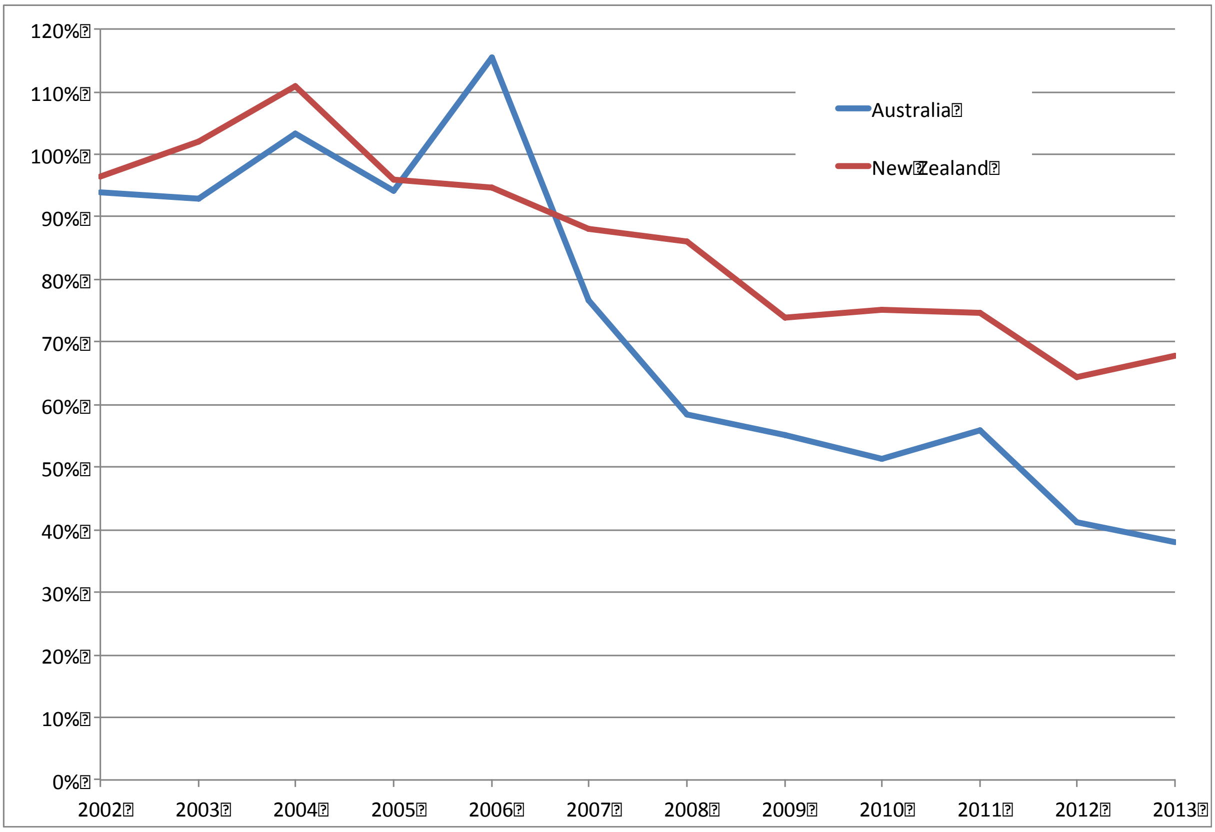
The New Zealand import data show that there were around 7 million fluorescent lamps imported into New Zealand in 2013 (Figure 10). The EECA / RightLight sales data (data source #15) shows that 2.6 million CFLs were imported in 2013, along with 2.5 million linear fluorescent lamps. The remaining approximate 1.9 million fluorescent lamps are likely to be non-self ballasted CFLs as well as other fluorescent lamps that are not subject to MEPS (and therefore no sales data collected).

In order to eliminate overlap between categories, Figure 11 illustrates the imports of all types of filament lamps into New Zealand as well as Australia over the past decade. These combined data include all incandescent, halogen, reflector, low voltage lamps, etc. These lamp types have been aggregated as this is the only way to compare like-with-like for Australia and New Zealand. The import data has also been normalised such that the average for the period 2002-2006 are equated for Australia and New Zealand (i.e. = 100%).

From Figure 11 we can see that sales of filament lamps fell around 62% in Australia and around 32% in New Zealand from the period 2002/2006 to 2013. In Australia, import restrictions on GLS incandescent lamps came into effect in February 2009, whereas New Zealand undertook an education campaign promoting efficient lighting.

The New Zealand import data is useful to the ReLAMP model, as it contains a continuous time-series of lamp imports. There may however be some uncertainty related to the accuracy of lamp category reporting by lamp importers, as well as overlap between categories as mentioned above. Other limitations of import data are discussed in section 3.1.6.

Figure 11 – Imports of all types of filament lamps into Australia and New Zealand (normalised)



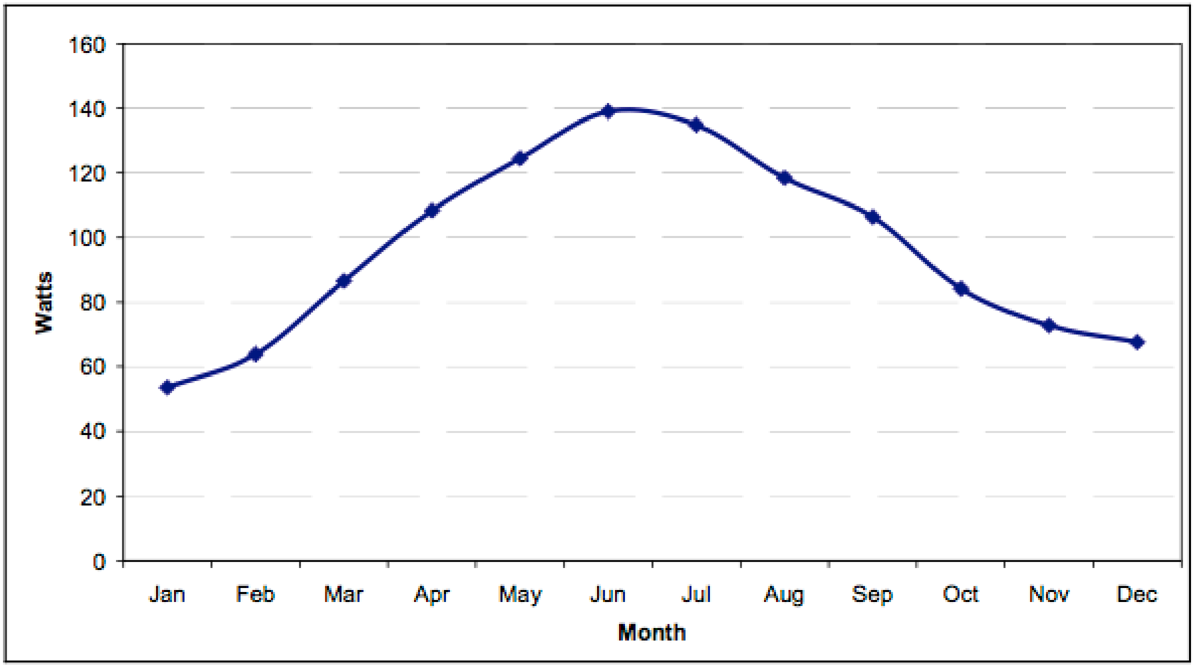
3.1.14 BRANZ Energy Use in New Zealand Households (data source #10)

This 2010 BRANZ study (Isaacs et al 2010) relates to the Household Energy End-use Project (HEEP) which monitored houses over the period 1997-2005. The study monitored 400 houses at various times over this period, and examined many facets of energy consumption, including lighting. It found that lighting made up 8% of household energy consumption, with hardwired lighting using 915 kWh/year and plug lighting using 40 kWh/year. The study also found a positive correlation between fixed lighting and floor area. Figure 12 shows average monthly lighting power for New Zealand households. The pattern shown in this figure is similar to that found in the Australian Residential Lighting Survey Pilot (E3 2013b; data source #2).

The study is useful to the ReLAMP model, as it provides an overview of lighting energy use in New Zealand. Due to the sample size, it can be regarded as reasonably representative. The study also includes demographic, dwelling details and user attitude details.

Energy consumption information in the study will be used to check the energy results of the ReLAMP model (section 4.3).

Figure 12 – Average monthly lighting power for New Zealand households, from BRANZ Energy Use in New Zealand Households, 2006-2010



3.1.15 BRANZ Home Lighting Survey, 2009 (data source #11)

The New Zealand Home Lighting Survey (Burgess and Camilleri 2009) was undertaken by BRANZ in 2009. It is a comprehensive in-home survey of residential lighting in New Zealand, complemented by a telephone survey to understand consumer demographics and behaviour. 140 houses were visually surveyed by trained personnel, and a telephone survey was used to understand occupancy, demographics, behaviour, etc.

The study found an average of 30 lamps per home – 18 of which were incandescent, 6 CFL, 3 halogen, 1 linear fluorescent, and 2 unidentified. The technology with the highest average use (per lamp – i.e. regardless of number installed) was the 50 W halogen downlight. It was found that the physical characteristics of the house impacted on the lighting make-up more than demographics. Table 3 shows lighting power density, by room type.

Table 3 – New Zealand lighting power density, from BRANZ Home Lighting Survey, 2009

Lighting power density by Zone (W/m^2) n = 150				
Zone	**National**	**Region A**	**Region B**	**Region C**
All Zones in home	13.56 ± 0.58	14.51 ± 1.38	13.50 ± 0.91	13.31 ± 0.82
Utility Zone	21.08 ± 1.31	22.66 ± 3.11	19.83 ± 2.04	21.42 ± 1.83
Living Zone	13.09 ± 0.76	13.23 ± 1.51	14.77 ± 1.20	12.36 ± 1.27
Bedroom Zone	9.82 ± 0.49	10.21 ± 0.98	9.69 ± 0.88	10.16 ± 0.73
Note regarding climatic regions used: region A = Coromandel and Franklin districts and all districts north of these (NZS4218 climate zone 1), region B = remainder of the North Island (NZS4218 climate zone 2 and the central North Island which is in climate zone 3), region C = South Island (rest of NZS4218 climate zone 3).				

The study is very useful to the ReLAMP model as it provides a baseline for lighting stock for New Zealand. As well as a comprehensive snapshot of the lamp stock and type, room details and usage details for lighting in homes in New Zealand were recorded. The study is weighted to the 2006 New Zealand Census, and can be regarded as representative. The data also includes demographics and dwelling characteristics, which may be of use in the future. The outputs from this study and report were used extensively as a baseline for the New Zealand section of the ReLAMP model.

3.1.16 BRANZ Lighting in New Zealand Homes, 2009 (survey) (data source #17)

This academic paper (Burgess, Camilleri and Saville-Smith 2007) is based on the BRANZ 2009 survey into Lighting in New Zealand Homes (data source #11) and covers similar topics.

3.1.17 SV Green Light Reports, 2008, 2009 and 2010 (data source #8)

The SV Green Light Reports were released in 2008, 2009 and 2010, for the purpose of gaining an understanding of the environmental attitudes and behaviours of Victorians. They include data on lighting technologies used in Victorian dwellings, by region. Also included are consumer attitudes to lighting and purchase intentions. The data was captured using a telephone survey, with findings outlined in Table 4.

Table 4 – Percentage of Victorian houses fitted with various lamp types, from SV Green Light Reports, 2008, 2009 and 2010

Green Light Victoria Findings	2008	2009	2010
% of houses with incandescent lamps	59%	53%	29%
% of houses with fluorescent lamps	39%	38%	32%
% of houses with CFLs	62%	66%	76%
% of houses with halogen downlights	39%	40%	29%
Average number of CFLs per house	7.8	9.2	11.8
Average number of halogen downlights per house	11.8	12.0	12.8

From 2008 to 2010, there appears to have been a move away from incandescent, fluorescent and halogen lamps, towards CFLs. The average number of both CFLs and halogen downlights per house appeared to be increasing.

The study is useful to the ReLAMP model as it provides trends on lighting technology changes in Victoria. The study is weighted to the 2006 Australian Census, and can be regarded as representative for Victoria. The data also includes demographics, dwelling characteristics and user attitudes.

3.1.18 SV Victorian Residential Energy Monitoring Program (REMP), 2012 (data source #21)

The SV Residential Energy Monitoring Program (REMP) was undertaken in 24 Melbourne houses from August 2010 to June 2012. This pilot study recorded all aspects of electricity consumption over an 8-12 week period for each house, which included data logging for selected lamps and lighting circuits. This included the power consumption of all lighting circuits (where present – 10 minute intervals), lamp on-time data for 10 individual hardwired lamps (10 minute intervals), and the consumption of a number of plug lamps (power data 1 minute intervals). Preliminary analysis indicates that lighting use in households is very difficult to pigeonhole into a demographic type, and that technology and lamp-to-switch ratio also plays a large role in total consumption.

The key outputs of the study are lamp stock, room details, usage details, and time of use data. A complete circuit and lighting audit was undertaken, and usage questions were asked (using the same format as in the E3 2010 Residential Survey and the E3 REMP Pilot).

The data is extremely useful to ReLAMP, although the study has a small sample size. The self-selected households were a mix of types and demographics, and although there was some effort to correct for bias, the sample is not considered representative. Due to this and the sample size, the dataset should be treated with some caution.

The data, use responses and analysis from this study may be used to better equate actual lighting use with householder responses. For the purposes of the ReLAMP model, an analysis was undertaken of the hours of use per lamp by room type, with (seasonally adjusted) results as follows:

- Weighted average for whole house: 1.4 hours.
- Living: 2.3 hours.
- Sleeping: 1.0 hours.
- Indoor-other: 0.8 hours.
- Outdoor: 0.8 hours.

Although imperfect, this data is considered the best available for Australian lighting usage. The major drawback with this data set is that the monitoring was undertaken for a relatively short period (around 2 months) so seasonal effects of lighting usage and energy cannot be readily determined from the data for each house (although a seasonal adjustment was performed). Houses were measured on batches of 4 or 5 and these were installed and removed at random times throughout the year over about a 22-month period. While on average, it is known that lighting usage is quite seasonal, the seasonality at an individual house level can be quite varied.

3.1.19 DHS Victorian Utility Consumption Household Survey, 2008 (data source #7)

The Victorian Utility Consumption Household Survey was undertaken by Roy Morgan Research in 2007 (report released in 2008) on behalf of the Victorian Department of Human Services (DHS). The survey was a written survey and interview of 2,061 homes, covering many aspects of household energy consumption, including lighting. Lighting data includes lighting technologies used in rooms throughout the house, split by region of Victoria and income (concession) level. These surveys typically cover representative samples of typical houses as well as low income houses, for comparison. The study report noted around 52% of houses used fluorescent lighting as the main source of lighting in kitchens, 56-75% used incandescent lighting in other rooms, mostly as incandescent globes (41-70%).

The raw data was analysed, by the authors of this report, into broad room types by technology, providing excellent data in the form required by the ReLAMP model. Hence the data is very useful for ReLAMP, as it provides lighting data by technology and room for Victoria. Note however that the BIS Shrapnel survey (data source #4) indicates that, for new Victorian homes built in 2007, 73% of light fittings were "small receded" (downlights) compared to 55% Queensland, 49% Western Australia, 44% NSW and 35% South Australia.

The DHS survey does contain some uncertainty as it is generated from householder responses although the survey was undertaken in person and used flashcards as prompts, so responses should be more reliable than through a telephone survey. The study also includes demographic, dwelling detail and utility data.

The outputs from this DHS study were used as inputs to the baseline for the Australian section of the ReLAMP model. As the data is from 2007, it provides a good trend to be established in the lighting stock through to the 2010 Residential Lighting Study.

3.1.20 South Australian DTEI Results from household survey on the use of energy appliances and products in the home (data source #6)

In 2011, the South Australian (SA) Residential Energy Efficiency Scheme (REES) released the results of a household survey related to the energy use of appliances and products in households. This was undertaken by ABS for the South Australian Department of Transport, Energy and Infrastructure (DTEI) and included some findings with respect to lighting. The study outlined the potential to change technologies from incandescent to CFL, 50 W to 35 W halogen, and total lamp numbers in South Australian homes.

The study was weighted to 530,000 houses, using 2,500 telephone survey responses. The survey suggests that 47% of 'non-priority households' (non-low income households) have 4 or more traditional (incandescent) lamps which are not connected to dimmers.

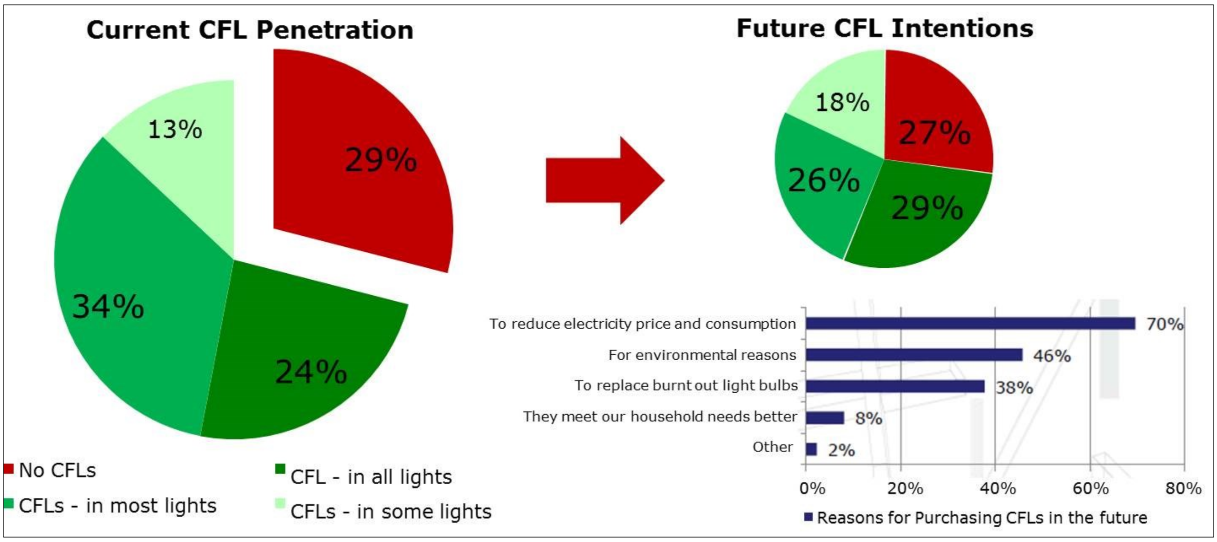
The study is useful to the ReLAMP model as it provides trends on lighting technology changes and user attitudes in South Australia. The study is weighted to the 2006 Australian Census, and can be regarded as representative. The data also includes demographics, dwelling characteristics and lighting control systems, which may be of use in the future. There were a range of 'don't know' responses concerning lighting, which may skew the results where these consist of a significant share of the responses.

3.1.21 Queensland Household Energy Survey 2009, 2011 and 2012 (data source #9)

The Queensland Household Energy Survey was conducted in 2009, 2011 and 2012, by Colmar Brunton Intelligence for utilities Energex, Ergon Energy and Powerlink. It includes data on lighting technologies (CFL and LED) used throughout Queensland households, by region. The dataset also includes lighting attitudes and intentions to change technologies, for example, CFL penetration and future purchase intentions for 2009 (see Figure 13; these were largely unchanged in 2012).

The data was captured using an online survey which found that state-wide CFL ownership increased from 71% in 2009 to 76% in 2012.

Figure 13 – Queensland CFL penetration and intentions, from Queensland Household Energy Survey 2009



The study is useful to the ReLAMP model as it provides trends on lighting technology changes in Queensland. The study is weighted to the 2006 Australian Census, and can be regarded as representative for Queensland. The data also includes demographics, dwelling characteristics and user attitudes.

3.1.22 Ausgrid SHAPE Data (data source #22)

The Ausgrid SHAPE Data Analysis Final Report was prepared by Energy Efficient Strategies (EES) in June 2013. In 2011, Ausgrid purchased OmegaWatt end use metering equipment to undertake a pilot end use energy monitoring program – the Ausgrid SHAPE Trial. A sample of 15 houses was selected, with participants being drawn from Ausgrid staff members and associates across the Sydney region. Ausgrid contracted EES to install the metering equipment and undertake the initial data processing. The houses were spread around Sydney in essentially random locations, with a slight bias towards the north and a slight bias away from the south west. Most were in the Ausgrid supply territory, with a number outside.

The final report documents the energy analysis of all metered channels for houses included in the SHAPE Trial. This includes approximately 12 switchboard circuits (on average), and around 15 individual plug-in appliances for each home.

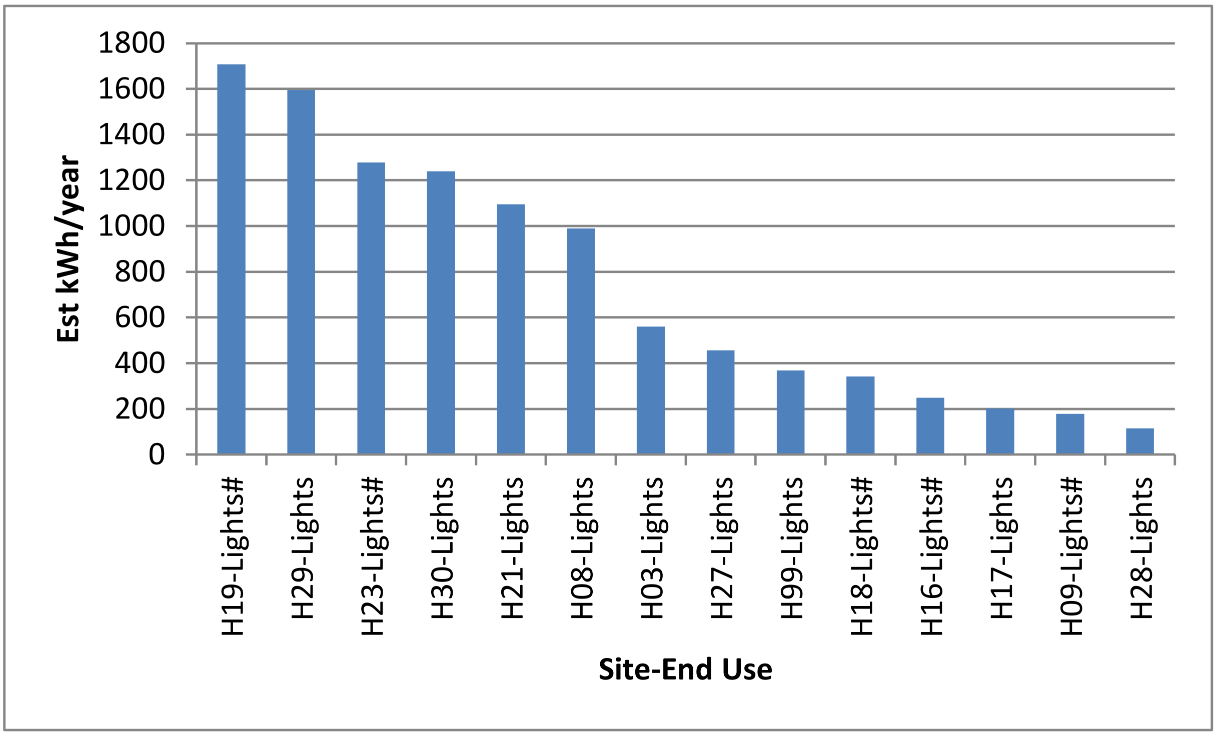
In most houses, lighting is a significant proportion of the total energy consumption. In the SHAPE sample one house did not have any separate lighting circuits while another 5 houses had separate lighting circuits. However, the lighting audit revealed that more than 20% of all household lights were on circuits other than these dedicated lighting circuits. These are marked with # in Figure 14. Even so, there is a large range in the energy consumption of the sample houses, with the highest to the lowest being a factor of more than 10 times. As with most end uses, the energy for lighting is a function of the number of lights, lighting efficacy (as well as the level of illumination) and user habits. In Figure 14, the houses with higher energy had almost 100 lights while the houses with the lower energy had few than 40 lights (noting that the average national value is around 50 lights per house). There is no doubt that lamp technology is an important driver – houses with large numbers of ELV halogen downlights generally had higher lighting energy.

Note that Figure 14 does not show total lighting energy consumption for each house – graphed is energy consumption only for the lighting circuits measured.

The Ausgrid SHAPE trial did not generally measure the on time for individual lamps (special meters are required to do this). One house had a number of plug in lamps that were directly metered using normal inline energy meters.

Most houses showed a seasonal pattern of usage as expected (higher in winter, lower in summer). Similarly, most houses showed peak usage in the evening, and many (but not all) houses had some morning use.

Figure 14 – Estimated annual energy for monitored lighting circuits



The energy estimates from this analysis were compared against the results from the ReLAMP model, although as noted above the Ausgrid analysis does not estimate total lighting energy consumption for each house.

3.1.23 General Conclusions from Reports and Data

The ReLAMP model makes use of a broad range of Australian and New Zealand studies that have covered various aspects of lighting over the years. This report includes the most complete dataset summary and review for lighting. The numbers of reports and data sources are categorised in Table 5.

Table 5 – Categorisation of data sources

	Australia	New Zealand
Number of reports	13	6
National reports	8	6
State reports	5	N/A
Data from the 1990s	1	
Data from 1997-2005		1
Data from 2006-10	8	2
Data from 2011-13	4	2
Time Series data	1	2
Projects/studies where lighting was a primary focus	6	4
Projects/studies where lighting was a component only	7	2

Not all of these data sources were used extensively in the ReLAMP model. Depending on the focus of the data source and the form of any quantitative data, elements of data may have been used as a guide, to corroborate other published data and trends, or to assess outputs from the ReLAMP model.

It can be seen for both Australia and New Zealand that there is a lack of data prior to the mid-2000s. The number of projects that included lighting conducted after 2005 coincide with development of policies in both countries to move the market from incandescent lamps to CFLs. The lack of historical data is troublesome, although the range of more recent studies does alleviate this issue somewhat. However, ongoing data collection efforts need to improve in order deepen the current level of understanding of the lighting market in Australia and New Zealand.

It appears that the lighting policies of the late 2000s did have a significant impact in both Australia and New Zealand, as shown by the change in imports – filament lamp imports fell around 62% in Australia and around 32% in New Zealand over the period 2002/06 to 2013 (refer to Figure 11). Counter to this, there has been an anecdotal trend of increasing sales and penetration of halogen downlights experienced in both countries. Collection and analysis of import data is extremely important to understand broad market trends – this is available in both Australia and New Zealand and has been a key input into the ReLAMP model.

Both countries undertook physical audits of residential lighting in recent years. For Australia this was the 2010 Residential Lighting Report (E3 2013a), and for New Zealand the 2012 EECA/IPSOS Lighting Report (an update of a 2009 study). Both studies had a sample of around 150 houses, and included a complementary data collection on householder behaviour and attitudes. The average Australian household was found to have 48 lamps, while in New Zealand this number was found to be 35. While the Australian number is higher, another New Zealand study found that there is likely to be a correlation between number of lamps and floor area. It is possible that larger houses, especially in new Australian housing stock, explain much of the difference in total lamp numbers (given that average floor areas are slightly larger in Australia). Australian households also have a higher penetration of ELV halogen downlights than New Zealand, resulting in more lamps per square metre. The data from both reports have been extensively used to establish baselines for the ReLAMP model.

The audit reports also gave an interesting comparison of installed lighting technology between Australian and New Zealand homes. While both countries had a similar proportion of CFLs installed in the average house (24–30%), the remainder of installed lighting was predominantly GLS incandescent lamps in New Zealand homes (57%) compared to a mixture of incandescent and ELV halogen lamps in Australian homes (totalling 57% of installed lighting).

For both Australia and New Zealand, there are a number of reports focussed on householder lighting use. In general, the householder responses to these surveys uphold the trends established by other studies. However, physical measurement of lighting, such as time-of-use monitoring is preferable to survey data (which is less reliable and heavily influenced by recent recollection). Some limited analysis of consumer response versus actual use of lights shows a broad correlation but unsurprisingly, a large variability.

Time-of-use monitoring data is extremely important for successfully assessing the energy consumption characteristics of lighting in houses. Historically, this has been a missing data link for many end uses including lighting, but fortunately for Australia at least there has been some recent work in this area. The 2010 REMP study (E3 2012) and the 2012 SV projects have both provided excellent real data for both lighting circuits and individual lamps. However these measurements are based on just a small handful of households and there are complications such as short measurement period for the SV data (a few months for each house) and a limited number of individual lamps covered due to difficulties in monitoring all lamps in a house. Unfortunately, time of use data is largely missing for New Zealand (at least in recent years), but the use of Australian data as a proxy could be sufficient in the first instance.

For paper, online or telephone questionnaires, it can be difficult to fully assess the accuracy of householder responses – bias, question format and psychological factors can all play a part in the answers that are given. It is well known that consumers are attuned to understanding the topic being investigated in a survey and this in turn is likely to influence their responses (e.g. a survey that is clearly about energy conservation is likely to illicit responses from the participant that paint them in a positive light if they believe this is an important or morally loaded topic – even if they are not very energy conscious in practice). This in turn will impact on the data derived from a questionnaire and the analysis in which it is used in. Good survey design which minimises the effect of bias is critical. Careful segmentation of the sample can also ensure that it accurately reflects different attitudes and helps to reduce inconsistencies and sample bias. Fortunately, many of the data sources available are from the ABS or BRANZ, both of which have significant capability in this area.

3.2 Lighting Attitudes and Behaviours

This section deals specifically with the reports and data sources that studied consumer attitudes and behaviours (aside from usage which is discussed in section 3.1) in relation to lighting. The key aspects from each report are summarised in the following sections. Note that these sources are not directly useful as inputs to the ReLAMP model, which does not deal with consumer attitudes and behaviours.

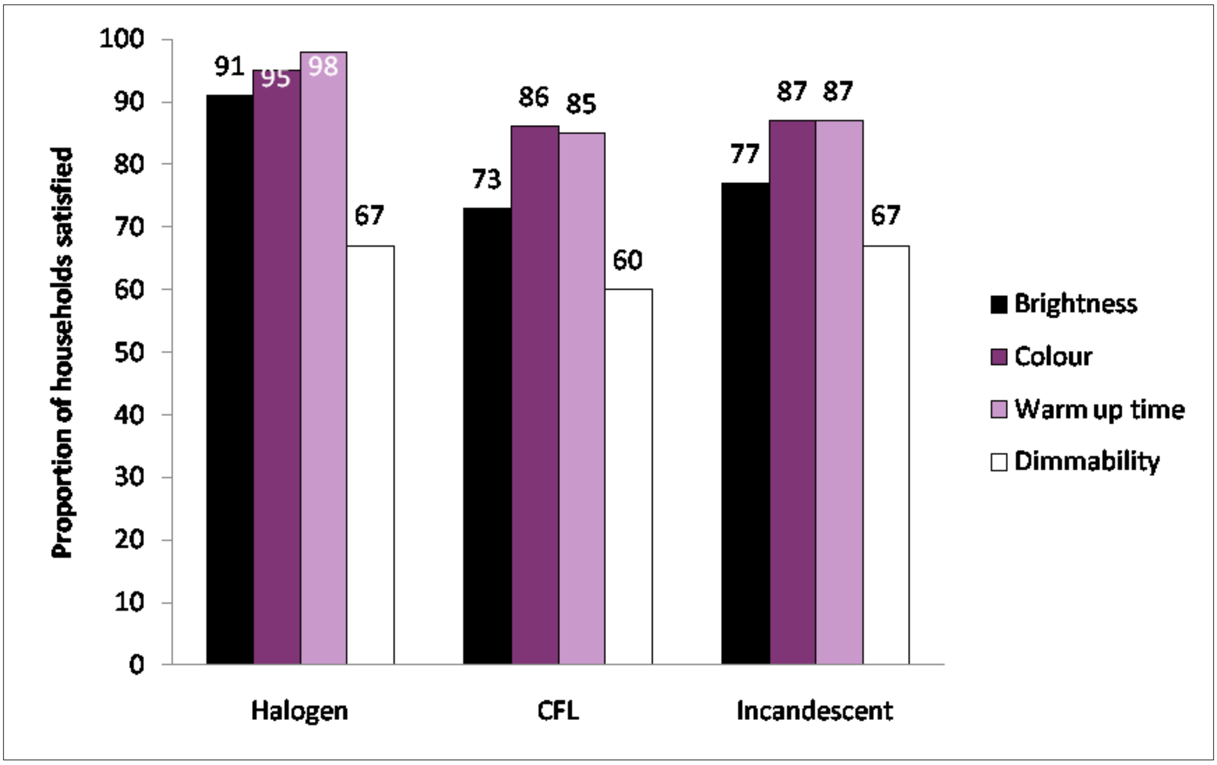
3.2.1 E3 Australian Residential Lighting Survey Pilot, 2013 (data source #2)

This study was undertaken in Australia in 2010, and included were a wide range of householder questions concerning behaviours and attitudes towards lighting.

Switches: It was found that 66% of people were satisfied with their current light switches, while 18% wanted to move their switches to better positions and 3% wanted less switches. Householders in older homes saw more reason to change than those in newer homes.

Lamps: Asked about the lighting that is used the most often in their living space, 80% of householders were satisfied with the brightness, 92% with the colour, 91% with the warm up time and 67% with the ability to dim the lights in this space. The satisfaction with lamp technologies is graphed in Figure 15 and indicates higher levels of satisfaction with halogen lamps compared to CFL and incandescent. Note that halogen includes ELV halogen downlights in this study.

Figure 15 – Satisfaction with various lamp types



Changes Undertaken: Around 49% of households indicated they had changed some of the light fittings in their main living space (more than one response was allowed) – 40% because of a room renovation, 33% for energy efficiency reasons, 33% because they wanted a different type of light, 25% didn't like the style/design of the existing light and 20% moved the location of the fitting.

Influences in Choices: Of those that had changed lamps, the influences in their choices were – 29% personal preference, 19% government energy efficiency information, 17% friends/family homes, 14% from magazines, 12% due to advice from an electrician, 11% due to advice from a builder/renovator, 11% due to advice from a lighting store, 5% due to display homes, 4% television shows and 4% due to price reasons.

Influences in Purchasing: The influences on householders in their lamp purchasing decisions were (more than one response was allowed) – 77% selected energy efficiency, 75% purchase costs, 73% wattage, 66% brightness, 60% colour, 52% lamp lifetime, 36% because it was the lamp type previously used, 22% brand and 16% for warm up times.

Lamps Purchased from: 64% of householders said they purchased lights from a supermarket, 47% from a hardware store, 18% from a speciality lighting store, 3% online and 5% said other options.

Lamps Purchased when: 82% said they bought lights as required, 17% bulk buy in advance, 11% when they are on special, and 6% for other reasons.

3.2.2 SA DTEI Results from household survey on the use of energy appliances and products in the home (data source #6)

This study was undertaken in South Australia in 2011. A number of questions were asked concerning householder intentions to change lamps to more efficient alternatives. 31% of households which contained 4 or more incandescent lamps were interested in changing them to CFLs. 23% of households had at least 4 changeable halogen lamps and were interested in changing these to more energy efficient globes.

3.2.3 BRANZ Home Lighting Survey (data source #11)

This survey was carried out in New Zealand in 2009 and investigated a series of lighting behaviours and intentions. Over the 2 years 2007–2009, 22% of residential lamps in New Zealand were changed. The most common change (68% of all changes) was from a standard incandescent lamp to a CFL. Around 74% of householders reported they used energy efficient lamps, and 8% said they would in the future, while 7% reported dissatisfaction in these lamp types. The main reasons for changing to energy efficient lamps were given as aesthetics (24%), energy efficiency (17%), light quality (16%), and initial cost (16%).

3.2.4 EECA/IPSOS Lighting Report 2012 (data source #14)

This report concerns a survey on lighting in New Zealand undertaken in 2012. It is an update on the 2009 BRANZ survey, although there are some differences in the behaviour and lighting intention questions asked.

It was found that 59% of houses had changed the style or type of bulbs between 2010 and 2012, with 89% of these changes being undertaken by someone in the house, and 11% by an electrician. Around 71% of householders said they bought their bulbs from supermarkets, 19% from a hardware store, 12% from a lighting specialist, and the remaining from other outlets.

When asked the main reasons for switching to an energy efficient bulb, 20% of householders said the on-going cost of operating the bulb, 17% said because of an energy efficient fitting or ability to use energy efficient bulbs, 16% due to better quality light, more reliable 9%, bulb look 5%, expert recommendation 5%, bulb purchase cost 4% and recommendation by other was 3%.

Around 20% of householders were unhappy with their energy efficient lighting – 59% of those dissatisfied said it wasn't bright enough, 16% because it was the wrong colour, 11% didn't like the look of the bulb, 11% said it took too long to reach full brightness, 8% said it didn't last long enough, 4% said it was too bright, and 19% had another reason.

3.2.5 Queensland Household Energy Survey 2009, 2011 and 2012 (data source #9)

This survey was undertaken in Queensland over a number of years, the data from 2009 includes some information on lighting behaviours and intentions.

It was found that 29% of householders did not have CFLs in their homes and 13% only use CFLs in some lights (Figure 13). Of those that didn't have CFLs, 73% intended to install them in the future, 27% either didn't intend to install CFLs or didn't know when they would install them. The main reasons for installing CFLs in the future was to reduce electricity price and consumption (70%), environmentally related reasons (46%), to replace burnt out bulbs (38%), and to meet household needs better (8%). It was found that 50% of householders aged 18-24 years had CFLs compared to 80% of those aged 50+ years. Householders in Northern Queensland were less likely to have CFLs in all lights compared to those in other parts of Queensland.

3.2.6 SV Green Light Reports 2008, 2009, 2010 (data source #8)

These three reports concern surveys undertaken in Victoria in 2008, 2009, and 2010. They include a small amount of information concerning householder's attitudes to CFL lamps.

The intention to replace incandescent globes with CFLs in 2008 was 94%, 2009 was 78%, 2010 was 81%. Householders who responded that they won't replace incandescent with CFLs or were unsure in 2008 was 16%, 2009 was 22% and 2010 was 6%.

3.2.7 General Conclusions Regarding Lighting Attitudes and Behaviours

For both Australia and New Zealand, there are a number of reports focussed on householder lighting behaviour and attitudes towards purchasing and changing lamp technology. The attitude / behaviour studies assessed in this report all use differing methodologies and survey questions, making comparison between them difficult. However, where possible, some common outcomes are stated below.

In Australia, lamps are reportedly purchased from supermarkets (64%), hardware stores (47%), specialty lighting store (18%), online (3%) and from other outlets (5%). In New Zealand, this has been reported as supermarkets (71%), hardware stores (19%), lighting specialty stores (12%) and other outlets.

In Australia, several reasons were given for changing lamp types. These were all of approximately equal influence and include: room renovation, energy efficiency and dissatisfaction with the existing lights. When selecting lamps, the primary influencing factors were reported to be energy efficiency, purchase cost, wattage, brightness, colour and lamp lifetime. Of lesser influence were the type of lamp used previously, brand and lamp warm-up. Around a third of households reported being interested in changing remaining incandescent/halogen lamps to CFLs.

In New Zealand, the primary reasons for changing to energy efficient lamps were given as aesthetics, energy efficiency, light quality and initial cost. Around 20% of householders reported being unhappy with their energy efficient lighting – 59% of those dissatisfied said it wasn't bright enough, 16% because it was the wrong colour, 11% didn't like the look of the bulb, 11% said it took too long to reach full brightness, 8% said it didn't last long enough, 4% said it was too bright, and 19% had another reason.

There is a wealth of information available for policy makers concerning lighting attitudes, which can be invaluable if used in the right context.

4. The ReLamp Model

The objective of this chapter is to derive a more complete picture of lighting installed in existing Australian and New Zealand homes, for the development of better informed lighting policies and evaluation of current/past policies.

In order to achieve these objectives, a dual-national lighting model (Australia and New Zealand) was developed. Construction of such a model enables identification of the data needs required to accurately describe and make projections about the lighting market in Australia and New Zealand, and to identify current and potential future trends in lighting energy consumption. Importantly, such a model will help to evaluate the possible energy impact of changes in policy, technology and user behaviour into the future. This practical exercise is expected to lead to a more informed understanding of what the data needs are, and the extent to which existing data sources can meet these needs. Where a weakness in the data is found, this is flagged in each of the sections below.

Please note that the quantitative results of this model, whilst considered to be the best achievable with current data sources, remain subject to considerable uncertainty.

4.1 Design of the ReLAMP Model

The ReLAMP model was designed with the following objectives in mind:

- Model residential lighting energy, both historical and projected, with the ability to identify key trends that will impact on future energy consumption.
- Create a complete picture of lighting installed historically in residential buildings in Australia and New Zealand.
- Create the basis for a definitive, ongoing model for residential lighting in Australia and New Zealand, which can be updated regularly.
- Make best use of existing data sources.

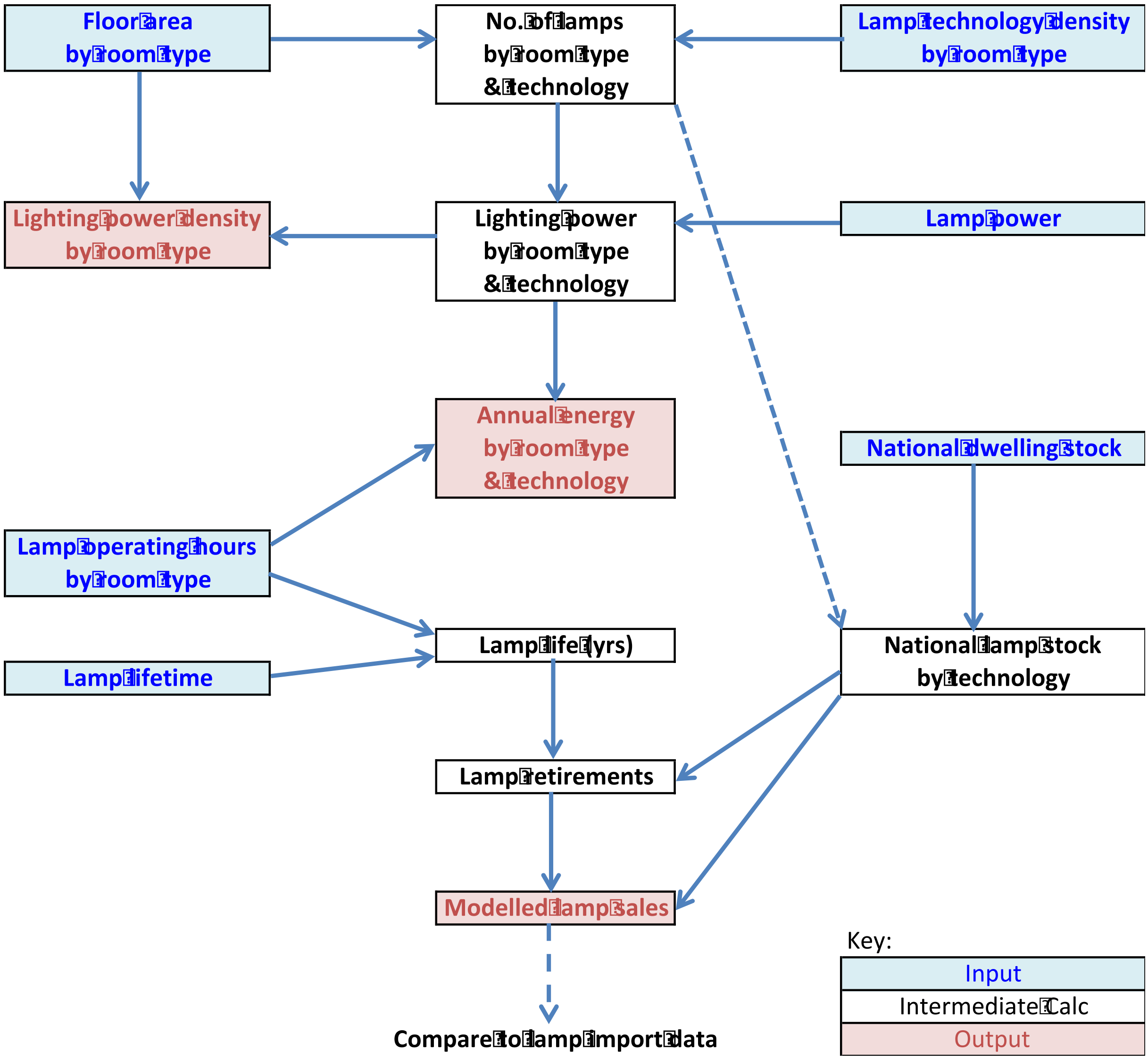
With these principles in mind, a "first pass" of the ReLAMP model was constructed using Microsoft Excel. Figure 16 is a flow chart of the model design.

At the core of the model is a representation of the installed stock of residential lamps. Historical data for lamp stocks are scarce and disaggregated. The alternative is to use lamp sales as the basis for the model, for which there is considerable data (lamp import data as a proxy for sales). However using this data creates several key modelling problems (among other direct data problems outlined in section 3.1.6):

- Lamp import quantities are volatile, and considerable smoothing is required in order to utilise these in a "stock and sales" model.
- Lamp sales data is for the entire market – identifying residential versus commercial lamp sales is difficult.

Taking these issues into consideration, the ReLAMP model was created with lamp stock as the basis, and lamp sales data (import data) was used as a comparative tool in order to check that the model outputs, particularly time-based results, were in agreement. The key attributes of the installed stock of lamps (power, lifetime) are assumed to change over time as new lamps replace existing lamps at the end of their life (stock turnover, which varies by technology). Note however that lighting is quite different to other appliances (e.g. fridges) as it is more common to replace lamps before they reach the end of their useful life. The various give away and incentive programs have resulted in mass replacement of incandescent and ELV halogen lamps, so modelled stock turnover rates may not be accurate.

Figure 16 – Flow chart of ReLAMP model



In Figure 16 the blue cells represent the key data inputs:

- National dwelling stock
- Floor area by room type
- Lamp technology density by room type (derived primarily from surveys of room sizes and lamp types)
- Lamp power
- Lamp operating hours, by room type
- Lamp lifetime

From these inputs, many outputs may be calculated. The key outputs are indicated in red in Figure 16 and are:

- Lighting power density by room type
- Annual energy by room type & technology
- Lamp sales (although use of a retirement function to estimate lamp stock turnover does present some difficulties due to the wide range of household lighting usage patterns).

The model covers the period 1990 to 2030 (with high-level forecasting only beyond 2012) and is segmented as follows:

- Lamp technologies
  - MV incandescent
  - MV halogen
  - ELV halogen
  - CFL
  - Linear fluorescent
  - LED
- Room types
  - Living
  - Sleeping
  - Indoor-other
  - Outdoor

The model is segmented in this way as the above technologies represent those commonly found in households. The segmentation of room type is primarily to allow the differing usage profiles of these room types to be captured. The effectiveness of this kind of segmentation will be examined as part of this study.

Note that beyond the last household lighting studies (2010 for Australia and 2012 for New Zealand) the ReLAMP model becomes (primarily) a lighting power density model. This is because information such as numbers of lamps and the rooms in which they are installed is too detailed for future predictions. See section 5.1 for discussion of future trends.

4.2 Key Inputs to the Model

4.2.1 Lamp Attributes

Lamp power (actually total lamp circuit power, which includes losses of any ballasts or transformers associated with a lamp) is a key input to energy calculations. The power inputs used in the ReLAMP model were derived from the E3 Residential Lighting Report (data source #1), the SV REMP project (data source #21) for 2010 and the Victorian Utility Survey (data source #7) for 2007. These are considered to be the best available data sources for lighting power, and considered suitable for both Australian and New Zealand.

The data used for both Australia and New Zealand can be seen in Figure 17. The following assumptions and estimations were also applied to the base data:

- ELV halogen total circuit power is estimated to diminish from 62 W (represents 50 W lamp with magnetic transformer efficiency of 80%) to 49 W (measured value from SV REMP data) over 1990-2010. This reflects the transition from magnetic to electronic transformers and 50 W to 35 W lamps as a result of the introduction of MEPS.
- Linear fluorescent ballast losses of 8 W (which represents a ballast with an energy efficiency index of B2).
- LED power decrease (note these are primarily MR16-style LED downlights). This is consistent with the recent (and predicted to continue) significant trend toward increased LED efficacy (US DoE 2013).

Average lamp lifetimes for both Australia and New Zealand can be seen in Figure 18. These data are typical nominal lamp lifetimes, which are estimated to increase over time for certain lamp types. Again, these are applied to both Australia and New Zealand.

Note that MV halogen lamp lifetimes are typically 2000 hours, and this has been the case for some time. Recent MEPs in Australia has meant an increase in halogen lamp efficacy, which has pushed efficacy/life trade off to the limit of commercially viable technology (source: discussions with industry). For ELV halogen lamps, an assumption was made that lamp life is increasing, due primarily to the increasing use of electronic transformers with “soft start” capability.

Note that this study does not deal with the efficacy of the lamps in homes, apart from Figure 17 (average lamp power) which is a function of lamp efficacy (assuming that illumination levels have not changed). With the exception of LEDs, the efficacy of these lamp types has not changed significantly over time and discussions with industry reveal that significant future improvements in efficacy of non-LED lamps is unlikely, as all research and development investment is being directed towards LED.

Figure 17 – Average lamp input power (new lamp sales, includes auxiliaries) (Australia and New Zealand)

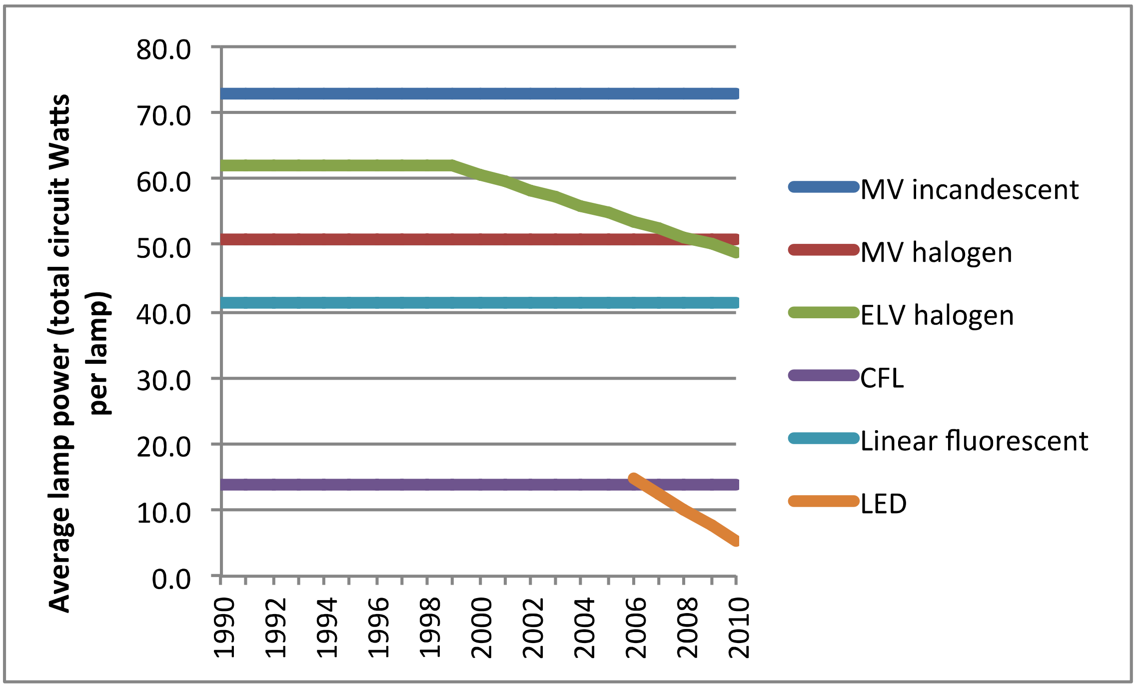
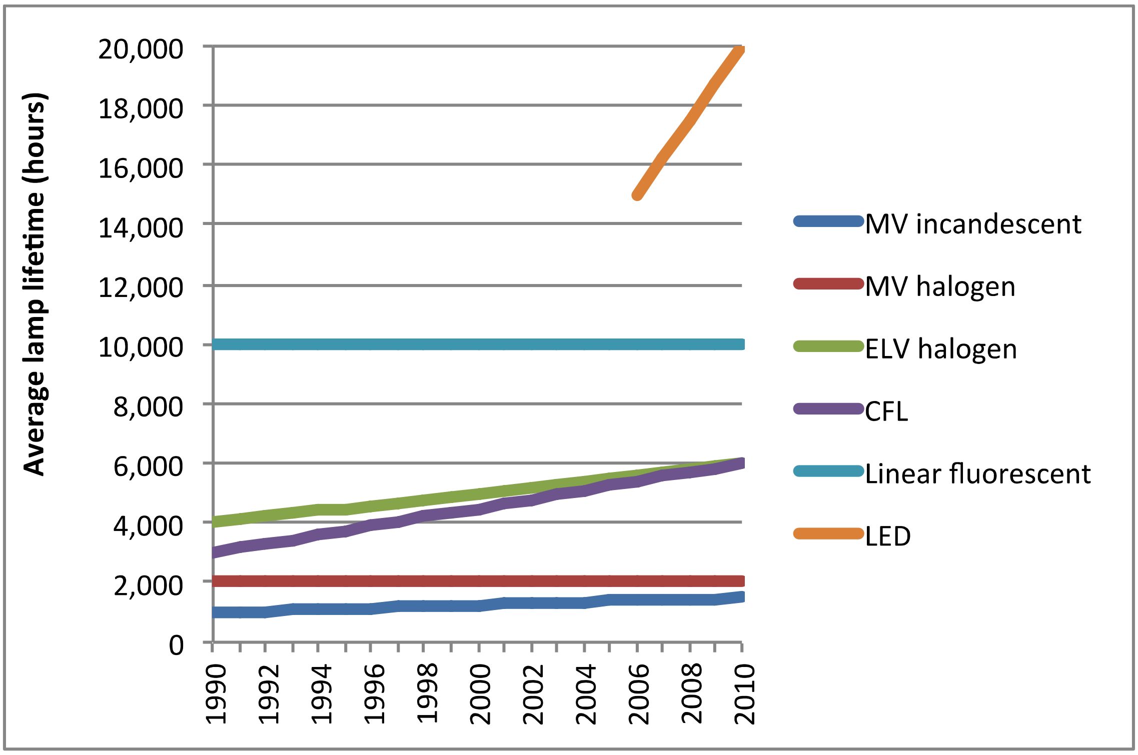
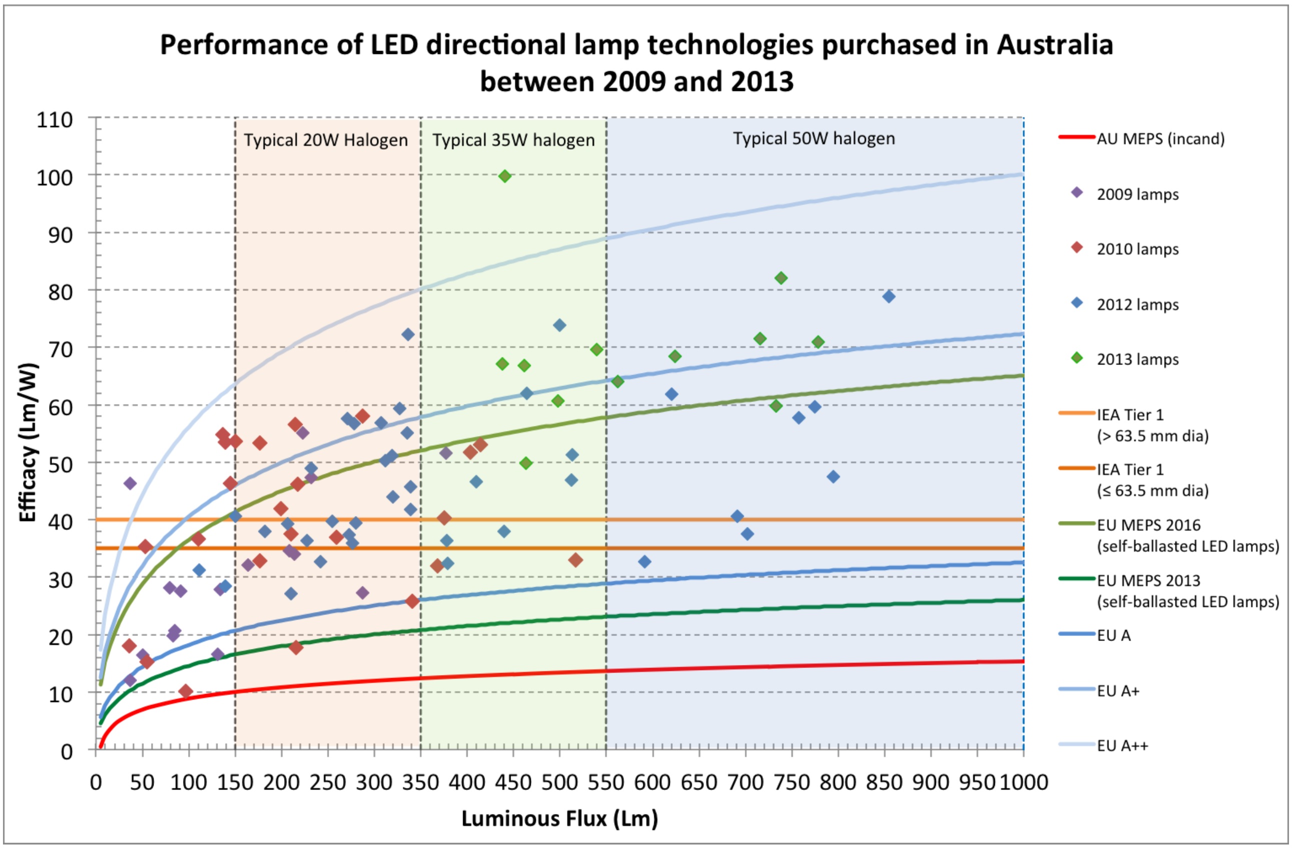


Figure 18 – Average lamp lifetime (Australia and New Zealand)



Note also that, at the time of writing, two product profiles were being prepared – one for LEDs and one for CFL, incandescent and halogen lamps. These product profiles contain extensive information about the performance of these lamps, particularly efficacy. Recent improvements in LED efficacy are graphed in Figure 19, which shows MR16 LED efficacy (and light output) improving from 2009 to 2013. This trend is expected to continue and result in estimated LED power as graphed in Figure 17.

Figure 19 – Tested efficacy of LED directional lamp technologies purchased in Australia between 2009 and 2013 (source: lamps tested by the Australian Government)



4.2.2 Operating Hours

The average lamp operating hours per day for Australia were taken from the E3 REMP project (data source #3) and the SV REMP project (data source #21). These data are considered more reliable than household surveys and considered to be the best current source of information for lamp operating hours in Australia. Seasonally adjusted results are as follows:

- Weighted average for whole house: 1.4 hours.
- Living: 2.3 hours.
- Sleeping: 1.0 hours.
- Indoor-other: 0.8 hours.
- Outdoor: 0.8 hours.

Although imperfect, this data is considered the best available for Australian lighting usage. The major drawback with this data set is that the monitoring was undertaken for a relatively short period (around 2 months) so seasonal effects of lighting usage and energy cannot be readily determined from the data for each house (although a seasonal adjustment was performed). Houses were measured on batches of 4 or 5 and these were installed and removed at random times throughout the year over about a 22-month period. While on average, it is known that lighting usage is quite seasonal, the seasonality at an individual house level can be quite varied.

For New Zealand, although data was available showing lighting usage *by room*, no data was available which gave lighting usage *by lamp*. Thus lighting usage data for New Zealand was equated to Australia.

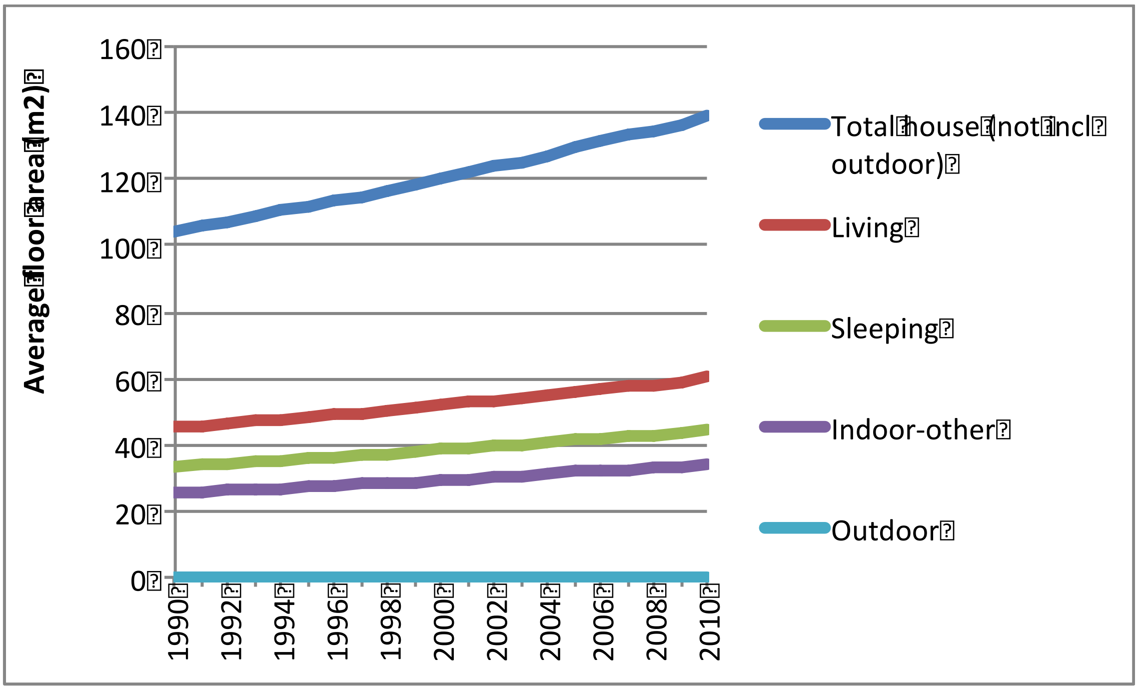
Data weaknesses: for Australia and New Zealand, the average lamp operating hours are derived from a very small sample size, and are not truly representative of the seasonality of lighting usage. Generally speaking, lighting operating hours is an area of significant data weakness.

One Australian utility has recently undertaken significant end-use monitoring of a number of dwellings (Ausgrid SHAPE data; data source #22) for periods in excess of 12 months. This data, which was kindly made available to E3, combined with data from other monitoring, could be mined and analysed in order to improve the accuracy of residential lighting usage estimates. Note however that significant analysis would be required to properly estimate this.

4.2.3 Floor Area and Dwelling Stock

The average (total house) floor area for existing Australian homes (see Figure 20) was taken from DEWHA (2008) which includes historical and projected floor area. The split of floor area, by room type, was taken from the 2010 Residential Lighting Report (E3 2013a) which contains data for houses surveyed in 2010 (although skewed to larger dwellings, as discussed in section 3.1.1). This split was applied consistently across all years in the ReLAMP model (i.e. no historical or estimated future trends in the room type split are readily available).

Figure 20 – Average floor area (Australia)



In New Zealand, the average (total house) floor area for existing homes was 121 m² in 2006, according to the HEEP study. Historical data for existing dwelling size was not readily available for New Zealand, thus the Australia historical dwelling size trend, and room type split, were also applied to New Zealand (see Figure 21).

Note that the classification of room types between the key Australian study (data source #1) and key the New Zealand studies (data sources #11 and #14) is somewhat different. Table 6 shows the classifications, and the key differences are shown in red bolded text. Note that in the ReLAMP model, the New Zealand "utility" areas have been equated to "indoor-other".

We can see that there are at least two rooms that are classified significantly differently – study/office and garage. However, as the New Zealand studies do not appear to record the sizes of the room surveyed, it is difficult to reclassify room types without further significant research.

The national dwelling stock for Australia (i.e. total number of dwellings) was taken from ABS Census data. For New Zealand, dwelling stock was taken from Statistics New Zealand Dwelling and Household Estimates.

Data weaknesses: historical and projected floor area breakdowns (split by room types) for Australia and New Zealand are both currently equated to Australian homes in 2010. There are also some differences in the classification of room types between Australia and New Zealand.

Figure 21 – Average floor area (New Zealand)

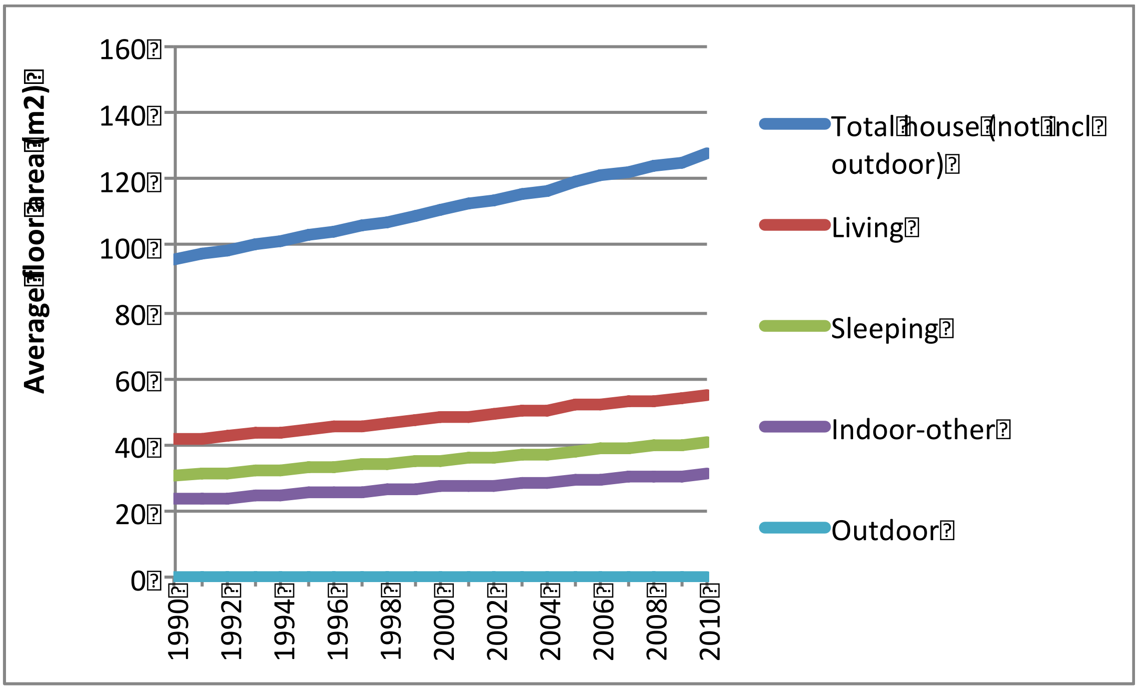


Table 6 – Classification of room types in Australian and New Zealand Studies

Room	Australia	New Zealand
Dining	Living	Living
Kitchen	Living	Living
Kitchen/Living	Living	Living
Lounge	Living	Living
Living-other	Living	Living
Conservatory	-	Living
Bedroom	Sleeping	Sleeping
Study / office	**Sleeping**	**Utility**
Basement	-	Utility
Rumpus	-	Utility
Bathroom	Indoor-other	Utility
Foyer-inside	Indoor-other	-
Hallway	Indoor-other	-
Laundry	Indoor-other	Utility
Other-inside	Indoor-other	-
Pantry	Indoor-other	Utility
Storage Room	Indoor-other	Utility
Toilet	Indoor-other	Utility
Walk-in Robe	Indoor-other	Utility
Garage	**Outdoor**	**Utility**
Other-outside	Outdoor	-
Outside-general	Outdoor	-
Verandah	Outdoor	-

4.2.4 Lamp Technology Density

For Australia, lamp technology density, by room type, were taken from a number of primary sources:

- 2010 Residential Lighting Report (E3 2013; data source #1) (most useful source);
- Victorian Utility Consumption Household Survey 2007 (Roy Morgan Research 2008; data source #7); and
- Lighting Installed in New Dwellings (BIS Shrapnel 2009; data source #4).

Figure 22 shows the number of lamps per house, for Australia, used in ReLAMP. The historical number of lamps (around 30 in the mid 1990s) has been estimated based on the increased number of ELV halogen lamp stocks (now an average of around 13 per house) and increases in house size, over the past two decades.

For New Zealand, lamp technology density, by room type, was taken from two key sources:

- The Home Lighting Survey (Burgess and Camilleri 2009; data source #11).
- 2012 EECA and IPSOS survey of 149 homes (data source #14).

Figure 23 shows the number of lamps per house, for New Zealand, used in ReLAMP. Again, the historical numbers have been estimated based on recent trends.

Figure 22 – Estimated average no. lamps per household (Australia)

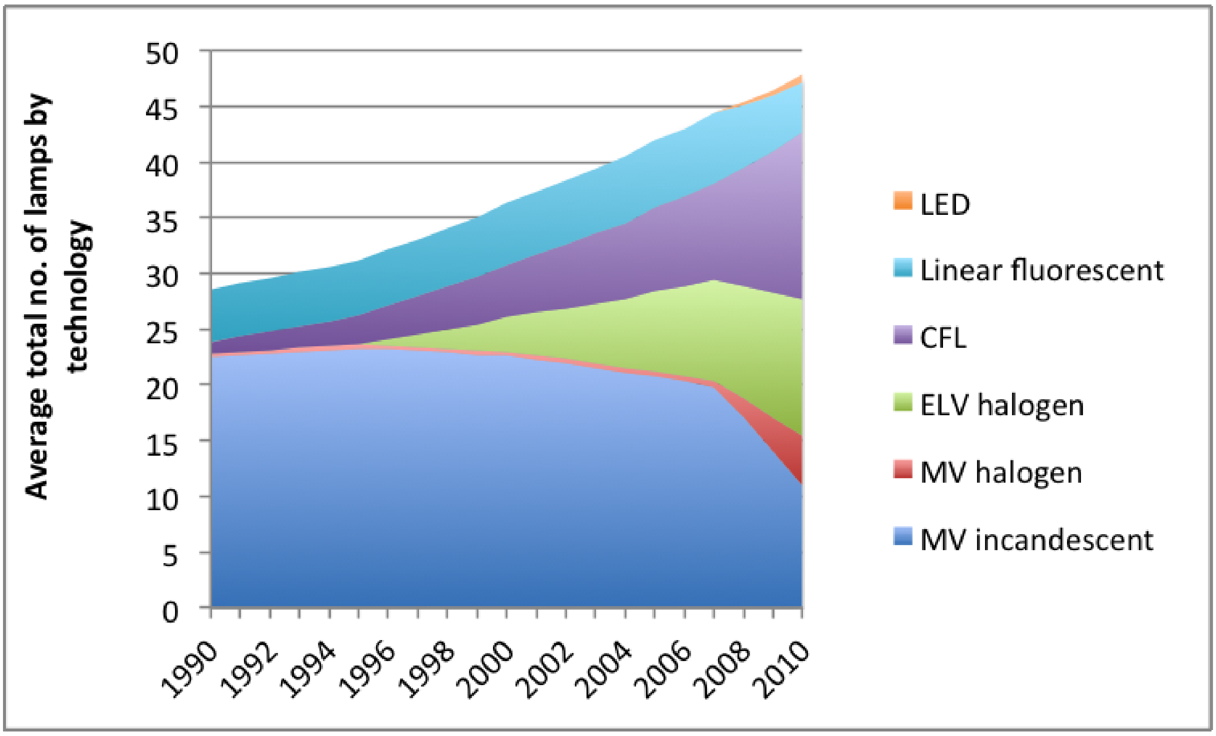
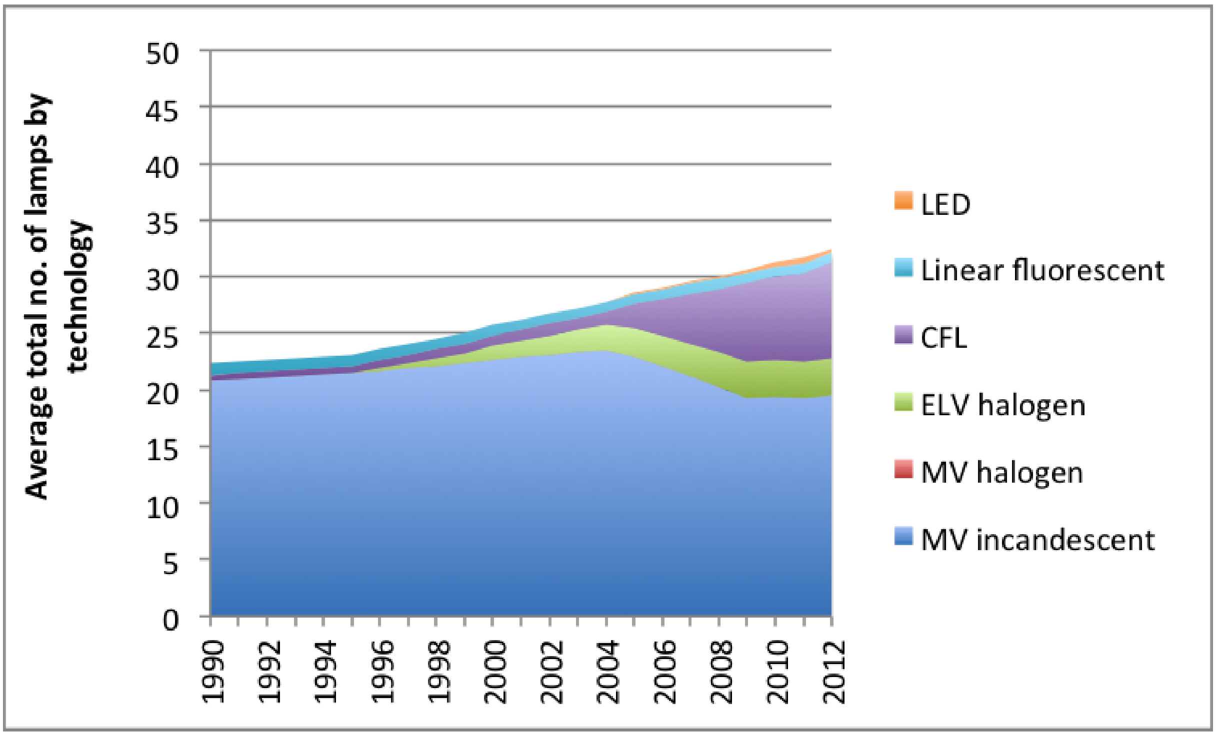


Figure 23 – Estimated average no. lamps per household (New Zealand)



4.3 Preliminary Results of Historic Trends

Please note that the quantitative results of this report, whilst considered to be the best achievable with current data sources, remain subject to considerable uncertainty.

The calculated lighting power density results, for Australian and New Zealand homes, are shown in Figure 24 and Figure 25 respectively.

Figure 24 – Calculated lighting power density (Australia)

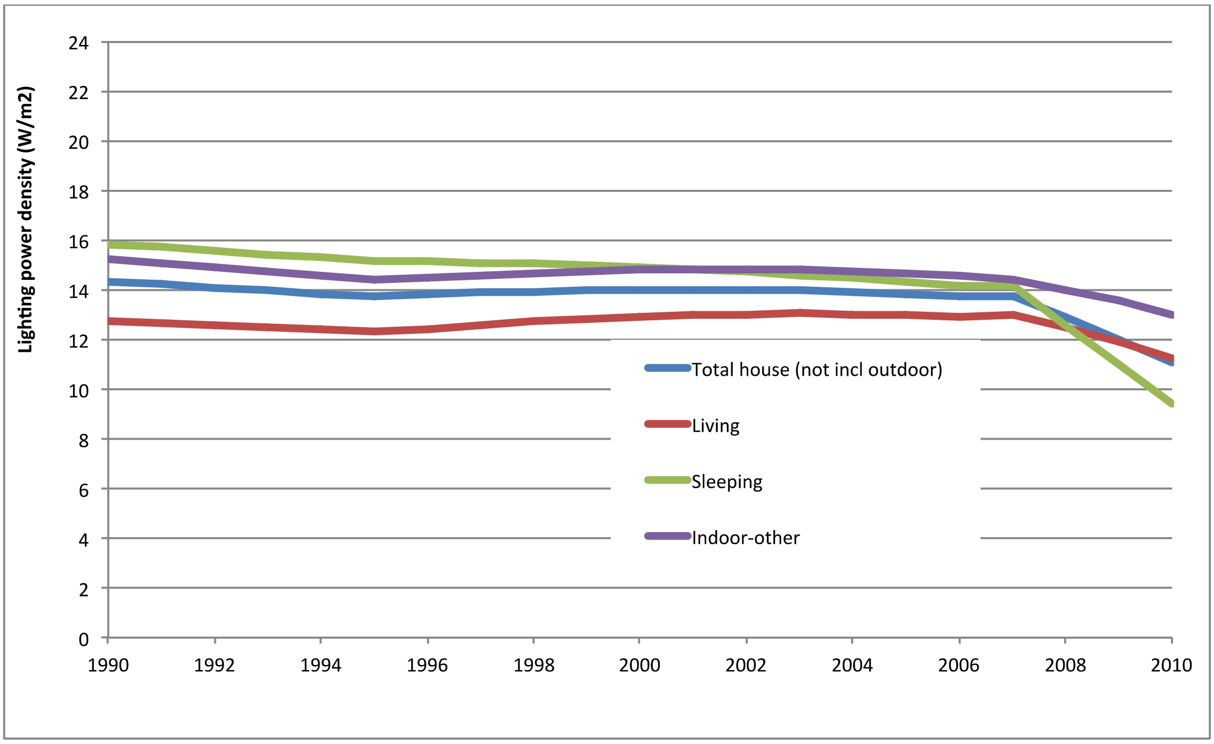
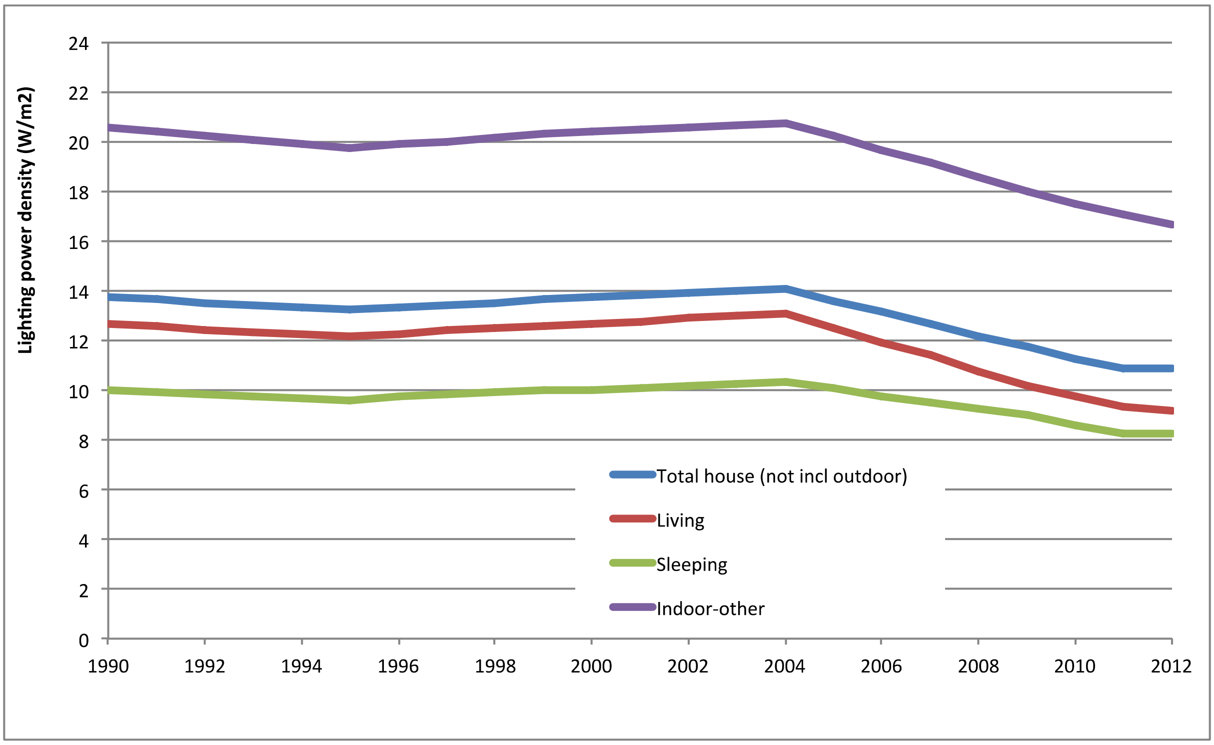


Figure 25 – Calculated lighting power density (New Zealand)



Based on the modelling conducted for this study, Australia was experiencing a gradual reduction in residential lighting power density from 1990 onwards, due to the increasing popularity of CFLs (Figure 24). In the mid-1990s, this began to reverse due to the introduction of ELV halogen lighting, which caused lighting power density to increase until around 2007. A distinct reduction in lighting power density commenced in 2007, when the phase-out of incandescent lamps was announced and state-based CFL giveaway programs were taking effect. In particular, lighting power density appears to have decreased more rapidly in sleeping areas than living or indoor/other areas of the home, with data sources showing a significant increase in CFL penetration in bedrooms over the past few years.

It is possible that the higher lighting power density in sleeping and indoor-other areas might be due to these spaces being smaller, leading to increased numbers of lamps per square metre, and/or the fact that lamps are operated infrequently in these areas and therefore replaced less often, thus transition to efficient lighting is slower in these areas.

New Zealand appeared to experience a decline in lighting power density commencing in 2005 (potentially due to CFL giveaway programs) (Figure 25). Indoor/other areas of the home have a significantly higher lighting power density than other areas (although note that this may partially attributable to room classification problems – see section 4.2.3).

The calculated lighting energy consumption, average per house, for Australia and New Zealand are shown in Figure 26 and Figure 27 respectively. The following is evident for Australia:

- An increase in residential lighting energy consumption until 2007 can be seen due to:
  - the increasing popularity of ELV halogen downlights (the ReLAMP model estimates that average household numbers increased from 3 per house in 2000, to more than 12 per house in 2010);
  - an increase in house size; and
- Lighting energy consumption begins to decrease from 2007, due to a decrease in incandescent lamp penetration.

Overall, the modelled Australian residential lighting energy consumption, at around 1000 kWh in 2010, is slightly higher than expected from previous estimates (e.g. internal E3 modelling). The average total number of lamps per household may also be overestimates as the 2010 residential lighting report (E3 2013; data source #1) had a bias towards larger homes and potentially homes with a higher number of halogen downlight fixtures.

Figure 26 – Calculated lighting energy consumption, per house (Australia)

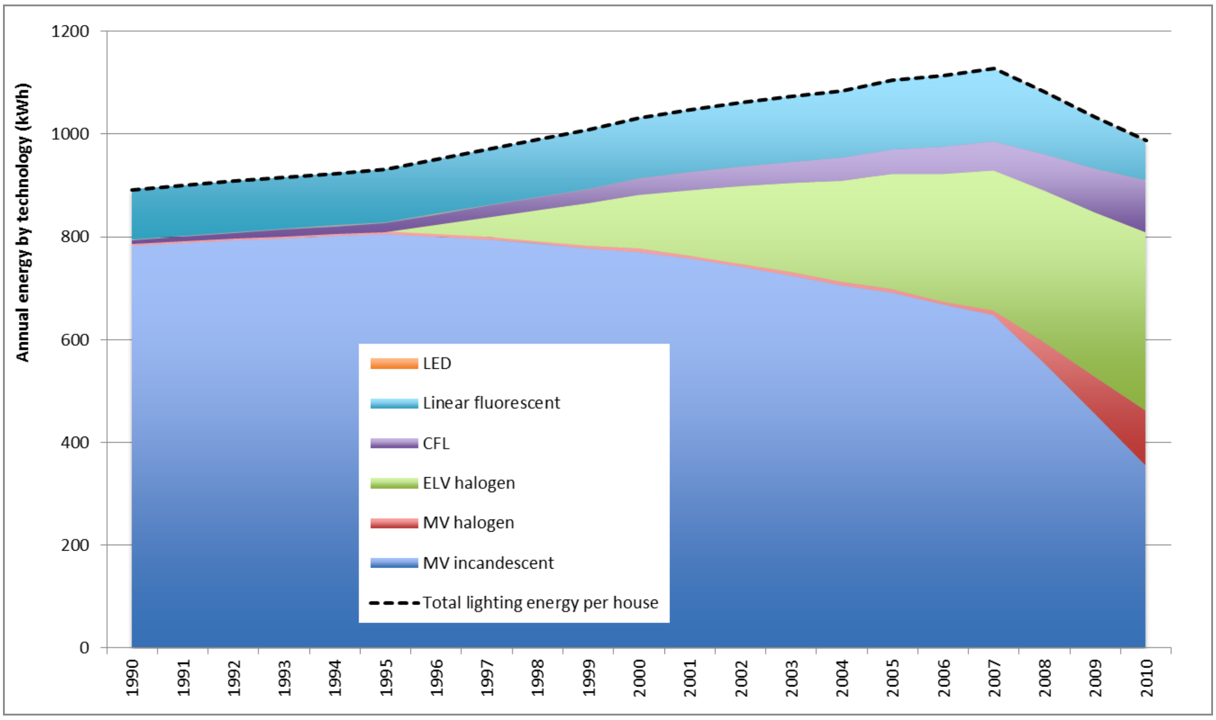
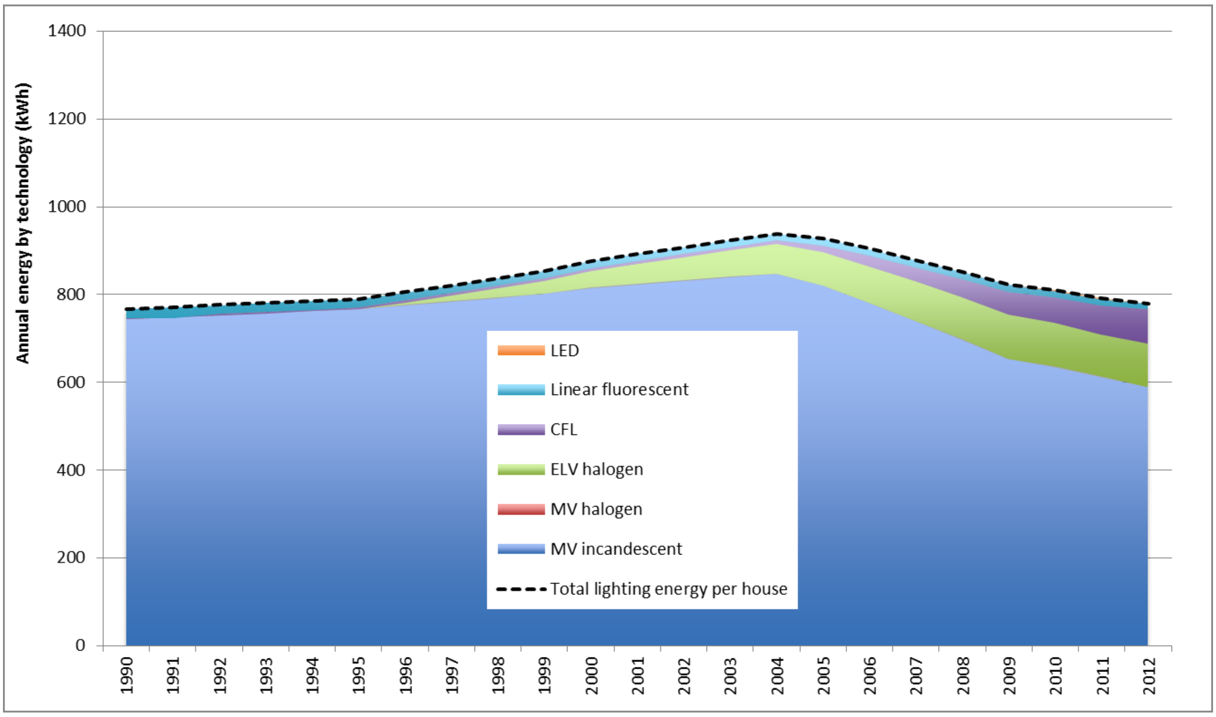


Figure 27 – Calculated lighting energy consumption, per house (New Zealand)



The modelled lighting energy consumption in New Zealand households is graphed in Figure 27 and from this it appears that New Zealand experienced increasing lighting energy consumption until 2004, when this trend was reversed due to the increasing popularity of CFLs, most likely as a result of CFL giveaway programs.

From the above figures we can see that Australia has been more successful in increasing the penetration of energy efficient lighting such as CFLs and reducing incandescent lamp penetration, leading to a significant reverse in the trend of increasing energy consumption (despite increasing house size and uptake of ELV halogens), more so than New Zealand. However, New Zealand potentially benefits from smaller average house sizes and a lower uptake of ELV halogens to have an overall average household lighting energy consumption that is lower than Australia but not trending downward like Australia.

However, there is considerable uncertainty in these estimates due to the data weaknesses noted throughout this report.

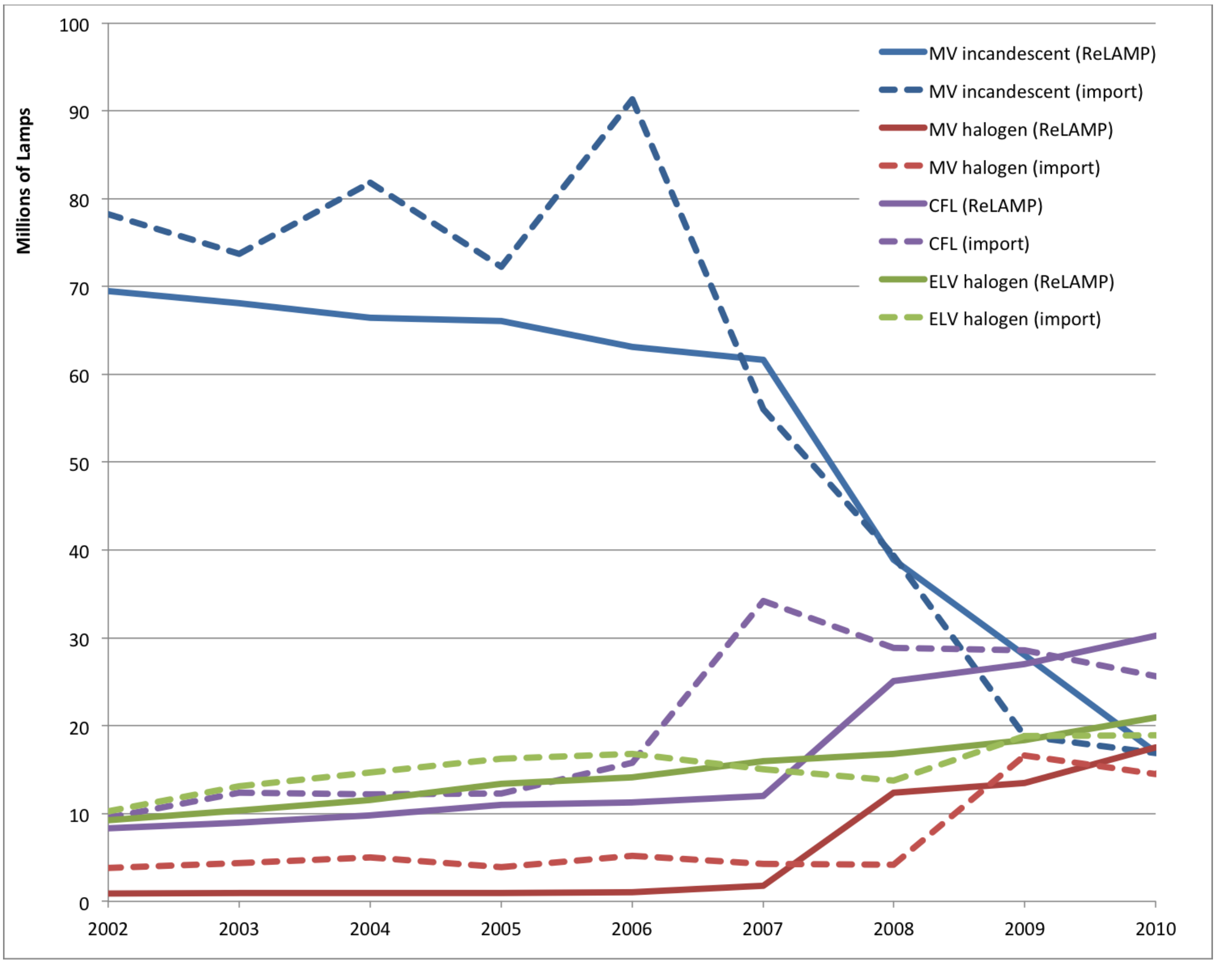
4.4 ReLAMP Results Compared to Other Studies

4.4.1 Comparison with Lamp Import Data – Australia

As discussed previously, the ReLAMP model was created with lamp stock as the basis and lamp import data was used as a comparative tool in order to check that the model, particularly time-based results, were in agreement. Note the limitations of import data as discussed in section 3.1.6.

The comparison between ReLAMP results and import data is demonstrated in Figure 28 for Australia, which compares model estimates ("ReLAMP") and import data ("import") for the modelled lamp types.

Figure 28 – Annual lamp sales (Australia) – comparison of ReLAMP results with import data



There is a reasonable correlation between the model estimates and the Australian import data, as follows:

- MV incandescent lamps – ReLAMP prediction and import data agree well, notwithstanding volatility of imports.
- MV halogen lamps – ReLAMP prediction and import data agree well. The RELAMP model shows an increase in uptake a year before import data, although this discrepancy is within the uncertainty of the model.

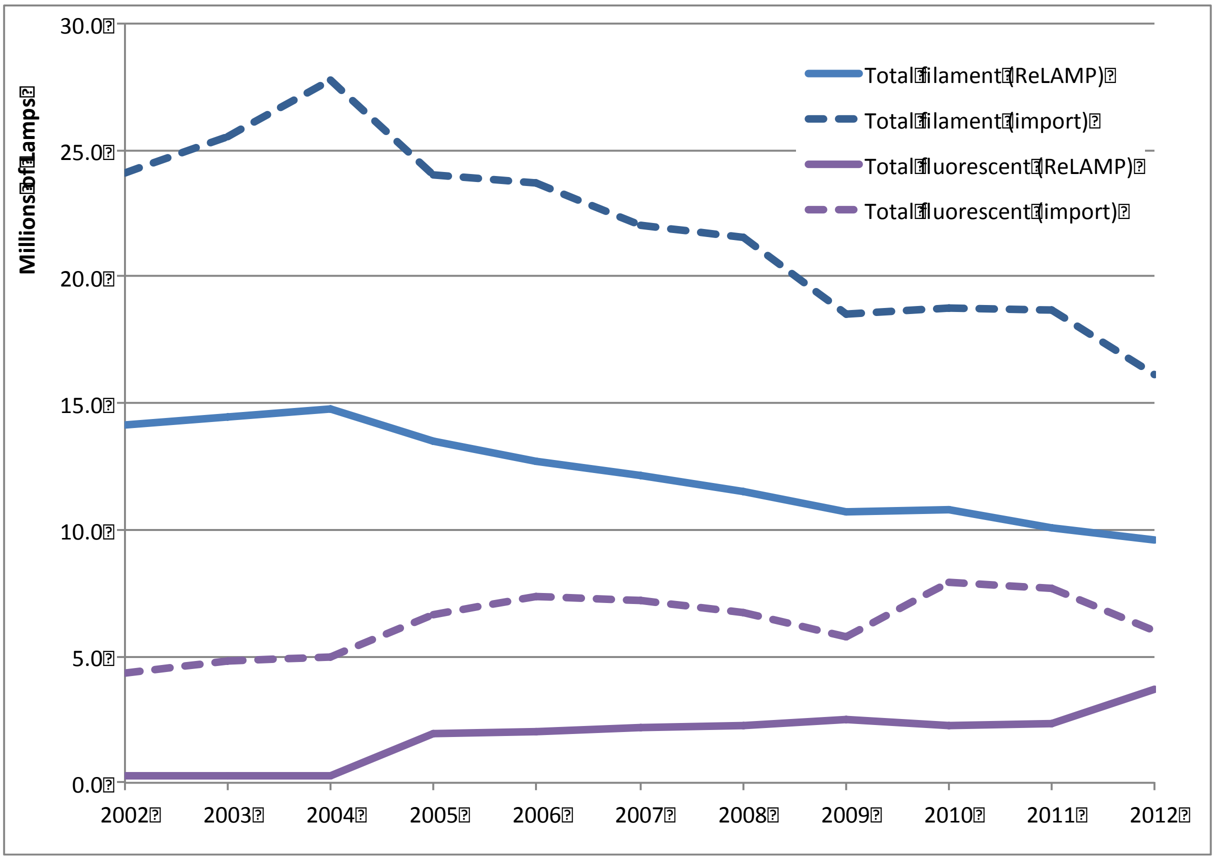
- CFLs – ReLAMP prediction and import data agree well, although import data suggests an earlier spike in CFL sales than ReLAMP. This is possibly associated with pre-ordering of CFLs to meet demand, as well as with "giveaway" CFLs not installed or whose installation was delayed.
- ELV halogen lamps – ReLAMP prediction and import data agree well.

Note that the import data for all lamps includes lamps sold into both the commercial and residential sectors. For MV incandescent, MV halogen and CFL lamps, the proportion of imports sold into the commercial sector is considered to be insignificant, in the context of the accuracy of modelling. For ELV halogen lamps, there are likely to be significant sales into the commercial sector. However the general trends predicted in the model for ELV halogen lamps, and those visible in the import data, agree well.

4.4.2 Comparison with Lamp Import Data – New Zealand

A comparison of New Zealand lamp import data with lamp sales predicted by the model is shown in Figure 29.

Figure 29 – Annual lamp sales (New Zealand) – comparison of ReLAMP results with import data



There are is good correlation between the *shapes* of the ReLAMP predictions and the New Zealand import data; however the sales predicted by the model appear significantly lower than the import data would suggest. There are several possible reasons for this:

- The import data is not particularly detailed (as discussed in section 3.1.13) and there are overlaps between lamp categories.
- There may be significant sales of lamps into the commercial building sector (the import data does not identify which sector lamps are sold into). This is particularly the case for fluorescent lamps, which are presumed to include integral CFLs, non-integral CFLs and linear fluorescent lamps – the latter two categories are primarily used in the commercial sector. Note that the 2013 sales data (data source #15) shows that 2.6 million integral CFLs were sold in 2013, which equates well with the discrepancy of import data and the ReLAMP model in Figure 29.

4.4.3 Comparison with Other Studies – Australia

The Australian results of the ReLAMP model were compared with the national lighting energy predictions made in Energy Use in the Australian Residential Sector 1986 – 2020 (DEWHA 2008). The results of each can be seen in Figure 30 and Figure 31, respectively. The ReLAMP energy predictions for residential lighting are somewhat higher than DEWHA (2008). This is possibly due to the lighting operating hours used in ReLAMP (discussed in section 4.2.2). Whilst these hours of use for the ReLAMP model have been derived from the limited usage studies undertaken, great care is required to extrapolate these measurements to estimate the usage of all lamps (naturally, end use metering of individual lamps tends to focus on lamps with more frequent or heavier use). The DEWHA (2008) report assumed a use of 2 hours per day for living areas and 0.5 hours per day for non-living areas (averaged over all lamps). However, lighting was an area of the study that was relatively weak due to lack of data.

Figure 30 – Australian residential lighting energy consumption (ReLAMP)

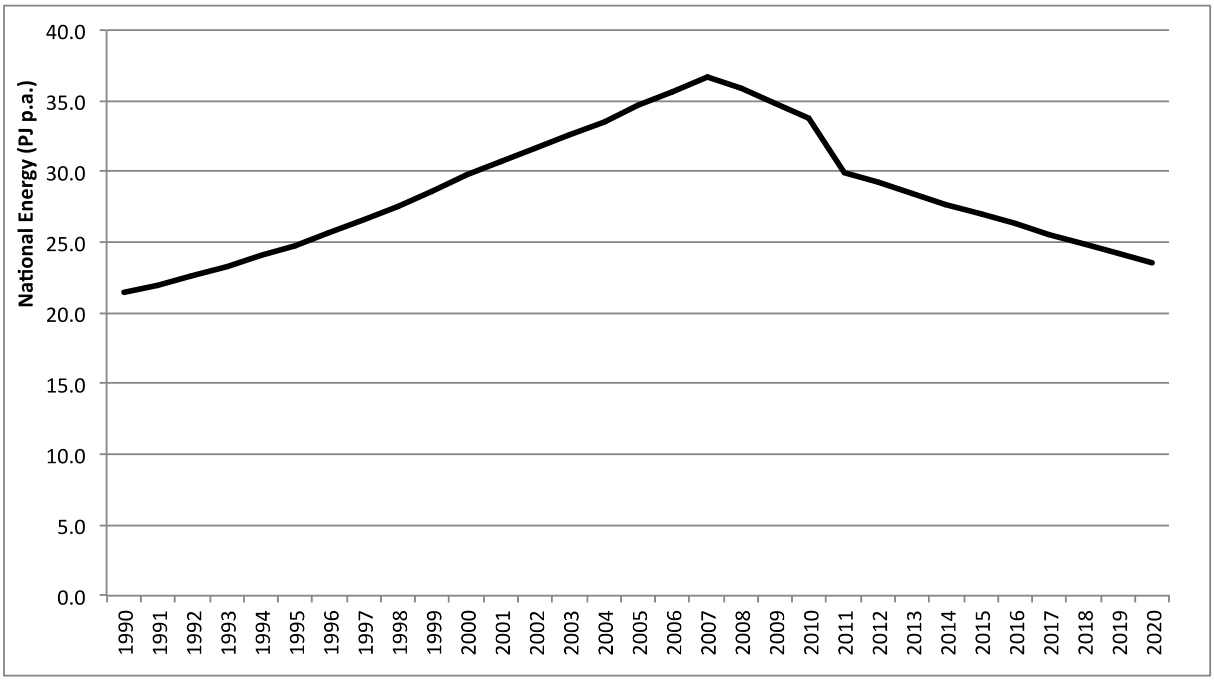
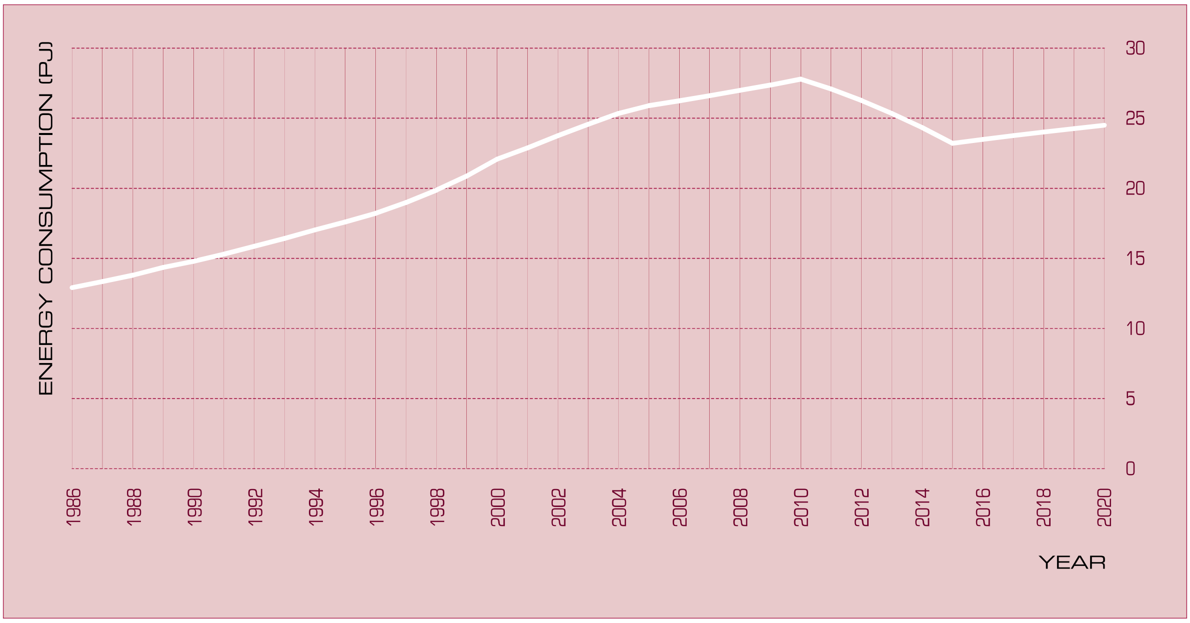


Figure 31 – Australian residential lighting energy consumption (DEWHA 2008)



The general shape of the historical national energy consumption trend is similar between the ReLAMP model and the DEWHA model. However, the ReLAMP model has national energy consumption peaking in 2007 compared to 2010 forecast by DEWHA. This could possibly be due to the fact that the DEWHA model did not take into account the state-based incentive schemes for CFLs and now LEDs.

Figure 30 puts in perspective the recent (estimated) reductions in residential lighting energy consumption in Australia. Forces such as population growth, house size and adoption of ELV halogen downlights mean that the energy savings achieved have only compensated for the increased lighting energy consumption seen in the 2000's and have not yet lead to a drop to pre-1990 levels of overall lighting energy consumption – this can only be achieved through a further cross market transition to much more efficient lighting such as LEDs.

The Residential End-Use Study (Pacific Power 1994) estimates annual residential lighting energy consumption (per NSW/ACT house) of 566 kWh in 1993/94. ReLAMP estimates 900 kWh in 1990. However, it is known that just over half of the houses had lighting energy measured in the Pacific Power study. Understandably, the ReLAMP estimates appear high in comparison. It may be possible to retrieve the raw data from this study to undertake additional analysis to improve the ReLAMP model.

In general, the lack of solid, whole house data measurements for lighting in Australia has hampered the calibration of the ReLAMP model.

4.4.4 Comparison with Other Studies – New Zealand

The BRANZ Energy Use in New Zealand Households study (Isaacs et al. 2010; data source #10) estimates 2006-2010 lighting energy use at 955 kWh per annum per household. ReLAMP estimates 810 kWh per annum in 2010. While lighting was not the main focus of the HEEP study, it did cover a large number of houses and sufficient had lighting included to give a reliable estimate.

The BRANZ Home Lighting Survey (Burgess and Camilleri 2009; data source #11) estimates of lighting power density are compared with ReLAMP (2009) results in Table 7. The ReLAMP predictions are somewhat lower than the BRANZ study. This may be due to the floor area data weaknesses discussed earlier.

Table 7 – Comparison of ReLAMP power density results with the BRANZ Home Lighting Survey (Burgess and Camilleri 2009) results for 2009

	BRANZ (W/m^2)	ReLAMP (W/m^2)
Total house (not including outdoor)	13.6	11.7
Living	13.1	10.2
Sleeping	9.8	9.0
Indoor-other	21.1	18.0

The EECA Energy End Use Database (data source #12) estimates total residential lighting consumption of 5.4 PJ in 2007 and 5.5 PJ in 2012. ReLAMP predicts 5.0 PJ in 2007 and 4.7 PJ in 2012. Thus the ReLAMP predictions are slightly lower than the End Use Database in these years.

Interestingly, the New Zealand ReLAMP estimates are in relatively good agreement, which was not the case for the Australian comparisons.

5. Discussion and Recommendations

5.1 Discussion of Future Trends

The ReLAMP model estimates average stock lighting power densities of 11-14 W/m² in 2010 for Australia and New Zealand. In both countries, there is a current trend towards the installation of more efficient lighting. LEDs are expected to play a key role in enhancing this trend, particularly as replacements for ELV halogen downlights (aided by state-based incentive schemes). However data is currently not available to support this prediction. Currently, it is possible for a room lit with LED downlights to have a lighting power density of 4 W/m² or better – in fact a recently built Australian house with predominantly LEDs had a power density of 2.6 W/m².

Commercially-available LEDs are currently capable of achieving around 50-100 lm/W. If LEDs universally reach 200 lm/W by 2020 (as is predicted by some experts) then lighting a house to an average of 200 lux (lux = lumens/m²) would require just 1 Watt of lighting power per square meter, or 1 W/m².

Although these may be achievable figures, the ReLAMP model needs to consider the *average* dwelling (the stock average of installed equipment). For this purpose, 4 W/m² has been used as the ultimate average lighting power density for Australia (Figure 32) and New Zealand (Figure 33), by 2030, although it is quite feasible that active policy measures and faster technology changes could achieve even more positive outcomes.

Figure 32 – Modelled historical and expected future lighting power density (Australia)

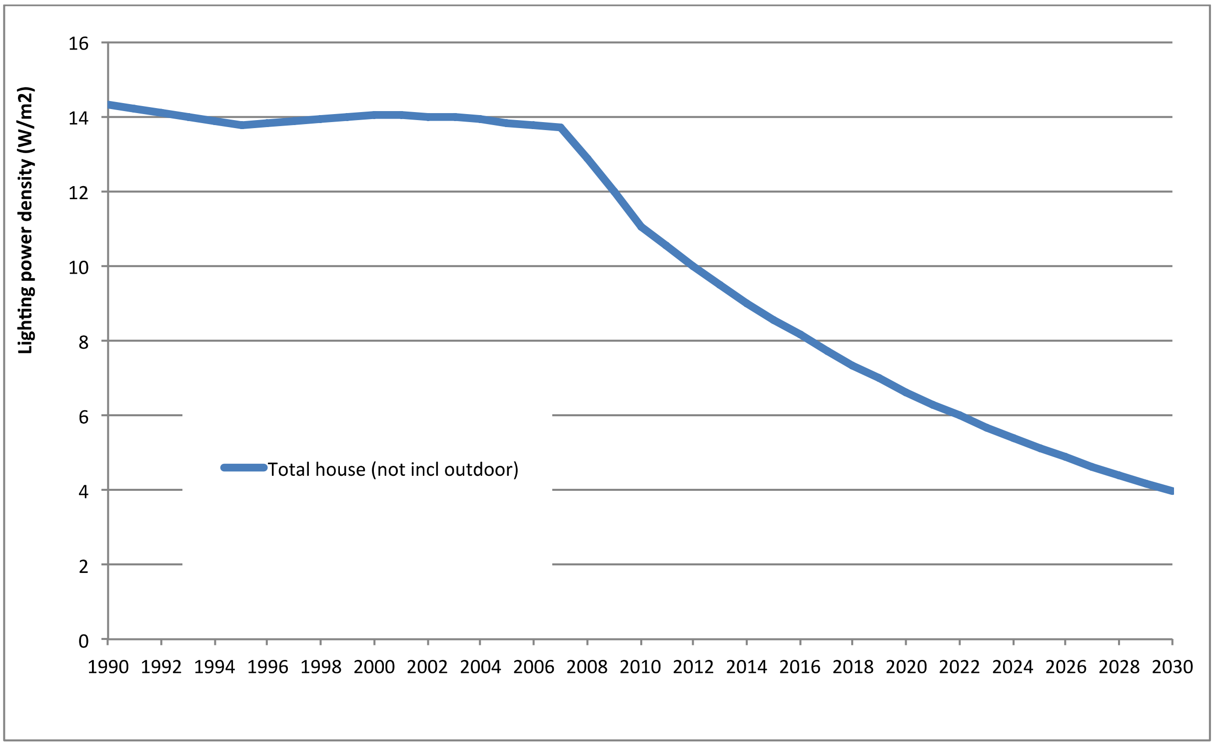
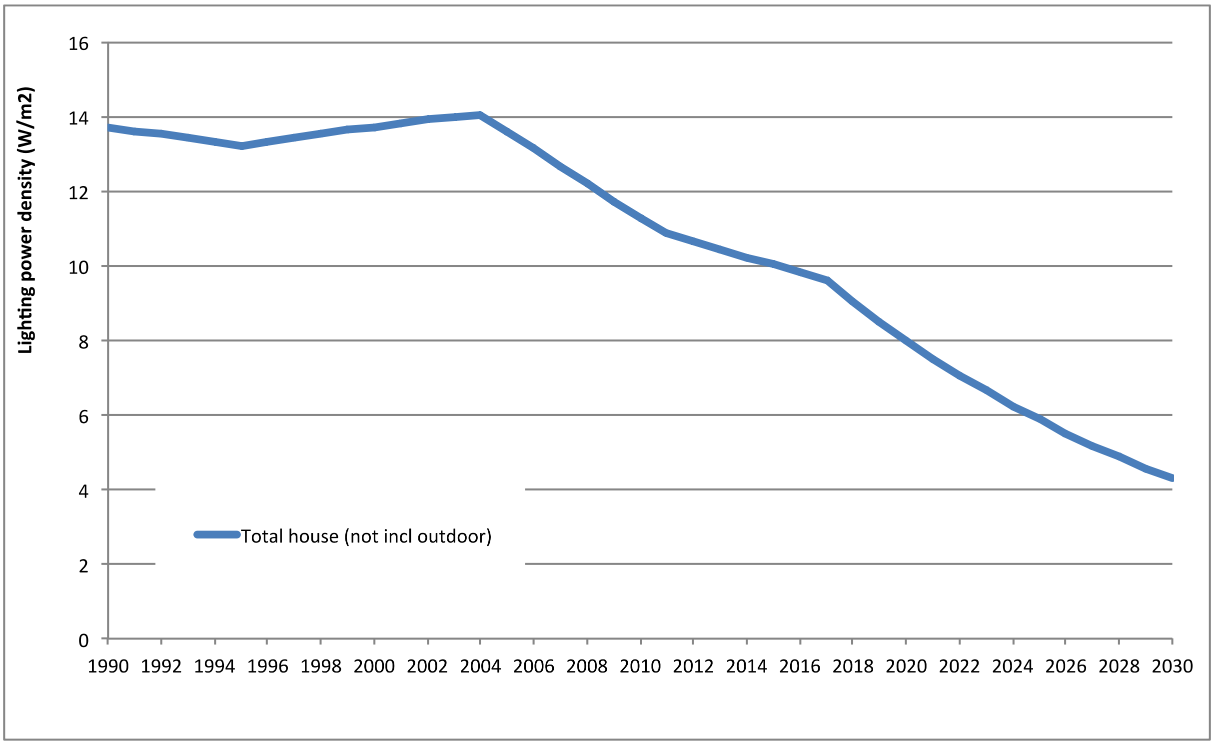


Figure 33 – Modelled historical and expected future lighting power density (New Zealand)



Note however that this significant downturn in lighting energy is essentially an educated guess, based on the recent improvements in LED quality and reductions in price continuing, to the point that these become a viable mass-market product in the medium term (as is predicted by many experts). Other scenarios are also possible, such as occurred with CFLs – these were subject to some uptake, then a stall due to product quality and a market not inclined to make a transition from familiar products. From this aspect it is still unclear as to what portion of the market will make the transition from MV and ELV halogen to LED, without any Government interventions such as MEPS.

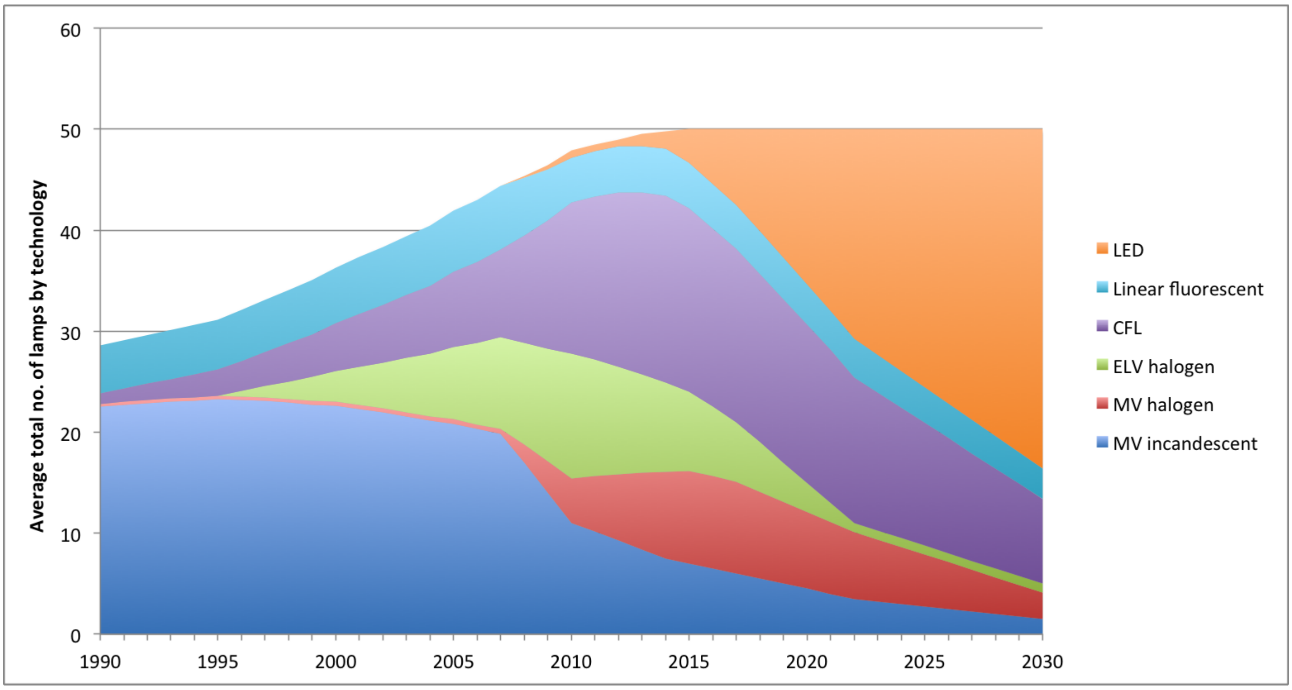
A potential breakdown of household lamp penetration, that could feasibly occur to 2030, is shown in Figure 34 (for Australia - a similar breakdown is possible in New Zealand). The forecast is a decline of all lamp types (except LEDs) and particularly ELV halogen. The average number of lamps per household is also predicted to increase slightly from 48 to 50.

If the aggressive LED trend were to eventuate, the annual energy consumption of lighting per home in Australia and New Zealand would decrease to around 400 kWh by 2030 (even though the average number of lamps per household is projected to increase slightly; Figure 34). This may be even lower if LED efficacies continue to improve and be taken up by the market. In more radical scenarios, where LED efficacy climbs to 200 lm/W, lighting energy consumption could be half this value. It is important to note that the radical prediction relies on the entire stock of lamps in homes converting to LED technology. CFL efficacy has been stagnant at around 50-70 lm/W for some years now, and is not expected to change in future as the technology has effectively reached its practical limit of efficiency (in terms of commercial manufacturing at high volumes and at a low price point). If LED technology is not taken up significantly, and homes are dominated by CFLs alone, then stock average power densities of around 5-6 W/m^2 can be expected.

In terms of national (Australian) residential lighting energy consumption, the ReLAMP model (Figure 30) predicts a more significant and sustained turndown compared to the DEWHA (2008) modelling (Figure 31). This is to be expected, as the impending impact of LED lighting was certainly not anticipated in 2008 when the DEWHA modelling was conducted.

It should also be noted that the ReLAMP model is not a formal forecast of the future – there are too many unknowns over the time frame to 2020, let alone 2030. Attempting to predict, with any accuracy, all details of the future of household lighting is not possible.

Figure 34 – Potential future breakdown of household lamp penetration (Australia)



However, once calibrated with the best available data, ReLAMP is a powerful tool to examine the impacts of changes in policy, technology and user behaviour into the future under a range of assumed conditions. A modelled scenario is based on a set of assumed future parameters, each of which has uncertainties associated with it. The value of the model is that it allows the impact of specific influences to be explicitly quantified to examine their potential as the basis for policy or market based programs. Absolute accuracy into the distant future is less important – identification of energy saving opportunities is the critical output.

5.2 Knowledge and Data Gaps

One of the purposes of this study was to encapsulate the "best available" data currently in existence into a market snapshot, and derive recommendations on how data collection and modelling for residential lighting can be better organised in the future. Having completed this exercise as only a "first pass" of the ReLAMP model, it has become clear that the following weaknesses exist in current data sets.

- There is a disconnect between in-home lamp survey data, and lamp import (sales) data. This comes about because very low use lamps in homes (lamps which are very rarely or almost never used) are replaced only after very long intervals. Also affecting this could be the impact of programs which replace incandescent and ELV halogen lamps before their end of life.
- This means that their effect on sales is probably insignificant. State-based incentive schemes also replace incandescent and ELV halogen lamps before their end of life. Thus trying to marry stock, as measured by in-home survey, and stock, as predicted by stock-from-sales modelling, is difficult. For Australia, stock-from-sales modelling predicts around 30-35 lamps per home. Recent in-home surveys counted around 48 lamps. They key reason for this difference is that surveys count all lamps in the home, including those that are rarely or never used. Stock-from-sales modelling does not reveal the existence of these lamps. Thus, in future, surveys should try to accurately identify rarely or never used lamps and isolate these.
- Average lamp operating hours are derived from a very small sample size. Operating hours should be carefully calibrated and correlated with related sources (which are also scarce) or further hours of use data should be collected.
- Lighting operating hours are extremely difficult to quantify without continuous monitoring of lighting circuits using a representative sample size. There is high variability between houses, a highly seasonal pattern, and individual lamps are highly variable from day to day. Longer-term end-use monitoring data from sources such

as Ausgrid (data source #22) and REMP (E3 2012; data source #3), and data from shorter studies, could be combined to develop an approach to seasonally adjust lighting usage data.

- It is difficult to get accurate “per lamp” operating hours for a representative sample in the stock – this requires monitoring many lamps in the home, including very low use lamps. Many previous studies have collected “per room” lighting hours, where the use of *any light* in the room has been logged or surveyed. This should not be confused with per lamp operating hours. Per room operating hours are not preferred as this approach does not allow differing mixes of lamp technology within a single room, or differing operating hours of lamps within a single room to be taken into account.
- A two-pronged approach is required to improve lighting data – energy monitoring of lighting circuits combined with monitoring a significant number of individual lamps (in the same houses). This needs to be done on a representative sample of households.
- There is no differentiation between older homes and new houses, which would highlight the impact of changing building code requirements for lighting.
- The lighting model should take into account give away and incentive programs.
- Several data sources rely on consumer responses and recollection, which is subject to inaccuracies and bias. These need to be weighted accordingly when considering their use in a lighting model.
- Data related to technology penetration, by room type, is scarce, particularly historically. Ongoing surveys like the recent audits in Australia (E3 2013a) and New Zealand (EECA and IPSOS 2012) will at least calibrate recent and current trends in the lighting stock.
- Classification of room types between studies has not been consistent. The size of rooms should also be measured when being surveyed, in order to allow calculation of lighting power density, etc.
- Lamp import data for New Zealand could be improved by more detailed categorisation of lamps, and removal of overlap between categories. Similarly, Australian lamp import categories could be more detailed to delineate LED lamps for general lighting purposes from LEDs used in cars and equipment.
- Data for floor area (split by room types) is scarce, particularly historical data. However, there are several data sources for Australia that could improve these estimates with some additional analysis.
- Lack of consistency in consumer knowledge and awareness surveys means it is nearly impossible to compare between studies.

References

Data Sources and Associated Reports Formally Reviewed in this Study

ABS Nov 97, Feb 98, May 99, Aug 99, Population Survey Monitor, Australian Bureau of Statistics (no. 4103.0) (data source #19).

ABS 2008, Environmental Issues: Energy Use and Conservation Survey, Australian Bureau of Statistics (no. 4602.0.55.001) (data source #5).

ABS 2013, Household Energy Consumption Survey, Australian Bureau of Statistics, http://www.abs.gov.au/ausstats/abs@.nsf/mf/4670.0 (data source #16).

ABS 2014, Lamp Import Data, data purchased from Australian Bureau of Statistics (data source #13a).

Ausgrid 2013, Ausgrid SHAPE Data Analysis Final Report, Prepared by Energy Efficient Strategies, June 2013 (data source #22).

BIS Shrapnel 2009, Lighting Installed in New Dwellings (data source #4).

Burgess J and Camilleri M 2009, The Home Lighting Survey, BRANZ (data source #11).

Burgess J, Camilleri M and Saville-Smith K 2010, Lighting in New Zealand Homes – lighting efficiency as a sustainability indicator, SB10 New Zealand Sustainable Building Conference (data source #17).

Department for Transport Energy and Infrastructure 2011, Results from household survey on the use of energy appliances and products in the home (data source #6).

E3 2012, Proof of Concept Residential Energy Monitoring Program (REMP), prepared for E3 by Energy Efficient Strategies (data source #3).

E3 2013a, 2010 Residential Lighting Report, prepared for E3 by Energy Efficient Strategies (data source #1).

E3 2013b, Australian Residential Lighting Survey – Pilot, prepared for E3 by Databuild (data source #2).

E3 2013c, Survey of Compliance with Registration Requirements – Lamps. Report on Compliance with Energy Efficiency Registration Requirements of Lamps in 60 Australian Stores (data source #18).

EECA and IPSOS 2012, Lighting Report, (survey) (data source #14).

EECA Energy End Use Database, accessed 2014 via on-line database http://www.eeca.govt.nz/energy-end-use-database (data source #12).

EECA / RightLight sales data (data source #15), awaiting data.

Isaacs NP, Camilleri M, Burrough L, Pollard A, Saville-Smith K, Fraser R, Rossouw P and Jowett J 2010, Energy Use in New Zealand Households – Final Report on the Household Energy End-use Project (HEEP), BRANZ (data source #10).

Queensland Household Energy Survey 2009, 2011 and 2012, Ergon and Energex (data source #9).

Roy Morgan Research 2008, Victorian Utility Consumption Household Survey 2007, prepared for the Department of Human Services (data source #7).

Statistics New Zealand 2014, Lamp import data, accessed via on-line database (data source #13b).

Sustainability Victoria 2008, Green Light Report, Sustainability Victoria (data source #8).

Sustainability Victoria 2009, Green Light Report, Sustainability Victoria (data source #8)

Sustainability Victoria 2010, Green Light Report, Sustainability Victoria (data source #8)

Sustainability Victoria 2012, Victorian Residential Energy Monitoring Program (REMP) (data source #21).

Other References

ABS 2000, Population Survey Monitor, private cross tabulations of appliance ownership through 1998 and 1999, Australian Bureau of Statistics.

ABS 2006, Building Approvals Data – Data sets specially prepared for this study by the Adelaide office of the ABS, purchased by DEWHA.

ABS2015.0, Census of Population and Housing - Selected Social and Housing Characteristics from the Census. Australian Bureau of Statistics.

BRANZ 2000, Energy Used in Australian Appliances - Analysis of 1993/94 RES Appliance Energy Use Data, BRANZ report UC0170/2, May 2000, for the AGO.

BRANZ 2005, Energy Use in New Zealand Households – Report on the Year 9 Analysis of the Household Energy End-use Project (HEEP), Report SR141, Building Research Association of New Zealand (http://www.branz.co.nz/cms_display.php?sn=33&st=1&pg=9636).

BRANZ 2006, Energy Use in New Zealand Households – Report on the Year 10 Analysis of the Household Energy End-use Project (HEEP), Report SR155, Building Research Association of New Zealand (http://www.branz.co.nz/cms_display.php?sn=33&st=1&pg=9636).

DEWHA 2008, Energy Use in the Australian Residential Sector 1986 – 2020, Department of Environment, Water Heritage and the Arts (DEWHA), 2008.

Pacific Power 1994, The Residential End-Use Study, Pacific Power and NSW/ACT electricity distributors, 1994.

US DoE 2013, SSL Pricing and Efficacy Trend Analysis for Utility Program Planning, US Dept of Energy, October 2013 (http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_trend-analysis_2013.pdf)

Residential Lighting Overview Report

www.energyrating.gov.au