Halogen Downlight Retrofit Trial
Foreword

There is a general recognition that the existing housing stock represents the largest potential for energy saving and greenhouse abatement in the residential sector. However, few studies have looked at how inefficient existing houses actually are, the extent to which their level of energy efficiency can be practically upgraded, or the cost and cost-effectiveness of doing this.

In 2009 Sustainability Victoria commenced a program of work to address these information gaps. Through the On-Ground Assessment study data was collected from a reasonably representative sample of 60 existing (pre-2005) stand-alone Victorian houses and used to: determine the energy efficiency status of the houses; identify the energy efficiency upgrades which could be practically applied to the houses; and, to estimate the upgrade costs and energy bill savings which could be achieved. The results of this initial work are published as The Energy Efficiency Upgrade Potential of Existing Victorian Houses [SV 2015].

The results presented in the On-Ground Assessment study report are estimates based on modelling, using data collected from real houses and focussing on energy efficiency upgrades which could be practically applied to the houses. The next phase of our work on the existing housing stock is to implement energy efficiency upgrades in houses and assess the actual impacts achieved. Through the Residential Energy Efficiency Retrofit Trials we are implementing key energy efficiency retrofits1 in existing houses and monitoring the impact to assess actual costs and savings, the impact of the upgrades on the level of energy service provided, and household satisfaction and acceptance of the upgrade measures. We are also seeking to identify practical issues which need to be taken into consideration when these upgrades are implemented.

This report covers the Halogen Downlight Retrofit Trial, which was undertaken in a total of 16 houses in 2011 and 2012. There is currently around 23 million 12 volt halogen downlights installed in Victorian homes. We estimate that annual energy bill savings of around $161 million per year, and a 5% reduction in residential electricity consumption, could be achieved if all existing halogen downlights were replaced with a suitable low energy alternative.

The Halogen Downlight Retrofit Trial has shown that it is viable to replace 12 volt halogen downlights with a suitable low energy alternative (either a CFL or LED downlight) and that significant energy savings can be achieved for a reasonable payback period. Across the houses involved in the trial the energy use of the retrofitted lighting was reduced by 71%, with the saving for the houses which had LED lamps installed (80%) being higher than for the houses which had the CFL lamps installed (57%). The average payback was 6.7 years, with the payback for the LED houses (7.9 years) being longer than the payback for the CFL houses (3.4 years), due to the significantly higher cost of the LED lamps at the time that the trials were undertaken. In this trial the LED retrofits performed better than the CFL retrofits: the light levels after the retrofits increased where LED lamps were used but decreased where 12 volt CFL lamps were used; overall the LED lamps resulted in a higher level of satisfaction with the retrofits, the main drawback for the CFL lamps being their relatively slow start-up and warm-up time; and, there was little if any rebound effect observed where LED lamps were used as a retrofit but the lighting was used for longer after the CFL retrofits decreasing the savings achieved. However, the replacement CFL lamps were still accepted by the households and were cheaper than the LED retrofits, thus giving a lower payback period.

We do not believe that the results found in this trial for the CFL retrofit lamp can be generalised to all CFL lamps or all CFL downlight lamps. Our results suggest that CFL lamps which display suitable characteristics (see below) would achieve similar results as those achieved for the LED lamps.

The trial suggests that low energy downlight lamps need to display a range of characteristics to ensure household satisfaction, reduce the cost of the retrofit and to maximise the energy savings achieved: 1. An essentially instantaneous start-up and warm-up time is critical to ensure household satisfaction and minimise (or eliminate) any rebound effect; 2. A light output and colour appearance which is comparable to the light output of the halogen downlight lamp they will replace; 3. Compatibility with a wide range of the transformers and converters which are found in existing halogen downlight installations, and easy access to information regarding their level of compatibility; 4. Compatibility with a wide range of the dimmers which are used with existing halogen downlight installations, and easy access to information regarding their level of compatibility; 5. Compatibility with a wide range of the existing halogen downlight fittings, especially the concave fittings; and, 6. Compatibility with both the old style and new style of the low voltage electrical connectors which the lamps plug into.

When reading this report it is important to keep in mind that the costs are based on the commercial cost of undertaking the halogen downlight retrofits, and do not include any subsidies which are available through the Victorian Energy Saver Incentive2. Even where households don’t access this subsidy, the installation of 12 volt downlight lamps can often be undertaken as a DIY project, and the retail cost of the LED lamps available to do this has declined significantly since 2012.

The savings documented in the report are based only on the electricity bill savings which result directly from the downlight lamp replacement. The savings are based on the electricity tariffs which applied at the time the analysis was undertaken. In general, these are on an upward trend, which means that the value of the savings should increase in real terms over time.

Today the cost of undertaking halogen downlight retrofits is likely to be somewhat lower than when the retrofit trial was undertaken – either because households can access a subsidy or because the cost of the replacement lamps is lower – and the energy bills savings may be larger. This means that the payback from undertaking this retrofit is likely to be somewhat lower than found for this trial, making this one of the most cost-effective energy efficiency upgrades that households can undertake.

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1 To end 2015 we have trialled halogen downlight replacements, comprehensive draught sealing, cavity wall insulation, gas heating ductwork upgrades, gas heating ductwork combined with gas furnace upgrades, window film double-glazing, pool pump replacements, heat pump clothes dryers, solar air heaters, gas water heater upgrades, halogen downlight replacements combined with ceiling insulation remediation and some comprehensive whole house retrofits.

2 The Victorian Energy Saver Incentive Scheme makes a subsidy available to households for replacing 12 volt halogen downlights with a low energy alternative. In many cases 12 volt low energy lamps (almost entirely LEDs) can now be replaced by an electrician for free, and a significant subsidy is available for replacing them with a 240 volt low energy lamp (usually an LED lamp and driver combination).
Acknowledgements

This study is based on the analysis of data and information collected from retrofit trials undertaken in 16 Victorian houses. We would like to especially thank these households for their participation in the study by allowing access to their houses to enable data collection and light level surveys, the replacement of halogen downlights in the main living areas of their homes with low energy lighting, and for participating in qualitative surveys before and after the retrofits were undertaken.

Sustainability Victoria contracted Moreland Energy Foundation Limited (MEFL) to manage household recruitment and liaison, data collection, to manage the halogen lighting retrofits and to prepare brief project reports. In particular we would like to thank Govind Maksay, who was MEFL’s project manager for this work. MEFL sub-contracted a number of organisations and individuals to undertake elements of the project. Sustainability Victoria also engaged Steve Coyne (Light Naturally) to develop a light level measurement procedure for use in the trial. We have acknowledged the different organisations which were involved in the Halogen Downlight Retrofit Trial below.

<table>
<thead>
<tr>
<th>Task</th>
<th>Responsible Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project conception, design &amp; funding, and project oversight</td>
<td>Sustainability Victoria</td>
</tr>
<tr>
<td>Light level measurement procedure</td>
<td>Steve Coyne (Light Naturally)</td>
</tr>
<tr>
<td>Lead contractor / project manager</td>
<td>MEFL</td>
</tr>
<tr>
<td>Household recruitment and liaison</td>
<td>MEFL</td>
</tr>
<tr>
<td>Data collection, surveys, light level measurements and analysis, and meter installation</td>
<td>MEFL</td>
</tr>
<tr>
<td>Halogen downlight retrofits</td>
<td>MEFL / Adams Eco Electrics</td>
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<tr>
<td>Analysis &amp; reporting for individual projects</td>
<td>MEFL</td>
</tr>
<tr>
<td>Analysis of data from 16 houses and final report</td>
<td>Sustainability Victoria</td>
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# Abbreviations and Acronyms

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>Av.</td>
<td>Average</td>
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<tr>
<td>CFL</td>
<td>Compact fluorescent lamp</td>
</tr>
<tr>
<td>DIY</td>
<td>Do it yourself</td>
</tr>
<tr>
<td>E3 Committee</td>
<td>Equipment Energy Efficiency Committee</td>
</tr>
<tr>
<td>Fluoro</td>
<td>Fluorescent</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt = 1,000 Watt</td>
</tr>
<tr>
<td>LED</td>
<td>Light emitting diode</td>
</tr>
<tr>
<td>lm</td>
<td>Lumen</td>
</tr>
<tr>
<td>MEFL</td>
<td>Moreland Energy Foundation Limited</td>
</tr>
<tr>
<td>MEPS</td>
<td>Minimum energy performance standards</td>
</tr>
<tr>
<td>MJ</td>
<td>Mega joule</td>
</tr>
<tr>
<td>No.</td>
<td>Number</td>
</tr>
<tr>
<td>OGA</td>
<td>On-Ground Assessment</td>
</tr>
<tr>
<td>SV</td>
<td>Sustainability Victoria</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>Yr(s)</td>
<td>Year(s)</td>
</tr>
<tr>
<td>W</td>
<td>Watt</td>
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</tbody>
</table>
Glossary and definitions

Average daily load profile
Graph which shows how the average electricity consumption varies during the day. In this report the daily load profiles are based on a 10 minute sampling interval.

Annual average daily operating time
The annual operating time of a particular light (expressed in hours) divided by 365. In this report we use it as a shorthand way of expressing the average operating time of a particular light (in hours per day). In reality the daily operating time of lighting changes throughout the year, as the daylight hours change.

Beam angle
Halogen downlights produce a conical beam of light. The beam angle is the angle between the two ‘outer’ edges of this beam – the outer edge is the point at which the intensity of the light is half the intensity of the light at the centre of the beam [US DoE 2008]. Lamps with a low beam angle are best suited to spot lighting applications while lamps with a wide beam angle are better suited to general lighting applications.

Efficacy
Also referred to as luminous efficacy. This is the total light output of a light (expressed in lumen, lm) divided by the rated power input to the light (expressed in Watts, W), giving the efficacy expressed in lumen per Watt (lm/W). It is the metric used to compare the energy efficiency of different lights.

Colour appearance
This refers to the general colour of the light given out by a particular light source, and is a shorthand way of expressing the colour temperature of the light source. Most lighting used in residential applications has either a “warm white” (colour temperature 2,700 to 3,000 K) or “cool white” (4,000 to 6,000 K) colour appearance.

Colour rendering
This is a measure of the extent to which a particular light source can render true colours, and is expressed as an index between 0 and 100. For residential applications the light source needs to have good colour rendering. A Colour Rendering Index (CRI) between 80 and 89 indicates good colour rendering and an index between 90 and 100 indicates very good colour rendering.

Colour temperature
The temperature of a black body radiator which gives the same colour appearance as a particular light source, expressed in degrees Kelvin (K)³. For example, a black body radiator which was at 2,700 K would have the same colour appearance as a common incandescent light globe.

Lighting power density
This is the total rated power consumption of all lighting installed in a particular room or an entire house, divided by the floor area of the room or house (expressed in Watts/m²).

Lumen
Lumen (lm) is the total amount of visible light given out by a particular light source.

Lux
Lux (lx) is a measure of the intensity of a light source, as perceived by the human eye. One lux is equal to one lumen per square metre. It is used as the measurement of the light level on a particular surface.

MEPS
Minimum energy performance standards. These are mandatory minimum energy efficiency benchmarks which are implemented via regulations. In Australia it is illegal to sell products which are less efficient than this benchmark.

MR16
Multifaceted reflector lamp, with a face diameter of 16 eights of an inch (around 50 mm). This is the type of lamp that is used in halogen downlight fittings.

Payback
Also called payback period. This is the amount of time (in years) it takes to recover the initial investment in an energy efficiency measure from the energy bill savings achieved.

Rebound
This is the extent to which the energy savings which are achieved in practice from an energy efficiency retrofit are less than the ideal (or expected) energy savings which can be achieved. For example, a rebound of 10% would mean that the actual energy savings achieved are 10% less than the ideal energy savings. For lighting retrofits rebound would exist if people use the lighting for longer hours after the retrofit than before.

Start-up time
The time taken for a light source to produce light after it is switched on.

Warm-up time
The time taken for a light source to reach full brightness after it is switched on.

³ Light colours. Fluorescent lamps and their selection criteria

⁴ http://en.wikipedia.org/wiki/Lux
1. Introduction

Background to the trial

There is a general recognition that the existing housing stock represents the largest potential for energy saving and greenhouse abatement in the residential sector. However, few studies have looked at how inefficient existing houses actually are, the extent to which their level of energy efficiency can be practically upgraded, or the cost and cost-effectiveness of doing this.

In 2009 Sustainability Victoria commenced a program of work to address these information gaps. Through the On-Ground Assessment study data on the building shell, lighting and appliances was collected from a reasonably representative sample of 60 existing (pre-2005) stand-alone Victorian houses and used to: determine the energy efficiency status of the houses; identify the energy efficiency upgrades which could be practically applied to the houses; and, estimate the upgrade costs and energy bill savings from implementing the upgrades.

Figure 1 shows the share of the main lighting types which were found in the OGA study houses. Inefficient lighting types – 240 volt incandescent light globes and 12 volt halogen downlights – accounted for 5% of the installed lamps found in the houses. The OGA study results are consistent with a larger national study which surveyed the lighting in 150 houses located in Victoria, New South Wales and Queensland [E3 2013]. This study found that 55.7% of the installed lamps were either inefficient incandescent light globes (30.9%) or 12 volt halogen lamps (24.8%).

Both the OGA study [SV 2015] and the E3 Committee study [E3 2013] suggest that there is a significant potential to upgrade the efficiency of the lighting in Victorian houses by replacing the incandescent light globes and the 12 volt halogen downlights with a suitable low energy alternative, either a compact fluorescent lamp (CFL) or LED lamp. Through the OGA study we assessed the cost-effectiveness of a total of 21 different building shell, lighting and appliance upgrades which could be applied to the 60 existing houses which participated in the study. The results of this analysis are summarised in Table 1 [SV 2015] – the results have been normalised to show the average savings and costs for the 60 houses studied. Lighting upgrades were one of the most cost effective energy efficiency upgrade measures, with most of the savings provided by replacing 12 volt halogen downlights with low energy downlights. Even though the share of 12 volt halogen lighting found in the OGA study houses was slightly lower than the share of incandescent lamps, the potential savings from the 12 volt halogen lamps were larger because they were more likely to be found in the main living areas of the houses where lighting is used for longer hours.

5 This includes both the older style lamps with tungsten-halogen filaments and the newer mains voltage halogen incandescent lamps. Note that some incandescent lamps, such as PAR38 lamps, are included in the Other category.

6 Halogen downlight fittings sit flush with the ceiling and use either a small 12 volt (also called extra low voltage) halogen reflector lamp or a small 240 volt halogen reflector lamp. The 12 volt lamps must use either the older magnetic transformer or the newer electronic converter to convert the 240 volt supply voltage to a 12 volt supply suitable for the lamps. The transformer/convertor consumes power as well as the 12 volt lamp.

7 In the OGA study houses 33.9% of the lights in living areas were 12 volt halogen, compared to 24.8% incandescent lamps. Conversely 20.9% of the lights in non-living areas were 12 volt halogen lamps compared to 30.0% incandescent. Lights in living areas are used for an average of around 2.2 hours per day while lights in non-living areas are used for an average of around 1 hour per day.
## TABLE 1: AVERAGE IMPACT OF ALL UPGRADE MEASURES, ACROSS THE STOCK OF 60 OGA STUDY HOUSES

<table>
<thead>
<tr>
<th>Across stock</th>
<th>% Houses Applied To</th>
<th>Gas</th>
<th>Elec</th>
<th>Total</th>
<th>Av. GHG Saving (Kg/Yr)</th>
<th>Av. Saving ($/Yr)</th>
<th>Av. Cost ($)</th>
<th>Av. Payback (Yrs)</th>
</tr>
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<tbody>
<tr>
<td>LF Shower Rose</td>
<td>56.7%</td>
<td>1,333</td>
<td>69</td>
<td>1,402</td>
<td>95</td>
<td>$57.9</td>
<td>$48.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Ceiling Insulation (easy)</td>
<td>11.7%</td>
<td>958</td>
<td>32</td>
<td>990</td>
<td>64</td>
<td>$19.3</td>
<td>$78.6</td>
<td>4.1</td>
</tr>
<tr>
<td>Lighting</td>
<td>93.3%</td>
<td>-</td>
<td>1,202</td>
<td>1,202</td>
<td>365</td>
<td>$93.5</td>
<td>$535.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Draught Sealing</td>
<td>98.3%</td>
<td>7,809</td>
<td>221</td>
<td>8,030</td>
<td>496</td>
<td>$153.9</td>
<td>$1,019.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>55.0%</td>
<td>135</td>
<td>16</td>
<td>152</td>
<td>12</td>
<td>$24.9</td>
<td>$190.9</td>
<td>7.7</td>
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<tr>
<td>Water Heater – High Eff.</td>
<td>58.3%</td>
<td>460</td>
<td>1,004</td>
<td>1,463</td>
<td>330</td>
<td>$58.2</td>
<td>$477.3</td>
<td>8.2</td>
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<tr>
<td>Ceiling Insulation (difficult)</td>
<td>33.3%</td>
<td>1,630</td>
<td>68</td>
<td>1,698</td>
<td>111</td>
<td>$33.8</td>
<td>$278.2</td>
<td>8.2</td>
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<tr>
<td>Heating</td>
<td>80.0%</td>
<td>6,239</td>
<td>215</td>
<td>6,454</td>
<td>411</td>
<td>$125.9</td>
<td>$1,110.6</td>
<td>8.8</td>
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<tr>
<td>Refrigerator</td>
<td>86.7%</td>
<td>-</td>
<td>1,202</td>
<td>1,202</td>
<td>365</td>
<td>$93.5</td>
<td>$1,103.7</td>
<td>11.8</td>
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<tr>
<td>Reduce Sub-Floor Ventilation</td>
<td>21.7%</td>
<td>589</td>
<td>12</td>
<td>601</td>
<td>36</td>
<td>$11.2</td>
<td>$166.7</td>
<td>14.9</td>
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<tr>
<td>Seal Wall Cavity</td>
<td>50.0%</td>
<td>903</td>
<td>24</td>
<td>927</td>
<td>57</td>
<td>$17.6</td>
<td>$270.4</td>
<td>15.3</td>
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<tr>
<td>TV</td>
<td>95.0%</td>
<td>-</td>
<td>696</td>
<td>696</td>
<td>273</td>
<td>$54.1</td>
<td>$964.3</td>
<td>17.8</td>
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<tr>
<td>Ceiling Insulation (Top Up)</td>
<td>43.3%</td>
<td>853</td>
<td>22</td>
<td>875</td>
<td>54</td>
<td>$16.6</td>
<td>$335.3</td>
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<tr>
<td>Underfloor Insulation</td>
<td>40.0%</td>
<td>1,803</td>
<td>10</td>
<td>1,813</td>
<td>102</td>
<td>$32.4</td>
<td>$687.0</td>
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<tr>
<td>Dishwasher</td>
<td>43.3%</td>
<td>-</td>
<td>112</td>
<td>112</td>
<td>34</td>
<td>$10.4</td>
<td>$258.1</td>
<td>24.9</td>
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<tr>
<td>Clothes Dryer – Heat Pump</td>
<td>45.0%</td>
<td>-</td>
<td>353</td>
<td>353</td>
<td>107</td>
<td>$27.5</td>
<td>$727.7</td>
<td>26.5</td>
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<tr>
<td>Cooling</td>
<td>40.0%</td>
<td>-</td>
<td>160</td>
<td>160</td>
<td>49</td>
<td>$12.5</td>
<td>$464.8</td>
<td>37.3</td>
</tr>
<tr>
<td>Wall Insulation</td>
<td>95.0%</td>
<td>5,283</td>
<td>130</td>
<td>5,412</td>
<td>331</td>
<td>$102.5</td>
<td>$3,958.7</td>
<td>38.6</td>
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<tr>
<td>Drapes &amp; Pelmets</td>
<td>100.0%</td>
<td>2,209</td>
<td>54</td>
<td>2,263</td>
<td>139</td>
<td>$42.9</td>
<td>$2,035.9</td>
<td>47.5</td>
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<td>Double Glazing</td>
<td>100.0%</td>
<td>2,278</td>
<td>66</td>
<td>2,344</td>
<td>146</td>
<td>$45.0</td>
<td>$12,145</td>
<td>270</td>
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<tr>
<td>External Shading</td>
<td>31.7%</td>
<td>-</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>$0.7</td>
<td>$463.6</td>
<td>694</td>
</tr>
<tr>
<td><strong>Total (ex Double Glazing)</strong></td>
<td></td>
<td>30,203</td>
<td>5,610</td>
<td>35,813</td>
<td>3,434</td>
<td>$989</td>
<td>$15,274</td>
<td>15.4</td>
</tr>
<tr>
<td><strong>Total (ex Drapes)</strong></td>
<td></td>
<td>30,273</td>
<td>5,621</td>
<td>35,894</td>
<td>3,441</td>
<td>$991</td>
<td>$25,383</td>
<td>25.6</td>
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The next phase of Sustainability Victoria’s work on existing houses has been to trial retrofit measures and assesses the actual impacts achieved. Through the Residential Energy Efficiency Retrofit Trials we are implementing key energy efficiency retrofits in existing houses and monitoring the impacts to assess actual costs and savings, the impact of the upgrades on the level of energy service provided, and household perceptions and acceptance of the upgrade measures. We are also seeking to identify practical issues which need to be taken into consideration when these upgrades are implemented.

As part of the Retrofit Trials we are investigating lighting upgrades. This is because they have a wide applicability across the existing housing stock and are one of the more cost effective upgrade measures. In this study we have focussed on the replacement of 12 volt halogen downlights with low energy downlights:

- While good energy savings are possible from replacing incandescent light globes with CFLs, this is a fairly straightforward retrofit which is well understood. CFL lamps have been readily available for over two decades, and became quite cheap from the early 2000s. Many households have already replaced incandescent light globes with CFLs and many millions of CFLs have been installed in Victorian houses over the last seven years under government incentive schemes;
- The majority of halogen downlights (around 80%) installed in Victorian houses use 12 volt halogen lamps [Ecovantage 2011];
- The largest potential energy saving from lighting retrofits is from replacing the 12 volt halogen downlights with a low energy alternative. This is because the halogen downlights are more common in the living areas of houses, where lighting is used for longer hours, and because they are installed at a higher density than the common incandescent (or CFL) light globes;
- Victoria seems to have a higher penetration of halogen downlights than the rest of Australia, especially in new houses. A 2007 study found that new Victorian houses installed an average of 38.3 halogen downlights per house (68% share of all lights) compared to a national average of 25.7 per house (52% share of all lights) [BIS Shrapnel 2007]. While the lighting power density limits which were introduced into the energy efficiency requirements for new dwellings from 2011 are intended to reduce the number of halogen downlights installed in new houses, these requirements still allow some halogen downlights to be installed. Also, a large number of halogen downlights were installed in the houses constructed or renovated between the mid-1990s and 2011. We estimate that there is currently around 23 million halogen downlights installed in Victorian houses. If all of these lamps were replaced with a low energy lamp, we estimate that this would achieve annual energy bill savings of around $161 million per annum (based on current energy prices) and reduce residential electricity consumption by around 5%.
- Low energy alternatives to existing 12 volt halogen downlights used in residential applications became available on the Victorian market from around 2008. In particular, since 2010 there has been an increasing range of LED downlight lamps available and the costs have decreased. Replacing 12 volt halogen downlight lamps is less straightforward than replacing simple incandescent light globes, and we wanted to contribute to the body of practical knowledge regarding this retrofit.

### Halogen downlight technology

Halogen downlights are a spot lighting technology. They became a popular choice for residential lighting in Australia from the mid-1990s, where they have been used to provide both general room lighting – traditionally the province of the common incandescent light globe – as well as bench-top and other task lighting. Halogen downlight fittings sit flush with the ceiling and house a small conically-shaped MR16 reflector lamp. The lamp consists of a parabolic reflector which surrounds a small tungsten-halogen light source contained in a glass capsule located at the centre of the reflector. The fittings can be either of the fixed or gimballed variety, with the latter allowing the lamp to swivel slightly within the fitting so that it can point in different directions.

![FIGURE 2: HALOGEN DOWNLIGHT LAMP AND FITTING](image)

**FIGURE 2: HALOGEN DOWNLIGHT LAMP AND FITTING**

Halogen reflector lamps produce a conical beam of light characterised by a certain beam angle – lamps with a wide beam angle (35° to 60°) are best suited to general room lighting applications, while lamps with a narrow beam angle (less than 35°) are best suited to feature lighting, task-lighting or general lighting in houses which have high ceilings. Where they are used to provide general room lighting, the

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8. To end 2015 we have trialled halogen downlight replacements, comprehensive draught sealing, cavity wall insulation, gas heating ductwork upgrades, gas heating ductwork upgrades combined with gas furnace upgrades, window film double-glazing, pool pump replacements, heat pump clothes dryers, solar air heaters, gas water heater upgrades, halogen downlight replacements combined with ceiling insulation remediation and some comprehensive whole house retrofits.

9. LED light globes are now also becoming available for this retrofit. Over the next few years we expect the product range available on the market to increase significantly and the cost to come down. LEDs have the potential to be more efficient than the CFLs and also to have a longer life.

10. We estimate that over 12.8 million incandescent light globes were replaced with CFLs at no cost in around 830,000 houses over the period 2009 to end 2015 under the Victorian Energy Saver Incentive Scheme.

11. Because they are a form of spot light, more lamps have to be installed in a given room compared to common incandescent light globes so that even light levels are achieved.

12. Research undertaken for the Victorian Government found that the greenhouse emissions from the average new 5 Star home was around 6% higher than the average Victorian home. While the 5 star energy efficiency requirements were resulting in reductions in heating, cooling and water heating energy use, these were more than being offset by increased lighting energy use. This was partly due to the larger size of these houses and partly due to a high incidence of halogen downlights in new Victorian houses [DSE 2007].

13. This estimate is based on SV’s 2008 Victorian Residential Energy End-Use Model, and is consistent with the data reported in [E3 2013].

14. The designation MR stands for “multifaceted reflector” and the 16 is the diameter of the face of the lamp in eights of an inch. The standard diameter is 50 mm and the typical height to the base (excluding the pins) is around 45 mm for 12 volt lamps and up to 76 mm for 240 volt lamps. (US DoE 2008)
Halogen downlights must be installed at a much higher density than the common incandescent light globes, so that uniform light levels are achieved throughout the room. Where one incandescent (or CFL) light globe is adequate to provide general lighting, it may be necessary to use three to four halogen downlights. This means that the power consumption of the lighting is also around two to three times higher16, and it can result in much higher light levels than necessary for normal residential use.

Halogen downlight lamps are available in both 12 volt (also called extra low voltage, or just low voltage) and 240 volt versions. The 12 volt versions used commonly in residential lighting can be identified by the two sharp pins of the GU5.3 base of the lamp. The 12 volt lamps must be used in conjunction with either a magnetic transformer or an electronic convertor, to convert the 240 volt mains electricity supply to the 12 volt supply required by the lamp. The transformer/convertor also consumes electricity (typically in the range of 4 to 10 Watts), increasing the total power consumption of the halogen light fitting.

Halogen downlight lamps are also available in 240 volt versions. These do not require a transformer/convertor (so no additional energy consumption) and can be recognised by the GU10 connector at the base of the lamp. The different connector types commonly found on halogen downlight lamps used in residential applications are shown in Figure 3.

**FIGURE 3: COMPARISON OF 12 VOLT AND 240 VOLT HALOGEN DOWNLIGHT LAMPS**

In this report we focus on the 12 volt halogen downlight fittings. Historically these have been used mainly with 50 Watt lamps, although 35 Watt and 20 Watt lamps are also available. Minimum energy performance standards (MEPS) for extra low voltage halogen reflector lamps, which were introduced in Victoria in 2012, mean that it is no longer possible to sell this type of halogen lamp with a power consumption greater than 37 Watt. Over time the MEPS regulations will reduce the energy consumption of the existing halogen downlights, even if the old lamps fail and are simply replaced with new halogen lamps. However, much greater savings are possible if the 12 volt halogen downlight lamps are replaced with a low energy alternative.

In addition to the relatively high power consumption of halogen downlights compared to other types of general room lighting, the use of halogen downlights – and downlights more generally – can result in increased heating and cooling energy use. When in use the halogen downlight lamps become very hot and mandatory minimum safety clearances must be provided around the light fitting to reduce fire risks16. Where batt-type insulation is installed, it is common practice for either a whole insulation batt or half a batt to be removed to provide the necessary safety clearances around the downlight fitting17. This can create a ‘Swiss cheese’ effect which considerably reduces the energy saving benefits of the insulation, increasing heating energy use in winter and cooling energy use in summer18. Replacing halogen downlights with lower energy, and cooler, alternative lighting in conjunction with a suitable downlight cover should make it possible to reduce the safety clearances and significantly improve the integrity of the ceiling insulation. This has the potential to provide additional energy savings, although this issue has not been explored in the halogen lighting retrofit trial discussed in this report19.

Other notable features of the standard 12 volt halogen downlight lamps are:
- a light output (for a 50 Watt lamp) of around 650 to 700 lumens;
- essentially instantaneous start and warm-up to full brightness;
- a luminous efficacy of around 13 to 15 lm/Watt;
- a “warm white” colour appearance, corresponding to a colour temperature of around 3000 K;
- very good colour rendering;
- the lamps can be easily dimmed using standard dimming circuits; and
- a relatively short life of around 2,000 to 3,000 hours.

The two main alternative low energy technologies are CFL lamps and LED lamps. To be a suitable replacement, the low energy lamps need to have many performance characteristics – light output, start-up time, colour appearance and colour rendering – which are equivalent to the 12 volt halogen lamps they replace.

While it is possible to replace the entire downlight fitting (lamp plus transformer/convertor) with an entire new 240 volt or 12 volt CFL/LED fitting, this usually requires the services of an electrician20 and so is likely to be more expensive than just replacing the 12 volt halogen lamp with a suitable 12 volt CFL/LED lamp. However, the small size of the 12 volt halogen downlight lamps means that there is limited space within the downlight fitting, and this can create challenges for the design of suitable CFL or LED lamps where it is necessary to have a light output that is comparable to the 50 Watt halogen lamps which are commonly used in residential downlights.

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16 Downlights are a significant cause of house fires in Victoria. Metropolitan Fire Board data cited in [ESV 2007] shows that there were 32 house fires attributed to downlights in 2005, 36 in 2006 and 21 in the first six months of 2007. The NSW Fire Brigades state that the temperature of halogen downlight lamps can reach up to 370°C [NSWFB 2011]. The Australian Wiring Rules AS/NZS3000: 2007/Amndt 2: 2012 requires the following default minimum clearances around halogen downlight fittings: 200 mm above the fitting and to a combustible building element, and 50 mm side clearance to bulk insulation and the transformer/convertor. [E3 2014]

17 AS/NZS3000: 2007 initially required a side clearance of 200 mm to bulk insulation [ESV 2007].

18 For example, in a 10m² room insulated with R3.0 batts, the insulation gaps typically left around downlights could reduce the effective R-value to R1.36 (if there were 3 downlights) and R1.13 (if there were 4 downlights) [NatHERS 2012].

19 In 2015 SV undertook a trial to investigate the impacts of replacing halogen downlights with LED lamps installed in conjunction with downlight covers and remodeling the ceiling insulation. This involved measuring both the lighting and the heating energy savings. The results of this trial will be published in a future report.

20 In some houses the downlight unit (lamp plus transformer/convertor) simply plugs into an individual power outlet located in the roof space. In this case the existing unit can simply be unplugged and a low energy downlight unit plugged in.
Compact fluorescent downlight lamps

There are significant challenges designing a suitable 12 volt CFL downlight lamp that can be used as a direct replacement for 50 Watt, 12 volt halogen downlight lamps:

- There is very limited space available for a standard CFL tube, making it difficult to produce enough light and efficiently reflect the light out of the lamp;
- The size of the CFL tube in relation to the reflector makes it difficult to produce a focused beam. This is less of an issue where the downlights are used for general residential lighting as in this case the use of downlights with a wide beam angle is advisable. However, this could be an issue where the downlights are intended for a spot-lighting application;
- The confined space also seems to lead to a longer warm-up time for the 12 volt CFL lamps compared to the more common 240 volt CFL light globe, where the tube is usually bare.

The CFL lamps may not work with standard lighting dimmers, which are quite commonly used with halogen downlight lamps.

LED downlight lamps

Light emitting diodes (LEDs) were first used in some niche lighting applications in the 1960s, but it was only in the mid-2000s that LED lighting developed to the stage where it could be used in residential lighting applications [IEA 2006].

LED technology has a number of advantages over both halogen and fluorescent lighting technology, especially for use in MR16 lamps. LEDs are a compact light source which, unlike both halogen and fluorescent lamps, produce little infra-red radiation (or heat) in the light output from the lamp. They are capable of very long life, with good quality lamps able to achieve lifetimes of 25,000 to 50,000 hours, and sometimes longer. In addition to this they are made from non-toxic materials [IEA 2006].

The best quality LEDs on the market are much more efficient than halogen downlight lamps and also more efficient than fluorescent light sources with a comparable light output, and the luminous efficacy of the LED lamps seems likely to increase significantly in coming years. The best LED downlights currently on the market with a light output comparable to a 50 Watt 12 volt halogen downlight lamp have a luminous efficacy of around 70 lm/Watt. The US Department of Energy and manufacturers of LED lighting have set an efficacy target of 160 lm/Watt by 2015 [IEA 2006]. If realised this would mean that an LED downlight lamp with a power input of around only 4 Watt would give the same light output as a 50 Watt, 12 volt halogen downlight lamp.

The main challenge for LEDs used in downlighting applications is management of the heat generated within the LED chip during operation. While the light output by the LED chip does not contain heat, heat is generated within the LED chip. If this heat is not dissipated properly the chip will overheat, which could cause it to reduce light output, shift the wavelength of the output light, reduce the lamp’s life or in the worst cases cause failure. Due to the need for the LED chip to dissipate heat most LEDs incorporate a finned heat exchanger, which can make the lamps quite long and bulky – the higher the light output and the lower the efficiency of the LED, the bigger this heat exchanger needs to be. [IEA 2006] Some LED lamps on the market dissipate the heat by using a small fan to draw air over the chip, eliminating the need for a heat exchanger.

As with CFLs, LED lamps may not work with the standard lighting dimmers that are often used with halogen downlights. However, LED lighting technology is dimmable from 0% to 100% of brightness with no loss of efficacy, no changes in colour appearance or colour rendering properties and no reduction in service life [IEA 2006].

How the trial was undertaken

The Halogen Downlight Retrofit Trial was undertaken in two stages, with 8 houses retrofitted in 2011 and a further 8 houses retrofitted in 2012. All 16 houses were located in Melbourne. In the first stage four houses were retrofitted with 12 volt CFL downlights and four houses with 12 volt LED downlights (LED1). In the second stage four houses were retrofitted with a downlight and driver unit (LED2) and four houses retrofitted with 12 volt LED downlights (LED3). The low energy downlights used in the retrofit trial represent only a sample of the downlights available on the market. They were chosen as they were considered to be some of the better performing lamps available on the market at the time. It is important to note that the lighting market is developing quite rapidly, especially the LED market. The range of products available to replace halogen downlights has increased since 2011/12 and the performance of the products available seems to have improved.

The Retrofit Trial involved a number of key steps:

1. Houses were recruited by MEFL to participate in the retrofit trial. The key target was houses with at least ten 12 volt halogen downlights in their main living areas (kitchen, dining, lounge and living rooms), where the downlights were not controlled by a dimmer switch and where they were used as the main form of lighting;
2. An electrician was used to undertake an initial site inspection to assess the electrical safety of the existing lighting system and the likely compatibility of the system with the chosen retrofit lamps;
3. The light levels in the living areas of the houses were measured at night time using a measurement procedure developed by Steve Coyne (see Appendix A4). The measurements were undertaken over a grid and the data used to calculate the average light levels (in lux) in the general circulation areas and on any bench-top areas. The average light levels provide an indication of the level of energy service provided by the downlights, before and after the retrofits. Light levels were measured to see if the low energy retrofit lamps were able to provide a similar level of energy service to the halogen lamps they replaced;

4. Around four OmegaWatt Lamp Count meters25 were installed at each house to monitor the operating times of up to four different groups of halogen downlights. In most cases this allowed the operating times of all retrofit fitted downlights to be monitored. The meters were installed around one month prior to the retrofits and left in place for around one month after the retrofits, to help assess whether the lights were being used differently by householders after the retrofits were undertaken. In particular we were interested to investigate whether or not there was a rebound26 effect associated with the halogen lighting retrofits. This data was also used to estimate the energy saving achieved by the retrofits;

5. Brief householder surveys were conducted before and after the retrofits. The aim was to assess people’s level of satisfaction with their existing lighting and see how this was affected by the lighting retrofits. While replacing halogen downlights with low energy lamps has the potential to achieve significant energy savings, the uptake of this energy efficiency measure is likely to be low if householders are not satisfied with the low energy lighting system;

6. The retrofit trial was undertaken mainly over the June – September period27, corresponding to the period of highest lighting use. This was intended to make it easier to measure the energy savings, and also to identify any rebound effect resulting from the lighting retrofit.

Four different low energy downlight lamps were utilised in the Halogen Downlight Retrofit Trial. A diagram and basic description of the properties of each of the lamps used in the trials is provided in Table 2. The lamps chosen for the stage 1 trial in 2011 (CFL and LED1) were lamps which had trialled well in an earlier halogen lighting retrofit trial [Ecovantage 2011]. Stage 2 gave the opportunity to trial some new lamps which had then come onto the market (LED2 and LED3). While we trialled only a sample of the lamps available on the market, and only tested each lamp in four houses, this did give us the opportunity to assess both CFL and LED replacements for the 12 volt halogen downlight lamps, and to also assess the approach of using “plug and play” lamps (12 volt lamps with GU5.3 base) to replace the 12 volt halogen downlight lamps, as well as replacing the existing lamp and its convertor/transformer with an LED lamp and driver which plugged into a 240 volt supply.

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25 These are small battery operated meters and data loggers with a light sensitive probe, which can be installed on the ceiling next to the halogen downlights. The meters were set to a 10 minute logging interval and record the amount of time (in seconds) that the lights were switched on during each 10 minute interval.

26 This is sometimes also called the take-back effect. Some economists argue that energy efficiency measures such as lighting retrofits result in lower energy savings than expected (10 to 50% less), because consumers choose to take some of the energy savings as a higher level of energy service. For example, [PC 2008] states that “energy efficiency makes energy appear cheaper relative to other items as less money is required to purchase the same energy services. Consequently, the household will tend to use more energy …”. For lighting retrofits the presence of rebound would mean that householders chose to operate their lighting for longer hours after the lighting retrofits.

27 In 2011 the trials were undertaken mainly over the July to September period, with the lighting retrofits being undertaken in late July or early August; in 2012 the trials were undertaken mainly over the June to August period, with the lighting retrofits being undertaken in early July.
TABLE 2: LAMPS USED IN THE HALOGEN DOWNLIGHT RETROFIT TRIAL

<table>
<thead>
<tr>
<th>Lamp Code and Description</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CFL</strong></td>
<td>![CFL Image]</td>
</tr>
<tr>
<td>15 Watt, 12 volt CFL lamp.</td>
<td></td>
</tr>
<tr>
<td>Light output &lt; 350 lm</td>
<td></td>
</tr>
<tr>
<td>Efficacy &lt; 23.3 lm/W</td>
<td></td>
</tr>
</tbody>
</table>

| **LED1**                  | ![LED1 Image] |
| 10 Watt, 12 volt LED lamp |         |
| Light output = 380 lm     |         |
| Efficacy = 38 lm/W        |         |

Lamp uses a small internal fan to draw in air and cool the LED chip.

| **LED2**                  | ![LED2 Image] |
| 10 Watt LED lamp and separate driver which plugs into 240 volt supply |         |
| Light output = 520 lm     |         |
| Efficacy = 52 lm/W        |         |

External heat exchanger used to cool the LED chip.

| **LED3**                  | ![LED3 Image] |
| 10.5 Watt, 12 volt LED lamp |         |
| Light output = 720 lm     |         |
| Efficacy = 69 lm/W        |         |

External heat exchanger used to cool the LED chip.
Lamp is dimmable using conventional dimmer circuits.

Overview of the report

In Chapter 2 we provide an overview of the houses which were recruited for the retrofit trial, and present the results of our analysis. In particular we look at the impact of the halogen downlight retrofits on the light levels in the living areas, household satisfaction with their lighting before and after the retrofits were undertaken, the way in which the lighting was operated before and after the retrofits and the issue of rebound, the impact of the retrofits on the load profile of the lighting, the energy savings achieved by the retrofits and the economics of the lighting retrofits. We also look at some of the practical issues associated with the lighting retrofits, and the ways in which these can be overcome.

In Chapter 3 we present our summary and conclusions. More detailed data and analysis is presented in the Appendices. In Appendix A1 we present the individual monitoring results for each of the 16 houses which participated in the study, including the overall average daily load profile of the lighting before and after the retrofit, as well as data on the operating time of the different lights which were monitored before and after retrofits. In Appendix A2 we investigate the impact of the retrofits in the different living areas:- kitchen, dining and living/lounge areas. In Appendix A3 we provide the detailed analysis results for each of the houses, and in Appendix A4 we provide the light level measurement procedure used in the study.
2. Results of the halogen downlight retrofit trials

Housing Sample

Details of the lighting found in the 16 houses which participated in the Halogen Downlight Retrofit Trial are shown in Table 3, including the total number of downlights replaced, their location in the houses and an estimate of the total power consumption of the downlights before and after the retrofits were undertaken. We also show the number of downlights which were monitored using the Lamp Count meters. The downlights were typically installed in groups which comprised between two to six lamps on a single switching circuit. For the trial we used an average of four Lamp Count meters per house, and these were allocated to the different switching groups so that we could monitor as many individual downlights as possible. However, in the houses with a large number of lamps and/or a large number of switching groups it was not possible to monitor all downlights. Also, in a small number of cases meter failures meant that no useful data was collected.

Impact on light levels

The light levels in the living areas of the houses were measured at night time before and after the retrofits were undertaken using a measurement methodology developed by Steve Coyne (See Appendix A4). The light levels (in lux) were measured over a grid in the general circulation and also on any bench-top areas, and the measurements at the different grid points were then used to estimate the average light levels in these areas.

The average light levels for each of the houses which participated in the study are provided in Appendix A3. This data has been summarised in Figures 2 and 3 below. Figure 2 shows the average light levels for the houses in which the halogen downlights were replaced by CFLs compared to the average light levels in the houses where LEDs were used as the retrofit lamp. Where CFLs were used the average light levels after the retrofit were roughly halved (-49%) in both the general circulation and the bench-top areas. Where LED lamps were used the average light levels increased, by around 28% in the general circulation areas and by around 16% in the bench-top areas. This result is consistent with the light outputs from CFL lamps compared to the various LED lamps (see Table 2). However, it is important to keep in mind that these light level measurements were undertaken early in the life of the retrofit lamps. The light output of both the CFL and LED lamps will suffer some degradation over the lifetime of the lamps, and so the light levels in the areas lit by the retrofit lamps would be expected to decline over time.

![Figure 2 - Average Light Levels, CFL vs LEDs](image)

Figure 3 provides a more detailed breakdown of the average light level data, and compares the CFL lamps with the various LED lamps used. This tells a similar story to Figure 2. In all cases the average light levels in the general circulation areas increased for the LED retrofits, regardless of which LED lamp was used. The light level increase was greatest (52%) where LED3 was used - the LED with the highest light output - and was smallest (11%) where LED1 was used - the LED with the lowest light output. The situation was more complex for the bench-top areas. In this case the average light levels increased for both LED1 (1%) and LED3 (48%), but decreased slightly (-7%) for LED2. The light levels for the bench-top areas were averaged over a smaller number of data points compared to the general circulation areas, and so the average light levels are likely to be more sensitive to the position of the measurement points relative to the downlights.

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28 It was not possible to measure the electrical power consumption of the downlights directly. The rated power of each halogen lamp was recorded by the electrician when it was replaced. The total power consumption was estimated based on the assumption that, on average, the power consumption of the transformer/convertor was 16% of the power consumption of the lamps. This should give a reasonable average estimate across the houses, but will tend to overestimate the power consumption where electronic convertors have been used and underestimate the power consumption where magnetic transformers have been used.

29 The Lamp Count meters have a small photo-electric sensor shrouded in a plastic sleeve at the end of a flexible probe. This is placed so that the sensor is close to and facing the lamp, and so that the plastic sleeve shades the sensor from other internal and external light sources. In some cases the sensor was placed too close to the hot halogen downlight lamps, melting the sleeve. This meant that no data was recorded.

30 These are the areas that people walk through, meaning that the light levels do not need to be as high. Light levels of between 40 and 80 lux are generally considered to be adequate for these areas.

31 The bench-tops were located in kitchen areas. In the areas where work such as cutting and food preparation needs to be undertaken higher light levels are required compared to the general circulation areas. A light level between 160 to 240 lux is generally considered to be adequate.
TABLE 3: DETAILS OF THE HOUSES WHICH PARTICIPATED IN THE RETROFIT TRIAL

<table>
<thead>
<tr>
<th>House Code</th>
<th>Number of Downlights Replaced</th>
<th>Location of Halogen Downlights</th>
<th>Estimated Total Downlight Power Consumption (Watts)</th>
<th>Number of Lamps Monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kitchen</td>
<td>Dining</td>
<td>Lounge / Living</td>
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<tr>
<td>CFL Retrofits</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>15</td>
<td>11</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>H2*</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>H3</td>
<td>18</td>
<td>5</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>H4</td>
<td>12</td>
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<tr>
<td>LED1 Retrofits</td>
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<tr>
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<td>H12</td>
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<td>LED3 Retrofits</td>
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<tr>
<td>H16</td>
<td>11</td>
<td>2</td>
<td>-</td>
<td>9</td>
</tr>
</tbody>
</table>

* Meter on group of 3 lights in the dining room was faulty and no data was recorded.
+ Meter on the group of 6 lights in the dining room was faulty and no data was recorded.
In Figure 2 we have used yellow shading to indicate the recommended light level range\(^{32}\) for both the general circulation and bench-top areas. In all cases the average light levels in the general circulation areas were either within the recommended range or exceeded it. In particular, the light levels exceeded the recommended range in all houses before the retrofits were undertaken (halogen downlights) and in the houses retrofitted with LEDs. In these cases the use of suitable dimmers or the use of some lower wattage lamps could have given further energy savings and still kept the light levels within the recommended range. In most cases the average light levels on the bench-top areas were below the recommended range. The exception was where the halogen downlights were replaced with the LED3 lamps. It’s relevant to note here that these are average light levels, and the light levels in the specific bench-top areas where fine work was undertaken may have been within the recommended range.

**Householder perceptions**

Surveys were conducted before and after the halogen downlight retrofits were undertaken to assess householder satisfaction with the lighting provided by the downlights in their living areas\(^{33}\). These surveys covered:

1. General level of satisfaction with the lighting installation;
2. Satisfaction with the light levels;
3. Satisfaction with the “colour”\(^{34}\) (e.g. colour appearance) of the lighting.

The survey results for each of the houses which participated in the Halogen Downlight Retrofit Trial are provided in Appendix A3. This data has been summarised in Figures 4 to 7 below. Figure 4 shows the average satisfaction ratings over the three categories surveyed, and compares the results for the houses retrofitted with the CFL lamps to those for the houses retrofitted with one of the LED lamps.

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32 Light level ranges were provided by Steve Coyne based on AS/NZS 1680.1:2004. There are no mandatory minimum light levels which apply to residential lighting.
33 Householders were asked to rate their level of satisfaction with different aspects of the lighting on a scale of 1 to 5, with 1 = extremely dissatisfied and 5 = extremely satisfied.
34 Halogen downlights have a “warm white” colour appearance, which means that the light has a slightly yellow tinge. CFLs can have either a “warm white” or “cool white” (often considered to be too “clinical” for use in living areas) colour appearance. LEDs come in a similar range of colour appearance to CFLs, although some poorer quality LEDs can have a slightly blue or green colour appearance.
Comments on satisfaction with the light levels

CFL households
Start-up time is the main issue but overall happy with them. (H1)
Light seems a bit softer and more dispersed. Light level during start-up is the main problem. (H2)
Overall they were good but the start-up time is a real issue – it is way too long. (H3)
The only deterrent is start-up time for the light. (H4)

LED households
[There is] much more consistent light with LED and generally very happy (H5)
Happy with the lower energy consumption. Also find reading on the couch easier. (H7)
Very pleased with the situation, especially given that we are now saving energy as well. (H9)

Figure 5 provides a comparison of the general level of satisfaction with the lighting for all four of the retrofit lamps. The level of satisfaction increased for all of the LED lamps but, as noted above, decreased for the CFL lamps. In addition to good light levels, satisfaction with the LEDs was often linked to lower energy use. Overall, the householders still expressed satisfaction with the CFL lamps, but it was the slow start-up time which was cited by all householders as the main issue (see comments above). A number of the householders with CFL lamps mentioned that they would like to have some LED lamps installed in conjunction with the CFLs, as the LED lamps could provide some instant light while the CFL lamps were warming up. At the end of the trial all CFL households were happy to retain their CFL lamps, but they were provided with a number of LED lamps to address this start-up issue.

Figure 6 provides a comparison of the satisfaction with the light levels for all four of the retrofit lamps trialled. With the exception of LED2 (very slight decrease in satisfaction) in most cases there was an increase in satisfaction with the light levels, with the largest increase found in those houses which were retrofitted with LED1 and LED3. The reasons for the variation in satisfaction across the different lamp types are not entirely clear. In some cases the householders perceived an increase in light levels and in some cases they perceived a reduction in light levels, but not enough to cause concern. In some cases the lighting was perceived as being softer and less glary than the halogen downlights, and this was seen as a positive. (See below for a selection of comments.)

FIGURE 6 – COMPARISON OF LAMPS: SATISFACTION WITH LIGHT LEVELS

Comments on satisfaction with the light levels

CFL households
Light is adequate when all are warmed up. No trouble undertaking tasks. (H1)
Is quite workable when [the lights have] warmed up. Start-up is the issue once again. (H2)
Feels like it is less glary and am generally happy with the light levels. (H4)

LED households
Only complaint is that the north facing kitchen bench could be brighter, but generally happy. (H5)
Enough light everywhere. Feels like the sewing area is brighter now or has a better distribution of light. (H8)
The light seems to be a tiny bit less bright than the halogens but almost imperceptible. This is a very minor concern. (H9)
No change. Happy with the light levels, even though it seems a bit dimmer than before. There is enough light. (H12)
Brighter than the original lights. (H14)
Good colour, better light. (H16)

FIGURE 7 – COMPARISON OF LAMPS: SATISFACTION WITH COLOUR APPEARANCE

35 MEFL reported that the CFLs took around 45 to 60 seconds before an acceptable level of light was reached.
Figure 7 provides a comparison of the satisfaction with the colour appearance of the lighting for all four of the retrofit lamps. There was little change in the level of satisfaction before and after the retrofits, although slight increases were recorded for LED2 and LED3. In some cases the householders perceived that the replacement lamps were slightly “cooler”, but this did not seem to cause any major concerns. A selection of the comments from the householders is provided below.

**Comments on satisfaction with the colour appearance**

**CFL households**
- Nice warm light from the CFLs. (H1)
- Softer, more dispersed and a little cooler as well. But I am happy with it. (H2)
- Good warm colour once warmed up. (H3)

**LED households**
- It seems that the light is a bit cooler than the halogen lights. Happy with this coolness in the kitchen, but would prefer slightly warmer light in the lounge if this was possible. (H5)
- Like the colour of the lights. No complaints. (H6)
- Find the light a little bit too sharp now as not as warm as before. Would prefer if it was a bit warmer, but would not stop [me] from using them (H7).
- No change. Happy with the light colour (H11)
- Happy with the colour. Seems better than before. (H12)
- Seems better. A bit brighter and sharper. (H13)
- The colour is better than before. (H14)

In general, consumers were less satisfied with the CFL lamp used in this retrofit trial. We understand that this lamp is no longer on the market, and has been replaced with a newer version which has a higher light output and a faster warm-up time.

**Economics of retrofitting**

A key reason for undertaking the Halogen Downlight Retrofit Trial was to obtain a better understanding of the actual costs and savings which can be achieved when replacing 12 volt halogen downlights with a low energy alternative. The costs of undertaking the lighting retrofits were documented by MEFL as part of the study, and include:
- The cost of the retrofit lamps;
- The cost of any replacement transformers (where required) or the cost of the LED drivers (LED2);
- The cost of any replacement light fittings (where required);
- The cost of any replacement connectors or power sockets (where required);
- The labour costs for the electrician for the installation work and for any modifications to the light fittings which were required. In this study we used an electrician to undertake the retrofit work. Where a 12 volt low energy lamp is used as a replacement, and where no electrical wiring work is necessary, the retrofit could be undertaken by a less skilled installer or as a DIY project by the householder, significantly reducing costs.

The energy consumption of the lighting, before and after retrofit36, was derived from the estimated installed power of the lighting combined with the metered operating times of the lighting. As it was not possible to monitor all of the downlights which were retrofitted, the analysis presented in the report is limited to only those downlights we were able to monitor. This means that for some of the houses larger energy savings would have been achieved in practice.

The operating times of the lighting were metered during the winter period – when lighting is used for longer than at other times of the year – and because the pre-retrofit lamps were monitored during June/July and the retrofitted lamps monitored during July to September, it was necessary to use a seasonal adjustment factor to estimate annual average daily operating time, the annual energy use before and after retrofits were undertaken, and therefore the annual electricity bill saving.

**Impact on electricity consumption**

In Figure 8 we show the average daily load profile37 of all monitored downlights in the different areas of the houses prior to the halogen downlights being replaced. A load profile shows how the electricity consumption of the downlights varies throughout the day; the average daily load profile was produced by averaging the daily load profiles for all houses over the pre-retrofit metering period. The highest lighting electricity consumption was in the kitchen, followed by the lounge/living areas and the dining room. All the profiles show a distinct peak in the evening between around 6 pm to 8 pm, and a smaller peak in the morning around 7 am to 8.30 am. As expected there is little or no electricity consumption from the lighting during the early hours of the morning (around 1.30 am to 5.30 am) and the electricity consumption of the lighting is fairly low – and relatively flat – during the daylight hours (around 9.30 am to 3.30 pm). The evening peak in the living/lounge areas of the houses is quite broad, while the evening peak in both the kitchen and dining rooms is quite sharp.

![Figure 8 – Average daily load profile of lighting in different living areas before retrofit](image)

36 Refer to the discussion before Table 3, which shows the estimated total installed power of the downlights before and after the retrofits were undertaken.
37 The Lamp Count meters recorded the operating time over a 10 minute interval. The load profile therefore shows the average power consumption over each 10-minute period during the day.
After retrofit

It is clear that there has been a significant reduction in the electricity consumption of the lighting after the retrofits at all times during the day. A comparison of the total installed power of the downlights before and after the retrofits suggests that the overall energy saving would be expected to be around 76.7%. Once the seasonal adjustment factors were applied (see below) we estimate that an energy saving would be expected to be around 79.9% - the LEDs had a lower power consumption than the CFLs; in practice we estimate that an energy saving of 57.3% was achieved, somewhat lower than expected.

Impact on usage of lighting

As part of the study we investigated whether the lighting retrofits had an impact on the way in which the households used the lighting in their living areas. The data collected from the Lamp Count meters was used to calculate the average amount of time the lighting was operated each day over the monitoring period, and this was subsequently used to estimate the energy savings achieved by the retrofits. The lighting was monitored mainly over the June to September period, the time of year that lighting is used for the longest time each day. To give an accurate estimate of the annual energy savings achieved by the retrofits it was necessary to estimate the annual average daily operating time of the lighting (hours per day).

Further, as the pre-retrofit lighting was monitored during June/July and the post-retrofit lighting was monitored during the July to September period the changing length of the days potentially had some impact on the average operating time measured during the pre- and post-retrofit periods. As we also wanted to understand whether or not people were using their lighting differently, e.g. for a shorter or longer time each day after the retrofits, we needed to estimate the annual average daily operating time both before and after the retrofits.

A more detailed breakdown of the average daily load profile data is provided in Figures 10 and 11. Figure 10 shows the average daily load profile of all monitored downlights in the CFL retrofit houses, and Figure 11 shows the average daily load profile of all monitored downlights in the LED retrofit houses. It is evident from these figures that the energy savings in the LED retrofit houses were greater than those in the CFL houses. A comparison of the total installed power of the downlights before and after the retrofits in the CFL houses suggests that the overall energy saving would be expected to be around 68.9%; in practice we estimate that an energy saving of 57.3% was achieved, somewhat lower than expected. A comparison of the total installed power of the downlights before and after the retrofits in the LED houses suggests that the overall energy saving would be expected to be around 79.9% - the LEDs had a lower power consumption than the CFLs; in practice we estimate that an energy saving of 79.9% was achieved, exactly as expected. A key reason for this result is that while there was little change in the usage of the lighting after the retrofits in the LED houses, lighting usage increased quite significantly in the CFL retrofit houses.

Similar graphs for the kitchen, dining and lounge/living areas are provided in Appendix A2.
A seasonal adjustment factor was calculated for each house for both the pre- and post-retrofit period and used to estimate annual average daily operating time of the lighting during each of these monitoring periods. The derivation of the seasonal adjustment factor made use of a lighting usage function, which was based on two main assumptions:

1. that the operating times of the lighting follow a sinusoidal pattern throughout the year, with the maximum occurring on the winter solstice (shortest day of the year) and the minimum occurring on the summer solstice (longest day of the year);
2. Summer lighting energy use is around 30% of peak winter use.

The distribution of the average annual daily operating times for all the lighting found in the 16 houses is shown in Figure 14, and similar distributions for the different areas of the houses are provided in Appendix A2. As was found to be common in our On-Ground Assessment study for most areas of energy use, there is significant variation in the way the lighting is used across the houses which participated in the Retrofit Trials. While it was most common for the lighting in the living areas to operate for an average of between one and two hours per day, some houses operated their lighting for less than this, and a significant number of houses (43.8%) operated their lighting for longer than this.
As noted above, we used the seasonal adjustment factor to estimate the annual average daily operating time of the lighting before and after retrofit, and this was used to estimate the energy savings achieved from the lighting retrofits. We also used this data to investigate whether or not there was a rebound effect from the lighting retrofits. A rebound would occur if the lighting was used for a longer period after the retrofits compared to before the retrofits, reducing the energy savings achieved. The results of this analysis are summarised in Figure 15. In this we show the increase (or decrease) in the annual average daily operating time of the lighting before and after retrofits for the different retrofit lamps. We have also estimated whether or not the energy savings achieved were more or less than the theoretical “ideal” energy savings, that is, the energy savings which would be achieved if the lighting was operated for exactly the same after the retrofits as before.

Our analysis produced quite a surprising result. For the CFL retrofit houses the average annual daily operating time of the lighting increased by 37.3% after the retrofits, reducing the expected energy saving by 16.9%. The average annual daily operating time increased in all the CFL houses, by between 26% to 58%. In contrast, there was no net change in the usage of the lighting in the LED retrofit houses: taken as a whole the average operating time of the downlights was the same after the retrofits as before and the actual energy savings were almost exactly as expected. There was some variation observed across the LED retrofit houses, with the LED1 houses showing a reduction in operating time after the retrofits (-8.0%), and the LED2 and LED3 houses showing a slight increase in operating time, 5.1% and 1.2% respectively. The annual average operating time of the lighting was observed to increase in 5 of the 12 LED downlight houses (by between 6% and 28%) and to decrease in 7 of the 12 LED downlight houses (by between 2% and 41%). For information on the impact in each of the houses refer to Appendix A3.

Further insights into the way in which the usage of the CFL downlights was different to the LED downlights after the retrofits is provided by the graphs in Figure 16. This compares the average usage profile of the CFL lighting before (blue line) and after (red line) the retrofits were undertaken. It is clear from this that the CFL lighting was operated for longer during both the morning and evening peak periods after the retrofits were undertaken. In contrast the average usage profile of the LED lighting after the retrofits is almost an exact match of the average usage profile of the halogen lighting before the retrofits in these houses.

The post-retrofit householder surveys obtained information on the householders’ perceptions of whether they used the lighting differently after the retrofits compared to before. In the majority of the houses (81%) the householders believed that they were using the lighting about the same amount. Three of the households indicated that they were using the lighting more after the retrofits, although the reasons for this varied (see below).

Reasons that lighting was used more after the retrofits

CFL households

[We] are turning them on earlier so as to provide time to warm up before beginning a task needing light... [We] get used to it but it takes 5 minutes to get to full strength. (H1)

The halogens were too bright, so we had stopped using them. (H2)

We are turning them on earlier so as to provide time to warm up before beginning a task needing light... [We] get used to it but it takes 5 minutes to get to full strength. (H1)

LED households

Not a massive change in use but [we] are a bit more relaxed about using the lights. [We are] less on the children’s back to turn off the lights. (H15)
The results observed in the Halogen Downlight Retrofit Trial suggest that there is little, if any, rebound effect in the economic sense across the houses which participated in the Retrofit Trial. While in some survey responses there is a suggestion that lighting usage has increased because people were now more relaxed regarding their lighting use, and less vigilant about turning the lighting off, the large difference observed between the CFL retrofit houses and the LED retrofit houses suggests that the increased usage of the CFL downlights after the retrofits is largely a technology effect rather than an economic effect. The main issue householders had with the CFL downlights used in the trial was their slow start-up and warm-up time. It seems likely that the longer post-retrofit operating times observed in the CFL houses are a result of householders modifying their behaviour to accommodate this warm-up time, and perhaps not switching the CFL downlights off as often to avoid this inconvenience. The LED downlights started essentially instantly and gave light levels that were similar to or greater than the halogen downlights they replaced. From the householders’ perspective they behaved in a very similar way to the halogen downlights, and they seemed to have been used in a similar fashion.

While increased operating times were observed in all CFL retrofit houses in this trial, we don’t believe this result is applicable to all CFL lighting, or all CFL downlights. As the effect seems to be largely linked to the relatively long warm-up time of the CFL downlights used in the retrofit trial, it may be applicable to CFLs which have a similar long warm-up time but we believe that it is unlikely to be applicable to CFLs and CFL downlights which have a start-up and warm-up time that is much closer to that of a halogen downlight.

Cost-benefit analysis

The cost of the materials used in the retrofits and the labour cost of the electrician were documented by MEFL as part of the study. As noted above, in addition to the cost of the lamps the materials cost could include the cost of a range of other materials such as light fittings, transformers or LED drivers, and the cost of any new connectors or power sockets required. The labour costs involved the basic retrofit cost, e.g. the cost of an electrician replacing the lamp, plus the cost of any additional work to install the other materials or to modify the light fitting in some way. These additional material and labour costs were incurred where a straight change-over of the 12 volt lamp was not possible – these are noted in Table 5 below for the different lamp types.

The average cost for replacing the downlight lamps for the different lamp types is shown in Table 4. This table also shows the average annual energy bill saving achieved per lamp for the retrofits and the payback period. The average cost of replacing the lamps was $61.41 per lamp, comprising $43.79 (71.3%) material costs and $17.62 (28.7%) labour costs. The average cost of the CFL retrofits ($27.53) was considerably lower than the average cost of the LED retrofits ($75.08), due to the much higher cost of the LED lamps at the time that the Retrofit Trial was undertaken. For most of the lamp types the labour costs involved in undertaking the retrofit were quite similar. The exception was LED2 - $23.05 compared to an average of $17.62 – due to the requirement to completely remove the existing halogen downlight lamp and transformer and install a power socket to allow the LED driver to be plugged in. The materials costs for LED2 were also slightly higher for these reasons.

42 The installation of a new power socket may not be necessary in all situations. In some newer halogen downlight installations individual power sockets are installed in the ceiling for each downlight. This means that the existing lamp and transformer can simply be unplugged and the new LED lamp and driver plugged back in. This would not require the services of an electrician and the retrofit costs would be somewhat cheaper.

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Materials ($/Lamp)</th>
<th>Labour ($/Lamp)</th>
<th>Total ($/Lamp)</th>
<th>Av. Saving per Lamp ($/Yr)*</th>
<th>Av. Payback (Yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All lamps</td>
<td>$43.79</td>
<td>$17.62</td>
<td>$61.41</td>
<td>$9.15</td>
<td>6.7</td>
</tr>
<tr>
<td>CFL</td>
<td>$8.74</td>
<td>$18.79</td>
<td>$27.53</td>
<td>$8.21</td>
<td>3.4</td>
</tr>
<tr>
<td>All LED</td>
<td>$57.93</td>
<td>$17.15</td>
<td>$75.08</td>
<td>$9.52</td>
<td>7.9</td>
</tr>
<tr>
<td>LED1</td>
<td>$53.73</td>
<td>$14.42</td>
<td>$68.15</td>
<td>$8.89</td>
<td>7.7</td>
</tr>
<tr>
<td>LED2</td>
<td>$63.12</td>
<td>$23.05</td>
<td>$86.16</td>
<td>$11.22</td>
<td>7.7</td>
</tr>
<tr>
<td>LED3</td>
<td>$56.96</td>
<td>$14.50</td>
<td>$71.46</td>
<td>$8.44</td>
<td>8.5</td>
</tr>
</tbody>
</table>

* Based on an electricity tariff of 28c/kWh.
The cost of electricity has risen significantly over the last 7 years. As noted previously, the cost of LED lamps has decreased in recent years. Subsidies with a 12 volt LED lamp by an electrician for free, and a substantial subsidy is available to have a 12 volt halogen downlights replaced by an electrician for free. This was offset to some extent by the lower price of LED lighting had accelerated in recent years. It predicts that by 2016 the price of LED lighting had accelerated in recent years. It predicts that by 2016 the price for LED retrofits (7.9 years) due to the much lower cost of the CFL retrofits. This lower cost was offset to some extent by the lower energy savings which resulted from the CFL retrofits.

The paybacks presented in Table 4 include the cost of an electrician to undertake the retrofit work. Where an electrician is not required the retrofit costs will be lower and the paybacks correspondingly lower. A number of technical features in the lamp technology can reduce the need for an electrician to be involved in the retrofit, including wide compatibility with the stock of magnetic transformers and electronic dimming circuits. A number of the lamps available on the market have converters found in existing houses, the ability to be easily installed in gimbal or concave downlight fittings, and compatibility with common dimming circuits. A number of the lamps available on the market have some or all of these improvements. In addition, there are a range of factors which make it likely that the paybacks achieved from halogen downlight retrofits will improve over coming years:

- The cost of electricity has risen significantly over the last 7 years, and seems likely to continue to rise in real terms over the coming decade, although possibly at a lower rate of growth;
- As noted previously, the cost of LED lamps has decreased in recent years and seems likely to decrease further, and quite rapidly, over the next few years.

The replacement of 12 volt halogen downlights is an eligible activity in the Victorian Energy Saver Incentive scheme, although there was little retrofit activity undertaken until around mid-2013. Under this scheme it is now possible to have 12 volt halogen downlight lamps replaced with a 12 volt LED lamps by an electrician for free, and a substantial subsidy is available to have a 12 volt halogen downlights replaced by a new complete unit (LED driver plus lamp).

Number of Houses

<table>
<thead>
<tr>
<th>Payback bands (Yrs)</th>
<th>0 - 2</th>
<th>2.1 to 4</th>
<th>6.1 to 8</th>
<th>8.1 to 10</th>
<th>10.1 to 12</th>
<th>12.1 to 14</th>
<th>14.1 to 16</th>
<th>16.1 to 18</th>
<th>18.1 to 20</th>
<th>20.1 to 22</th>
<th>22.1 to 24</th>
<th>24.1 to 26</th>
<th>26.1 to 28</th>
<th>28.1 to 30</th>
<th>30.1 to 40</th>
<th>40.1 to 50</th>
<th>50.1 to 60</th>
<th>60.1 to 70</th>
<th>70.1 to 80</th>
<th>80.1 to 90</th>
<th>90.1 to 100</th>
<th>100.1 to 200</th>
<th>200.1 to 300</th>
<th>300.1 to 400</th>
<th>400.1 to 500</th>
<th>500 +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Houses</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 17 shows the distribution of the paybacks for the halogen lighting retrofits across the 16 houses involved in the Trial. The payback period was less than 10 years in the majority (68.8%) of the houses, with all of the CFL retrofit houses included in this group. The paybacks were somewhat longer than this in 5 of the houses, corresponding to those houses in which the average daily operating of the lighting was quite low – the average annual operating time of the lighting in these houses was 0.87 hours per day, compared to the average for all houses of 2.16 hours per day.

Practical issues

One aim of the Halogen Downlight Retrofit Trial was to investigate the practical issues involved with undertaking the retrofits. It is important for householders and sections of the energy services industry involved with undertaking retrofits to understand these issues and know how to avoid or overcome them. The issues encountered during the trial when replacing the halogen downlights with low energy downlights are summarised in Table 5 – in this we indicate the percentage of houses where there was an issue for at least some of the lamps, either during the installation process or noted by the householders. There were at least some issues associated with all retrofit lamps. The main issues encountered during this Trial were (see below for further details):

1. Compatibility with the existing transformer/converter;
2. Compatibility with the existing light fitting;
3. Compatibility with the existing wiring;
4. Electical interference with the TV or radio;
5. Slow start-up and warm-up time;
6. Humming.

43 For example, LED1 had a small internal fan to dissipate heat from the LED chip, meaning the lamp was a similar size and shape to a halogen lamp, and LED3 could be separated into two separate parts to facilitate installation in gimbal fittings.
44 The retail price index for electricity in Melbourne increased by 88% from 2006/07 to 2013/14. The retail price of electricity is expected to remain fairly flat in the short term. [State of the Energy Market 2012, Australian Energy Regulator 2012]
45 A recent report on the global lighting market noted that the reduction in the price of LED lighting had accelerated in recent years. It predicts that by 2016 the payback for the use of LEDs in residential lighting applications will fall below 2 years. [McKinsey 2012]
46 The subsidy available under this scheme is variable, and depends on the characteristics of the LED lamp being installed, and the market price of the certificates generated as a result of the activity.
Compatibility with the transformer

In some cases the 12 volt retrofit lamps were not compatible with the existing transformers/convertors. This was an issue in some of the CFL and LED1 retrofit houses, but was not an issue in any of the LED3 retrofit houses. It was not relevant to the LED2 retrofit houses, as in this case the existing transformer was replaced with an LED driver matched to the replacement lamp.

Research undertaken for the US Department of Energy also found that transformer compatibility can be an issue. The transformers used with the halogen downlights generally require a minimum connected electrical load (e.g. power consumption), and as the LEDs and CFLs have a much lower power consumption compared to the halogen lamps they replace this may not be sufficient for the transformers to work correctly.\(^{48}\)

Where compatibility issues occurred it created a range of issues, including making the lamp flicker, pulse or not start at all, and in some cases led to early failure of the retrofit lamps. Transformer compatibility did not seem to be a major issue in the houses which had the older style magnetic transformers, and was more likely when the existing halogen lighting system used the newer electronic convertors.

Compatibility with the downlight fitting

There were a range of issues which meant that the retrofit lamps were not compatible with the existing downlight fittings:

1. The main compatibility issue occurred when the retrofit lamp was too long to fit correctly in the existing downlight fitting (see Figure 18);
2. In some cases where the halogen downlights had a downlight cover, the cover was not long enough to accommodate the replacement lamp (see Figure 19);
3. Another common issue occurred when the clips used to hold the halogen lamp in the fitting were not compatible with the shape of the retrofit lamp (see Figure 20); and
4. In some cases, small tags used on the ring of some fittings did not allow the retrofit lamp to sit flush with the fitting (see Figure 21).

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\(^{47}\) For example for house H1 the measured average operating time of one downlight group before the retrofit was 3.63 hrs/day, and we calculated the average lighting usage factor as 0.967. This gave a seasonal adjustment factor of 0.672 and an estimated annual average operating time of 2.44 hrs per day.

\(^{48}\) The US DoE 2008 report also notes that a similar issue occurs for dimming circuits. However, in this trial we recruited houses which did not use dimmers with their halogen downlights.
FIGURE 18 – RETROFIT LAMP TOO LONG FOR FITTING

Figure 18 provides examples of both open downlight fittings and fittings which have concave caps, and illustrates how in some cases the retrofit lamp is too long to fit correctly in the fittings with concave caps. In some cases it was possible for the electrician to trim back the concave cap with tin snips to make the opening wider so that the retrofit lamp could fit properly, and in other cases they needed to install a new downlight fitting compatible with the retrofit lamp. When sourcing a replacement fitting it is important to source a fitting with the same ceiling cut-out dimensions as the existing fitting – the standard cut-out for a fixed downlight fitting is a 70 mm diameter circle, while the standard cut-out for a gimbal fitting is a 90 mm circle. LED3 was designed to separate into two parts, and had a taper either side of the join. This facilitated the installation of the lamp into the fittings which had concave caps.

A similar issue could also occur where the retrofit lamp was too long for a downlight cover (sometimes called a “heat can”) which was used in conjunction with the halogen downlight fitting – see Figure 19. In this case the downlight cover could be removed, if adequate safety clearances could still be provided around the downlight, or a new downlight cover compatible with the retrofit lamp could be installed. This would increase the retrofit costs.

Figure 20 shows a halogen downlight fitting which uses angled spring clips to hold the halogen downlight lamp firmly in the fitting and compares this to one of the LED lamps used in the retrofit trial. In this case, the shape of the retrofit lamp means that it was not possible to hold the lamp firmly in the downlight fitting. The electrician undertaking the retrofits noted that in some cases it might be possible to bend the spring clips to accommodate the longer shape of the retrofit lamps, but that this was fairly time consuming and would not ensure that the lamp fitted flush with the fitting. It was considered to be quicker and better to simply replace the existing downlight fitting with one that was compatible with the retrofit lamp.

FIGURE 19 – DOWNLIGHT COVER WON’T ACCOMMODATE RETROFIT LAMP

FIGURE 20 – DONWLIGHT FITTING CLIPS NOT COMPATIBLE WITH RETROFIT LAMP SHAPE

49 It was found to be possible to trim the concave caps where these were made out of plastic or soft metal, but this was not possible for the fittings made out of harder cast metal. Note that if an electrician modifies an existing light fitting they are responsible to ensure that the fitting is still electrically safe.
Halogen lamps have a flat profile on the face of the lamp. LED1 did not have a flat face profile (see Table 2), and this meant that it did not sit flush in the light fittings where the fittings used small metal tags to help hold the halogen downlight lamp in place. This issue was easily fixed by removing one of the small tags, as shown in Figure 21.

Compatibility with wiring

Two main issues were encountered relating to the compatibility of the retrofit lamp with the existing wiring:

1. Some retrofit lamps were not compatible with the older style connector leads, meaning that new connector leads had to be installed (see Figure 22);
2. Where the existing lamp and transformer are replaced with an LED lamp and separate LED driver, in some cases a surface power socket needs to be installed so that the LED driver can be plugged directly in to a 240 volt power supply.

For LED3 the GU5.3 pins on the base of the lamp were located in a recess. The lip around the recess meant that it was not possible to fit the older style connector leads found in some of the houses – See Figure 22. These leads connect the transformer/convertor to the 12 volt lamp. The older style leads use screws to ensure the pins are held securely and to make the electrical connection, while in the newer style connectors the pins are simply pugged directly into the socket. Where the older style leads were used it was necessary to replace them with the new style leads.

The LED driver for LED2 used a lead which plugged directly into a 240 volt power supply. For all houses in which this was installed for the retrofit trial, the electrician had to install a separate surface mounted power socket to allow the LED drivers to be plugged in to the 240 volt supply. This will not always be necessary. In some newer halogen downlight installations each downlight has a separate power socket to provide the 240 volt supply to the transformers/converters. In this case no modification would be required and the LED drivers could be simply plugged into the existing sockets, without the need for an electrician.

TV and radio interference

Two houses in which LED3 were installed experienced some problems with electrical interference with the TV and/or radio when the downlights were operating. At MEFL’s request the issue was investigated by engineers acting for the lighting manufacturer, who determined that the problem was caused by a faulty earth connection in the printed circuit boards within some of the lamps. New lamps were supplied and retrofitted. This fixed the problem in one of the houses. In the other house this fixed the problem with the TV, but some electrical interference was still experienced with the radio. At the end of the trial the householder requested that the original halogen lamps be re-installed. The manufacturer of this lamp has since made some design and production changes to the lamp.

50 The manufacturer advised MEFL: “An EMS (electromagnetic compatibility) issue on transformers that are not commercially available anymore appears to have exacerbated a manufacturing inconsistency with a low-level occurrence factor, from the initial production run. Issues rectified in the product design included an adjustment to the design to rectify this.”
Slow start-up time

As noted previously the CFL retrofit lamps were relatively slow to start and could take up to 5 minutes to achieve full brightness. This led to reduced householder satisfaction with the CFL retrofits compared to the LED retrofits, and also seems to have led to the CFL downlights being used for longer hours after the retrofits.

A slight start-up delay, of around half a second, was experienced with LED2. In some houses this slight delay also meant that downlights which were on the same lighting circuit did not come on at exactly the same time when switched on. Three of the four households in which this lamp was installed did not have any concerns about this issue. In the other house, the householder was concerned that the delayed start could be taken as a sign that there were electrical wiring problems in the house and that this could impact negatively in future if the house was sold. The householder asked for the original halogen downlights to be re-installed at the end of the trial.

Humming

LED1 contains a small fan which is used to draw air through the fitting to keep the LED chip inside the lamp cool. The noise from the fan is almost imperceptible, and in three of the four houses in which this lamp was used did not create any concerns. One householder contacted MEFL during the trial to advise that they could hear a humming noise, and sought reassurance that this was not an electrical problem. Once the householder was aware of the source of the faint hum, they were no longer concerned with the noise and it did not bother them.
### 3. Summary and Conclusions

#### Summary

We estimate that there is around 23 million 12 volt halogen downlights installed in Victorian homes. The use of the halogen downlights to provide general lighting in houses results in a high lighting power density and much higher electricity consumption than is necessary to provide adequate lighting. In addition to this, the high operating temperature of the downlights means that minimum safety clearances must be maintained around the downlights and any thermal insulation. Common insulation installation practices mean that this can significantly degrade the performance of ceiling insulation, and result in increased heating and cooling energy use. Inadequate safety clearances around the downlights, due to insulation being installed too close to or covering the downlights, or downlights which are installed too close to building members or which come into contact with other combustible materials (e.g. leaf litter) are a significant cause of house fires in Victoria.

Significant energy savings would be achieved if the existing stock of 12 volt halogen downlights installed in Victorian houses was replaced with a low energy alternative – we estimate that annual energy bill savings of around $161 million per year could be achieved if all existing halogen downlights used in residential applications were replaced with a suitable low energy alternative, reducing total Victorian residential electricity consumption by around 5%. Further savings on heating and cooling energy consumption could be achieved if the coverage of the ceiling insulation was improved at the same time that the retrofits were undertaken.

A total of 16 houses were recruited to participate in Sustainability Victoria’s Halogen Downlight Retrofit Trial, which was run in two stages:– 8 houses in 2011 (stage 1) and 8 houses in 2012 (stage 2). The aim of the trial was to assess the practicality, costs and savings, and householder perceptions when 12 volt halogen downlights located in the living areas of the houses were replaced with a low energy alternative. The houses were split into four equal groups and four different low energy retrofit lamps trialled, one 12 volt CFL, two 12 volt LEDs, and one LED and LED-driver pair (which replaced the existing 12 volt halogen lamp and its transformer). The retrofit lamps selected for the trial were chosen because they were considered to be some of the best lamps available on the market at the time. Since the completion of the trial the range of low energy downlight lamps suitable for replacing 12 volt halogen downlights has expanded – especially for LED lamps – and the general performance of the lamps seems to have improved.

The Retrofit Trial found that it was viable to replace the 12 volt halogen downlights with a low energy alternative, and that the paybacks for doing this were quite good. The average payback for the retrofits undertaken in this trial was 6.7 years – 3.4 years where no electrical wiring work was required. Where no electrical wiring work is required the retrofit could be undertaken by a less skilled person or as a DIY project, reducing the retrofit cost. Improvements to the design of the low energy lamps which make them compatible with a wide range of the existing transformers/convertors found in houses, compatible with standard dimming circuits and compatible with concave downlight fittings are helping to reduce the need for the involvement of an electrician, reducing retrofit costs substantially.

The replacement of 12 volt halogen downlight lamps with a low energy alternative is an eligible activity in the Victorian Energy Saver Incentive scheme. Under this scheme the halogen lamps can now be replaced with a 12 volt low energy lamp by an electrician for free, and a substantial subsidy is available to replace the 12 volt halogen lamps with a 240 volt low energy downlight fitting.

Replacing the 12 volt halogen downlights with low energy alternatives was found to result in a substantial energy saving. Across the houses involved in the trial lighting energy use was reduced by 71.0%, slightly lower than the expected savings of 76.7%. The CFL retrofits resulted in an average energy saving of 57.3% (compared to an expected saving of 68.9%) while the LED retrofits resulted in an average energy saving of 79.9%, exactly matching the expected level of saving. There were two reasons why the LED retrofits achieved larger savings than the CFL retrofits: (1) the power consumption of the CFL was slightly higher than the power consumption of the LEDs; and (2) in the CFL retrofit houses the householders operated the lighting for a significantly longer time (37.3%) after the retrofits, resulting in an energy saving that was 16.8% lower than would have achieved if there was no change to the operating time of the lighting. In contrast, in the LED retrofit houses there was no net change in the operating time of the downlights after retrofit. While small increases in operating time were observed in a few of the LED houses these were counteracted by small decreases in operating time in other houses.

One of the key reasons for the marked change in behaviour observed between the CFL retrofit houses and the LED retrofit houses was the relatively long warm-up time of the CFL lamps used in the retrofit trial (several minutes to achieve full brightness), compared to the almost instantaneous warm-up time for the LEDs. This resulted in householders turning the CFLs on earlier than needed, to provide enough time for the lights to reach full brightness, and probably also not turning the lights off as frequently to avoid the inconvenience of the long warm-up time.

While some economists argue that the so-called rebound effect means that the energy savings which result from low energy lighting retrofits will always be lower than expected, the results achieved in this trial suggest that this is not necessarily the case. Rather than an economic effect, we believe that the rebound observed in the CFL retrofit houses is a technology effect, due largely to the long warm-up time of the lighting used in this trial. No net rebound was observed for the LED retrofit houses. The LED lamps used in the trial gave an almost instantaneous light output and resulted in light levels comparable to the halogen downlight lamps they replaced. From the householder perspective the LED lamps performed in a very similar way to the halogen lamps, and for this reason were used in the same way.

We do not believe that the rebound observed in the CFL retrofit houses in this trial can be generalised to all CFLs or even all 12 volt CFL downlight lamps. Our results suggest that CFL lamps which have a quick start and warm-up time, and a light output comparable with halogen downlight lamps, should give results similar to those achieved for the LED lamps.

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51 To date all replacement lamps have been LED lamps.
Light level measurements were undertaken before and after the retrofits, to assess whether or not the replacement lamps were providing a similar level of lighting service to the halogen downlights. The light levels in the CFL retrofit houses were roughly halved, while the light levels in the LED retrofit houses increased, by between 11% (LED1) and 52% (LED3) on average in the general circulation areas. The measured changes in the light levels after the retrofits were undertaken are consistent with light outputs of the lamps used, with the CFL having the lowest light output (and roughly half the light output of a 50 Watt halogen lamp) and the LEDs having a light output that was comparable to or higher than the light output of a 50 Watt halogen lamp. It should also be noted that the light output of both the CFLs and LED lamps will reduce to some extent over the lifetime of the lamps.

In general, householders reported increased satisfaction with the light levels achieved after the retrofits, even in the CFL houses where light levels were reduced. The use of halogen downlights to provide general lighting results in much higher light levels than are necessary, and as small bright light sources they can also produce glare. In this context lower light levels and softer lighting can be perceived as an improvement by householders.

Overall the households in which the LEDs were used as the retrofit lamp reported increased satisfaction with the lighting in their living areas after the retrofits while the houses in which the CFLs were used as the retrofit lamp reported a slight reduction in their level of satisfaction. The main reason for this was the relatively slow start-up and warm-up time of the CFLs compared to the LEDs.

Conclusions
The low energy lamps used to replace 12 volt halogen downlights need to display a range of characteristics to ensure householder satisfaction, reduce the retrofit costs and also to maximise the energy savings achieved:

› A fast, essentially instantaneous, start-up and warm-up time is important to ensure householder satisfaction, as well as reducing the likelihood of rebound as a result of householders operating the lighting for a longer time after the retrofits;

› A light output that is similar to the halogen downlight lamp being replaced seems to be important but not critical. However, light levels which are adequate for the tasks being undertaken should still be provided after the retrofit. Higher light levels are required on bench-top areas where fine work is undertaken (e.g. the kitchen) compared to the general circulation areas of the home;

› 12 volt lamps should be compatible with both the old style and new style of connector leads.

At the time our trial was undertaken the LED lamps available on the market were the most viable retrofit for 12 volt halogen downlights, due to their higher light output, lower power consumption and much quicker warm-up time compared to the CFL lamp trialled. However, there have been improvements in both the CFL and LED products available on the market since the trial was completed. We believe that low energy lamps which display the characteristics noted above should all result in a high level of householder satisfaction, regardless of the lamp type.

Halogen downlight replacement can be undertaken by an electrician (essential where electrical wiring work is required), or another energy service provider or householder where electrical wiring work is not required. There are a range of issues which should be taken into account when replacing the 12 volt halogen downlight lamps with a low energy lamp:

› Ensure that the light output of the low energy lamp is comparable to the light output of the halogen lamp it is replacing. The light output of a 50 Watt, 12 volt halogen downlight lamp is around 650 to 700 lumen. The light output of the low energy lamp might be stated on the packaging or on the specification sheet provided by the supplier or manufacturer (often available on the internet). Alternatively, the packaging for some products provides a statement, or info-graphic, which indicates the wattage of the halogen lamp that the light output of the low energy lamp is equivalent to;

› Make sure that the colour appearance of the low energy lamp is suitable for the application. In general, a “warm white” colour appearance (or colour temperature in the range of 2,700 to 3,000 K) is preferred in most living and bedroom areas of the home. Lights with a “cool white” colour appearance (or colour temperature in the range of 4,000 to 6,000 K) may be found to be acceptable in kitchen and bathroom areas;

› Ensure that the lamp has a quick start-up and warm-up time. Information relating to this may be available in the specification sheet for the lamp, but operating the lamp in the shop (if possible) or at home is the best way to determine if the performance of the lamp is acceptable;

12 volt lamps should be compatible with both the old style and new style of connector leads.

12 volt lamps need to be compatible with a wide range of the downlight fittings found in existing houses, particularly the gimbal (or concave) fittings. Lighting suppliers and retailers should also ensure that it is easy for electricians and householders to identify a downlight fitting which is compatible with a particular low energy lamp, for those situations where the downlight fitting needs to be replaced;
Make sure that the lamp is compatible with the existing transformer/converter, any dimmer which is used with the existing lighting, the connectors, as well as the existing downlight fitting. It is important to obtain information on the nature of the downlight fitting (including the cut-out dimensions), type and model of existing transformer/convertor, the type of connector and whether or not there is a separate plug for each downlight or whether they are hard wired. Compatibility with the fitting is likely to be most critical where the existing fittings are of the gimbal or concave type. Some information on compatibility with transformers/convertors and dimmers may be available on the specification sheets for the lamps, or on manufacturer websites. However, the best way to assess these compatibility issues is to purchase a test lamp which seems likely to meet your requirements and trial it at home. In addition to checking the compatibility issues, this allows the light output and colour appearance, start-up and warm-up time to be assessed. It also provides the opportunity to see if the lamp causes any electromagnetic interference with television and radio reception.

Where electrical compatibility issues (transformers/converters, dimmers, electrical connectors) exist which require electrical wiring work to be undertaken it will be necessary to engage an electrician to undertake the work. Depending on the extent of the compatibility issues it may be cheaper to replace the existing fittings and/or transformer/convertor with ones compatible with the low energy lamp. Some low energy downlight fittings are available as a complete unit (e.g. downlight fitting and lamp and LED driver) which simply plug into a power outlet in the ceiling. If the existing downlights were already plugged into power outlets in the ceiling an electrician would not be necessary, as the existing downlights could be simply unplugged and the new downlight plugged back in.

Where new downlight fittings are installed it is important to check that the cut-out diameter for the new light fitting is the same as the cut-out diameter for the old light fitting – fixed downlights usually have a cut-out diameter of around 70 mm, while gimbal downlights have a cut-out diameter of 90 mm.
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APPENDICES

A1: Monitoring results for each house

Below we have provided basic information for each house involved in the retrofit trial, as well as the monitoring results, including the usage profile and the average daily load profile.

The average usage profile is the output from the Lamp Count meter and shows the average amount of time (in seconds) the lights operated during each 10 minute interval during the day over the monitoring period – a reading of 600 indicates that the light was on for the whole 10 minute interval. The average usage profile for each house has been weighted to take into account the number of downlights in each group of lights monitored. Profiles are provided for both the pre-retrofit and post-retrofit monitoring periods.

The average usage profile has been provided for all lights monitored in each house as well as for the individual groups of lights which were monitored.

The average load profile for each house shows the average total power consumption (in Watts) of all lights monitored during each 10 minute interval during the day.
House H1 – CFL
15 lamps retrofitted
Monitoring period: 23/6/11 to 6/9/11
Retrofit date: 8/8/11

House H1 – Av. Usage Profile

House H1 – Av. Daily Load Profile

House 1, Light 1 - Kitchen
Av. Operating Time

Before
After

House 1, Light 3 - Kitchen
Av. Operating Time

Before
After

House 1, Light 4 - Lounge
Av. Operating Time

Before
After
House H2 - CFL
26 lamps retrofitted
Monitoring period: 30/6/11 to 30/8/11
Retrofit date: 8/8/11

House 2 - Av. Usage Profile

House 2 - Lighting Load Profile

House 2, Light 1 - Lounge

House 2, Light 2 - Lounge

House 2, Light 3 - Lounge

House 2, Light 4 - Kitchen

House 2, Light 5 - Kitchen
House 3 - CFL
18 lamps retrofitted
Monitoring period: 30/6/11 to 6/9/11
Retrofit date: 29/7/11

House 3 - Av. Usage Profile

House 3 - Av. Daily Load Profile

House 3, Light 1 - Kitchen

House 3, Light 2 - Dining

House 3, Light 3 - Lounge
House 4 - CFL

12 lamps retrofitted
Monitoring period: 30/6/11 to 8/9/11
Retrofit date: 8/8/11
House H5 – LED1
14 lamps retrofitted
Monitoring period: 23/6/11 to 1/9/11
Retrofit date: 29/7/11

House 5 - Av. Usage Profile

House 5 - Av. Daily Load Profile

House 5, Light 1 - Kitchen

House 5, Light 2 - Living
House H6 – LED1

15 lamps retrofitted
Monitoring period: 23/6/11 to 30/8/11
Retrofit date: 29/7/11

House 6, Light 2 - Dining

House 6, Light 3 - Lounge

House 6, Light 4 - Kitchen

House 6, Light 1 - Lounge

House 6 - Av. Usage Profile

House 6 - Av. Daily Load Profile
House H7 – LED1
14 lamps retrofitted
Monitoring period: 23/6/11 to 30/8/11
Retrofit date: 29/7/11
House H8 – LED1
9 lamps retrofitted
Monitoring period: 30/6/11 to 8/9/11
Retrofit date: 29/7/11
House H9 – LED2

12 lamps retrofitted

Monitoring period: 24/5/11 to 16/8/11

Retrofit date: 6/7/11
House 10 – LED2

15 lamps retrofitted
Monitoring period: 25/5/12 to 16/8/12
Retrofit date: 9/7/12
House 11 – LED2

13 lamps retrofitted

Monitoring period: 25/5/12 to 15/8/12

Retrofit date: 12/7/12
House H12 – LED2
15 lamps retrofitted
Monitoring period: 31/5/12 to 23/8/12
Retrofit date: 10/7/12

House 12 - Av. Usage Profile

House 12 - Av. Daily Load Profile

House 12, Light 1 - Living

House 12, Light 2 - Dining

House 12, Light 3 - Kitchen

House 12, Light 4 - Kitchen
House H13 – LED3
23 lamps retrofitted
Monitoring period: 24/5/12 to 23/8/12
Retrofit date: 11/7/12
House H14 – LED3
14 lamps retrofitted
Monitoring period: 24/5/12 to 15/8/12
Retrofit date: 12/7/12
House H15 – LED3
21 lamps retrofitted
Monitoring period: 25/5/12 to 13/08/12
Retrofit date: 9/7/12
House H16 – LED3
11 lamps retrofitted
Monitoring period: 31/5/12 to 13/8/12
Retrofit date: 11/7/12

House 16 - Av. Usage Profile

House 16 - Av. Daily Load Profile

House 16, Light 1 - Living

House 16, Light 2 - Living

House 16, Light 3 - Kitchen
A2: Detailed results for different areas of the home

Kitchen

FIGURE A1 – AV. DAILY LOAD PROFILE OF LIGHTING IN KITCHEN, BEFORE AND AFTER RETROFIT

FIGURE A2 – DISTRIBUTION OF AVERAGE OPERATING TIMES FOR KITCHEN LIGHTING
Living / Lounge Room

FIGURE A3 – AV. DAILY LOAD PROFILE OF LIGHTING IN LIVING/LOUNGE ROOM, BEFORE AND AFTER RETROFIT

FIGURE A4 – DISTRIBUTION OF AVERAGE OPERATING TIMES FOR LIVING/LOUNGE ROOM LIGHTING
Dining Room

FIGURE A5 – AV. DAILY LOAD PROFILE OF LIGHTING IN DINING ROOM, BEFORE AND AFTER RETROFIT

FIGURE A6 – DISTRIBUTION OF AVERAGE OPERATING TIMES FOR DINING ROOM LIGHTING
In this section we present the detailed results for each house involved in the Halogen Downlight Retrofit Trial. The results are based on the lighting which was monitored – in some houses which had a large number of lights and/or a large number of switching groups it was not possible to monitor all downlights which were retrofitted. In a few houses meter failures also meant that not all lighting was monitored.

### Light levels

Table A1 shows the average light levels for both the general circulation areas and the bench-top areas in the 16 houses which participate in the Retrofit Trial, based on the measurement procedure set out in Appendix A4.

<table>
<thead>
<tr>
<th>House</th>
<th>Light level (Lux) – General circulation areas</th>
<th></th>
<th>Light level (Lux) – Bench-top areas</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Change (%)</td>
<td>Before</td>
</tr>
<tr>
<td>CFL retrofits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>121</td>
<td>58</td>
<td>-52%</td>
<td>152</td>
</tr>
<tr>
<td>H2</td>
<td>121</td>
<td>70</td>
<td>-42%</td>
<td>109</td>
</tr>
<tr>
<td>H3</td>
<td>169</td>
<td>73</td>
<td>-57%</td>
<td>158</td>
</tr>
<tr>
<td>H4</td>
<td>136</td>
<td>77</td>
<td>-43%</td>
<td>140</td>
</tr>
<tr>
<td>Av CFL</td>
<td>137</td>
<td>69</td>
<td>-49%</td>
<td>140</td>
</tr>
<tr>
<td>LED1 retrofits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H5</td>
<td>104</td>
<td>124</td>
<td>19%</td>
<td>122</td>
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<td>H6</td>
<td>130</td>
<td>143</td>
<td>10%</td>
<td>121</td>
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<td>H7</td>
<td>76</td>
<td>83</td>
<td>9%</td>
<td>121</td>
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<td>H8</td>
<td>86</td>
<td>90</td>
<td>5%</td>
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<td>Av LED1</td>
<td>99</td>
<td>110</td>
<td>11%</td>
<td>121</td>
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<tr>
<td>LED2 retrofits</td>
<td></td>
<td></td>
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<tr>
<td>H9</td>
<td>114</td>
<td>131</td>
<td>15%</td>
<td>157</td>
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<tr>
<td>H10</td>
<td>110</td>
<td>154</td>
<td>39%</td>
<td>133</td>
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<tr>
<td>H11</td>
<td>126</td>
<td>153</td>
<td>21%</td>
<td>140</td>
</tr>
<tr>
<td>H12</td>
<td>184</td>
<td>168</td>
<td>-9%</td>
<td>126</td>
</tr>
<tr>
<td>Av LED2</td>
<td>134</td>
<td>151</td>
<td>13%</td>
<td>108</td>
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<tr>
<td>LED3 retrofits</td>
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<td></td>
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<tr>
<td>H13</td>
<td>174</td>
<td>270</td>
<td>55%</td>
<td>171</td>
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<tr>
<td>H14</td>
<td>110</td>
<td>189</td>
<td>72%</td>
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<td>H15</td>
<td>199</td>
<td>295</td>
<td>48%</td>
<td>223</td>
</tr>
<tr>
<td>H16</td>
<td>142</td>
<td>193</td>
<td>36%</td>
<td>120</td>
</tr>
<tr>
<td>Av LED3</td>
<td>156</td>
<td>237</td>
<td>52%</td>
<td>133</td>
</tr>
<tr>
<td>All houses</td>
<td>131</td>
<td>142</td>
<td>8%</td>
<td>125</td>
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<tr>
<td>CFL houses</td>
<td>137</td>
<td>69</td>
<td>-49%</td>
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<tr>
<td>LED houses</td>
<td>130</td>
<td>166</td>
<td>28%</td>
<td>121</td>
</tr>
</tbody>
</table>
Operating time

Table A2 provides data on the average operating time of the lighting in the houses which participated in the Retrofit Trial, before and after the retrofits were undertaken. The "raw" operating time (see the left hand column) is the average daily operating time of the lighting during the monitoring period, as measured with the Lamp Count meters. The adjusted operating times are the raw operating times which have been adjusted to take into account the seasonal adjustment factor, and converted into average annual daily operating times.

In the houses in which CFLs were used in the retrofits the average annual operating time of the lighting has increased by 37.2%. In the houses in which LEDs were used in the retrofits, on average, there has been no net change in the operating time, although the results vary slightly for the different LED lamps used. However, overall for the LED lamps the operating of the downlights after the retrofits is largely the same as before the retrofits.

Energy use and savings

Table A3 provides data on the estimated energy savings achieved by the halogen downlight retrofits. The left hand side of the table shows the estimated annual energy saving achieved, based on the measured operating times of the lighting before and after the retrofit adjusted to take into account the seasonal adjustment factor. The right hand side of the table gives the energy saving which would be achieved if the lighting operated for exactly the same time after the retrofit as before the retrofit. It also shows the actual energy saving expressed as a percentage of this ideal energy saving.

In the houses in which the CFLs were used in the retrofits, the actual energy saving is 16.8% lower than the ideal energy saving, reflecting the fact that in these houses the lighting operated for longer hours after the retrofits than before. In the houses in which the LEDs were used in the retrofits, on average the actual savings exactly matched the ideal savings. There is a slight variation in this result depending on which LED lamp was used in the retrofit, although the variation from the ideal savings is very small (-1.3% to 2.1%).
<table>
<thead>
<tr>
<th>House</th>
<th>Average daily operating time - raw (Hrs/day)</th>
<th>Average annual daily operating time - adjusted (Hrs/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
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### TABLE A3: ENERGY SAVINGS FROM THE DOWNLIGHT RETROFITS, ACTUAL SAVINGS VS IDEAL SAVINGS

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<tr>
<th>House</th>
<th>Energy Use &amp; Saving - Adjusted Time (kWh/yr)</th>
<th>Energy Use &amp; Saving – Ideal (kWh/yr)</th>
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<td>Saving</td>
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<tr>
<td>All LED</td>
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<td>110.6</td>
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</table>
Economics of halogen lighting retrofits

Table A4 provides data on the cost of the retrofits and the estimated annual energy bill savings and paybacks in the houses which participated in the trial. The average cost of the CFL retrofits was substantially lower than for the LED retrofits – due mainly to the much lower cost of the CFL lamps compared to the LED lamps at the time the retrofit trials were undertaken – and this is reflected in a much lower payback period.

<table>
<thead>
<tr>
<th>TABLE A4: ECONOMICS OF HALOGEN DOWNLIGHT RETROFITS</th>
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</tr>
<tr>
<td>H3</td>
</tr>
<tr>
<td>H4</td>
</tr>
<tr>
<td><strong>Av. CFL</strong></td>
</tr>
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<td>LED1 retrofits</td>
</tr>
<tr>
<td>H5</td>
</tr>
<tr>
<td>H6</td>
</tr>
<tr>
<td>H7</td>
</tr>
<tr>
<td>H8</td>
</tr>
<tr>
<td><strong>Av LED1</strong></td>
</tr>
<tr>
<td>LED2 retrofits</td>
</tr>
<tr>
<td>H9</td>
</tr>
<tr>
<td>H10</td>
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<tr>
<td>H11</td>
</tr>
<tr>
<td>H12</td>
</tr>
<tr>
<td><strong>Av LED2</strong></td>
</tr>
<tr>
<td>LED3 retrofits</td>
</tr>
<tr>
<td>H13</td>
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<tr>
<td>H14</td>
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<td><strong>Av LED3</strong></td>
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<tr>
<td>CFL</td>
</tr>
<tr>
<td>LED</td>
</tr>
<tr>
<td><strong>All</strong></td>
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</table>
Householder perceptions

Surveys were conducted with householders to obtain information on their level of satisfaction with the downlights in their living areas of their homes before and after the retrofits were undertaken. Householders were asked to rate their level of satisfaction on a scale of 1 to 5 with 1 representing “extremely unsatisfied” and 5 representing “extremely satisfied”. The survey covered their general satisfaction with the lighting, their satisfaction with light levels and their satisfaction with the colour appearance of the lighting. Table A5 provides the survey responses for each of the households which participated in the study.

### Table A5: Householder Satisfaction with Halogen Downlight Retrofits

<table>
<thead>
<tr>
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<th>General satisfaction</th>
<th>Satisfaction with light levels</th>
<th>Satisfaction with colour appearance</th>
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<tbody>
<tr>
<td></td>
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<td>After</td>
<td>Before</td>
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</tr>
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<td>3.5</td>
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<td>H8</td>
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<td>3.4</td>
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<tr>
<td><strong>All LED</strong></td>
<td>4.1</td>
<td>4.6</td>
<td>4.0</td>
</tr>
</tbody>
</table>
A4: Light level measurement procedure

Introduction

Date: 28 June 2011

Originator: H. Ewan updated S. Coyne

Description: Guidelines for completing residential lighting assessment (including illuminance measurements using a lux meter).

Equipment:
- Measuring tape (x2)
- Copy of report template & pen
- Lux meter
- Portable stand to support lux meter at 850 mm above floor in circulation areas
- Digital camera
- Velcro dots and sticky dots (optional)

Assessor attire: Assessor who will be taking measurements should be wearing dark muted clothing (particularly shirt) so as to not unduly influence the light measurements.

Time of Assessment: Undertaking light level measurements during the nighttime is the preferred approach. If the lighting assessment is to be conducted during daylight hours, the following issues need to be firstly addressed.

› Can the daylight be satisfactorily excluded from all the interior spaces to be assessed (eg via drawing of curtains or lowering of blinds)?
› If not,
  – Ensure there is no direct sunlight penetrating into areas to be measured, otherwise these spaces can have daylight levels over 100 times higher than the electric lighting and would compromise validity of results.
  – Ensure sky conditions stable enough to measure (on the same grid as the electric lighting) with daylight present without electric lighting and then subtract this reading from that measured when the electric light is on with the stable daylight still present.

If these issues cannot be satisfactorily addressed then the assessor should consider rescheduling to an evening or when sky conditions have stabilized without direct sun penetration.
Measurement procedure

1. Either using an existing plan of the house or a sketched drawing, record the measurement of critical dimensions (e.g., length, width, ceiling height) of each room in which the lighting is to be assessed. Also include the dimensions and location of counter areas (e.g., kitchen and laundry benches and any fixed desks in study/bedrooms, etc.).

Mark the location of lights on the drawing of the area in which light levels are to be measured giving a unique identifier to each light fixture (e.g., L1, L2, ...). Additional information can be recorded by having a different prefix to the identifier based on the type of light if so desired (e.g., D1 for downlight, P1 for pendant, S1 for surface mount, etc.). Note that this can be completed using an existing drawing (if available) or a sketch made during the installation of the lights.

2. From the plan above, identify the main areas of interest, including:
   - Counter (benchtop) areas
   - Fixed sitting areas/directions
   - Circulation areas that are regularly occupied during normal use
   - Stairways

3. For each area of interest conduct a visual assessment of the lighting quality and identify key areas/orientations for considered attention during assessment. This should be carried out with particular attention to the predominant directions of view that an occupant would engage while undertaking their normal activities within the space.

   Points to consider are:
   - potential glare from light sources
   - the visual performance of the light to achieve the intended effect(s) including:
     - shadowing over critical task areas due to light’s position behind the occupant
     - a directional light’s ability to accent light a print hanging on a wall
     - silhouetting of facial features in security sensitive (e.g., main entrance/hallway) and personal grooming (e.g., vanity/bedroom) areas
   - brightness of the surfaces within the space and the intended effect

4. Determine a suitable measurement grid for a room based on the following considerations:
   - Light level measurements will be taken using a grid. At times it can be helpful to use Velcro dots (carpet) and sticky dots (timber/tile surfaces) to mark grid positions when setting out the measurement space.
   - Avoid taking measurements closer than 500 mm from a wall where possible, except for fixed task/counter areas (see the figure in step 4 below). This can be achieved by drawing a border 500 mm in from the walls in a room.
   - Create an even grid which is as close to square as possible inside this border with the size of the grid no greater than 1,000 mm in either dimension.
   - Light level measurements should be taken at each grid intersection, as shown below.
› For very small rooms/spaces one measurement in the centre of the floor plate will suffice.

› In all situations care should be exercised in making sure that the grid measurement points do not match with the layout of lighting fixtures so as to give an incorrect average reading for the space. (e.g. All grid points situated directly under a light will produce an elevated average for the room. Conversely, all grid points situated between lights will give a low average for the room.)

› For any rooms where significant furniture elements obstruct a complete measurement grid, carefully consider only measuring a part of the room that is indicative of the entire space. Record these variations and the mark on the plan the indicative area measured.

› Fixed task/counter areas should be excluded from room grid measurements if those fixed task/counter areas which are also going to be assessed under under conditions set out in step 5 below.

Example grid and measurement points for non-rectangular room with bench space excluded from room illuminance calculation.

All light level measurements for the room grid are to be taken at 850 mm above the floor.

In large areas with typical spaces and a repeating pattern of luminaries, smaller measurement area(s) may be selected to represent the typical space(s) including the lighting installed.

5 Determine a suitable measurement grid for fixed task/counter areas within rooms based on the following considerations.

Fixed task/counter areas require more detailed measurements

› Measurements should be taken in a smaller (approx 300 – 500 mm) grid pattern across the counter space. (This can include grid points closer than 500 mm to walls.)

› All light level measurements for the fixed task/counter grid are to be taken at the surface.

› The same precautions as above in step 4 should be addressed.

Example grid and measurement points on kitchen bench for counter/task area illuminance calculation.

6 Record details of lighting installation:

› An inventory listing of the light fittings using the unique identifiers marked on the plan.

› This inventory should include:

   ➔ General description (fixture type, lamp type, dimmer)

   ➔ Where possible

      ➔ Wattage

      ➔ Voltage (ELV, MV)

      ➔ Colour temp

➢ Take a photo of each room to assist with the analysis of assessment, documentation in reporting and record prior to any changes in lighting configuration.

7 Record measurement conditions, including:

➢ Date of measurements

➢ Make and model of lux meter, calibration date, time of day, and if during daylight hour; sky conditions and steps taken to ensure that any daylight is excluded from the interior.

➢ Details of any other factors that might affect results (e.g. interior surface reflectances, state of maintenance / cleanliness, etc.)

8 Turn lights on for at least 15 minutes prior to taking readings to allow the lights to stabilize. Any air conditioning or ventilation systems should be operating normally.

9 Close curtains and lower blinds (if during daylight hours or typically would be closed during the evening) and switch off any lights that would not normally be on and that could interfere with the readings (e.g. light on bench top extraction hood). All lights that would normally be on should be left on and any supplementary lighting should be noted (e.g. fluorescent tube light fitting above a working surface that is not intended to be de-lamped).

Record the use and position of any standard lamps or table lamps if required by the occupants to attain the desired light levels.
10. Turn on lux meter and, with optical sensor covered up, check that meter reads 0. If not zero note this value and substrate from all subsequent measurements. Consider calibrating meter in near future.

11. Select units (lux) and, if necessary, a suitable scale (options will depend on type of lux meter).

12. Check that light levels have stabilized prior to beginning measurements.

Light levels are stable when they are no longer increasing or decreasing

(Note that some oscillation is possible as a result of voltage fluctuations. The magnitude of the oscillations will depend on the type of light source and the proximity of the sensor to the light source, however, at counter areas these oscillations are typically within a few lux of the nominal value to be recorded.)

13. Carry out the following measurement steps (14 – 16) on:

- Each room based on the determined room measurement grid
- Each counter area within the room based on the counter measurement grid

14. Place sensor at the predetermined horizontal positions and record nominal lux readings. Care should be taken not to cast a shadow on the sensor when taking a reading or being in a position where a directional light may be incident directly on your attire while reading the light meter.

15. After completing the readings within the grid check one of the first readings to ensure that there are no significant changes (e.g. as a result of lamps stabilizing or unwanted daylight influence). If there is a change of more than 10% check another position and if necessary consider re-measuring the space after gaining confidence with state of stabilisation.

16. Calculate the average illuminance for the areas of interest.

There is no accepted or recommended minimum average illuminance for residential spaces but a comparison can be drawn with similar activities within the office environment. These specified levels are published AS/NZS 1680.1:2006 “Interior and workplace lighting Part 1: General principals and recommendations” and are:

- Counter area: 160 - 240 lux
- Other areas: 40 - 80 lux