Cavity Wall Insulation 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 (OGA) 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 retrofits’ 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 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.

In this report we present the results of our Cavity Wall Insulation Retrofit Trial, which was undertaken in a total of 15 houses in 2012 and 2013. Infrared thermal imaging was used to assess winter heat losses through the external walls of the houses, before and after the retrofits were undertaken. In addition to this household surveys were undertaken and energy use and internal and external temperatures monitored before and after the retrofits were undertaken to assess the impact of the cavity wall insulation retrofits.

It is straightforward to insulate walls in new dwellings or in additions, as well as in major renovations when either the internal or external wall cladding are removed as part of the renovation. However, insulating the walls of existing houses which are not being renovated is more difficult. Pump-in cavity wall insulation is a potentially attractive option for these existing houses as it can be installed in houses with brick-veneer, weatherboard or cavity brick walls without removing either the external or internal wall claddings.

Wall insulation was one of the main building shell retrofit opportunities for existing houses identified in the OGA study. This work suggested that around 95% of the pre-2005 housing stock could benefit from the addition of external wall insulation, improving thermal comfort and increasing the House Energy Rating by an average of 1.02 stars. When implemented, this upgrade was estimated to give average energy bill savings of $108 per year for a payback of around 39 years on the investment if pump-in cavity wall insulation was undertaken in houses which used a reasonably representative mix of heating and cooling systems. If similar results were achieved across the entire stock of pre-2005 Victorian houses, this would result in total annual energy bill savings of around $200 Million per year, reduce greenhouse gas emissions by around 647 kT per year and reduce total residential gas consumption by around 8%.

The Cavity Wall Insulation Retrofit Trial has shown that pump-in cavity wall insulation is an effective strategy for reducing energy consumption in existing Victorian houses. The insulation has reduced the heat losses through the external walls of the houses, reducing heating energy consumption and resulting in better heat retention inside the house during winter and giving higher internal temperatures during the night time and daytime hours when the heaters are not operating. Householders experienced this as increased thermal comfort and a reduction in the difficulty of heating their homes. Based on the analysis of the data collected during the Trial we estimate that average heating energy savings of at least 15.5% have been achieved, resulting in average heating energy savings of 7,633 MJ per year for gas and 62 kWh per year for electricity, average greenhouse savings of 503 kg per year, and an average energy bill saving of $151 per year, noting that in the Trial all houses used gas ducted heating as the main form of heating.

The average cost of insulating these houses was $4,437, giving an average payback on the investment of around 29 years.

The results of the Trial are consistent with the modelled results from the OGA study. In this case the average energy bill saving for those houses which had gas ducted heating was $157 per year (for both heating and cooling) for an average payback of 28 years.

The results of our analysis are likely to have underestimated the savings which can be achieved from installing cavity wall insulation, as they are based on our estimate of the “technical” energy saving from the gas ducted heating when the heating is operating. Our savings are based only on heating, and additional savings would be achieved in houses which used air conditioning or evaporative cooling during summer months. Some households in the Trial used electrical room heating – oil filled column heaters or room air conditioners – to supplement their gas ducted heating systems, and reported that the use of this supplementary heating could be stopped or significantly reduced after the cavity wall insulation retrofit. As we did not meter the supplementary heating this energy saving is not included in our result. Further, better heat retention inside the houses meant that households either stopped or significantly reduced the operation of their heating overnight and during the middle of the day, and this energy saving was not necessarily recognised by our analysis methodology.

The energy bill savings are based on the energy tariffs that applied at the time the analysis was undertaken. It seems likely that energy costs will continue to rise, especially for gas in the short to medium term. This means that the energy bill savings derived from this retrofit will increase over coming years and this, in turn, will improve the cost effectiveness of this retrofit.
Further, the savings documented in the report are based only on the energy bill savings which result directly from the installation of the cavity wall insulation. We have not included any value associated with the greenhouse gas savings resulting from the upgrade, or comfort or health improvements which could result from the upgrade. Currently, there is not widespread agreement on how to include the value of greenhouse abatement in such analysis, and as yet there is no evidence base which would allow the comfort and health benefits for households in Victoria to be included. While some of these benefits might accrue directly to the households, they will be shared with governments and society more broadly.

The cavity wall insulation industry in Victoria, and in Australia generally, is a relatively small, low volume industry, and the cost of installing the insulation is high compared to countries such as the UK where a large cavity wall insulation retrofit industry has operated over several decades. The higher costs in Australia are likely to be due to partly to the small size of the industry, but may also be due to the greater thickness of the wall cavities – generally brick-veneer and weatherboard walls compared to cavity brick in the UK – and to larger house sizes. If the market for cavity wall insulation in Victoria increased significantly, this higher volume would be likely to result in lower installation prices and would improve the economics of installing this type of insulation.

Acknowledgements

This study is based on the analysis of data and information collected from pump-in cavity wall insulation retrofit trials undertaken in 15 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, thermal imaging, the installation of pump-in cavity wall insulation, providing access to their gas billing data, 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, on-site data collection, manage the installation of the cavity wall insulation and to prepare brief project reports. In particular we would like to thank Govind Maksay (2012) and Matthew Sullivan (2013), who were MEFL’s project managers for this work. We have acknowledged the different organisations which were involved in the Cavity Wall Insulation Retrofit Trial below.

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<th>Sustainability Victoria</th>
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Abbreviations and Acronyms

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<tr>
<td>Av.</td>
<td>Average</td>
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<tr>
<td>BBA</td>
<td>British Board of Agrément</td>
</tr>
<tr>
<td>Diff.</td>
<td>Difference</td>
</tr>
<tr>
<td>CIGA</td>
<td>Cavity Insulation Guarantee Agency</td>
</tr>
<tr>
<td>CWI</td>
<td>Cavity Wall Insulation</td>
</tr>
<tr>
<td>DIY</td>
<td>Do it yourself</td>
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<tr>
<td>Elec.</td>
<td>Electrical</td>
</tr>
<tr>
<td>HER</td>
<td>House Energy Rating</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour, used to measure electrical energy consumption. 1 kWh = 3.6 M.J.</td>
</tr>
<tr>
<td>kT</td>
<td>Kilotonnes = 1,000 Tonnes</td>
</tr>
<tr>
<td>MEFL</td>
<td>Moreland Energy Foundation Limited</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoule</td>
</tr>
<tr>
<td>OGA</td>
<td>On-Ground Assessment</td>
</tr>
<tr>
<td>RFL</td>
<td>Reflective foil laminate</td>
</tr>
<tr>
<td>SV</td>
<td>Sustainability Victoria</td>
</tr>
<tr>
<td>Temp.</td>
<td>Temperature</td>
</tr>
<tr>
<td>UF</td>
<td>Urea formaldehyde</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>VAT</td>
<td>Value added tax</td>
</tr>
</tbody>
</table>

Glossary and definitions

Building shell
The key external elements of a house, including walls, roof/ceiling, floor and windows.

FirstRate5
Thermal modelling program which can be used in Victoria to assess compliance with house energy efficiency regulations. The program calculates the annual heating and cooling energy required (expressed in MJ/m²/Yr) to maintain specified comfort conditions inside a house in a particular climatic location. It also assigns a House Energy Rating so that the energy efficiency of different houses can be compared.

House Energy Rating
Star rating from 0 to 10 obtained from thermal modelling program such as FirstRate5, which rates the thermal efficiency of the building shell of a house. The higher the rating the more energy efficient the house is.

R-value
Thermal resistance. This is a measure of the extent to which a certain material resists the transfer of heat through it in response to a temperature difference across the material. The higher the R-value, the greater the insulating effect of the material. R-values can be applied both to individual insulation products (e.g. an insulation batt) and to composite building sections (e.g. wall, floor, roof/ceiling).

Thermal mass
Materials which have the ability to absorb and store a significant amount of heat when ambient temperatures are higher and release this heat when ambient temperatures are lower. In the context of house construction this includes materials such as bricks and masonry, and a concrete slab on ground. The presence of thermal mass inside a house tends to stabilise internal temperatures.
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 (OGA) 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.

Of the 60 houses which participated in the OGA study it was found that 95% did not have any insulation in their existing walls. This was one of the reasons why the energy efficiency of the existing housing stock was found to be so low: the average House Energy Rating (HER) of the existing (pre-2005) houses was found to be only 1.81 Stars, with the pre-1990 houses having an average HER of 1.57 Stars and the post-1990 houses having an average HER of 3.14 Stars. This is substantially less efficient than houses constructed from 2005 to 2011, which were required to achieve a 5 Star rating, and houses which were constructed after 2011, which are required to achieve a 6 Star rating. The addition of cavity wall insulation was found to be one of the best measures to increase the energy efficiency of the building shell of the existing houses. It led to an average increase in the HER of 1.02 Stars in the houses in which it was implemented, and an average increase of 0.97 Stars across the stock of 60 houses.

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 wall insulation measure was based on the installation of pump-in cavity wall insulation. 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.

Pump-in cavity wall insulation was found to provide one of the largest energy and energy bill savings of all the energy efficiency measures modelled, and was ranked third behind comprehensive draught sealing and heating upgrades in terms of the savings which could be achieved across the housing stock. It was estimated that the installation of the insulation could provide average energy bill savings of around $103 per year across the stock of 60 houses or around $108 per year in the houses in which it was implemented. This corresponded to a heating energy saving of 13.1% and a cooling energy saving of 10.9%. However, pump-in cavity wall insulation was also found to be one of the more expensive energy efficiency measures to implement, with an average cost of $3,959 across the stock of houses and $4,167 in the houses in which it was implemented. This is substantially higher than the cost of installing ceiling or underfloor insulation. The relatively high cost of pump-in cavity wall insulation led to quite a long average payback period of 39 years.

The economics of pump-in cavity wall insulation was considerably better in houses which had gas ducted heating, especially those with high annual heating use. The average annual energy bill saving for houses which had gas ducted (central) heating was $157 per year for an average payback of around 28 years.

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2 The costing in the OGA study are based on the use of a hydrophobic (water resistant) granulated rockwool insulation product. Pump-in cavity wall insulations using other materials, such as expandable foam, are also available. It is also possible to install insulation batts and boards by removing either the internal or external wall cladding (weatherboard houses), but this is generally only undertaken as part of a major renovation.
## 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>
</thead>
<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>$335.8</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>
</tr>
<tr>
<td>Water Heater – High Eff. Gas</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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
<td>20.2</td>
</tr>
<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>$784.7</td>
<td>24.3</td>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<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>27.0</td>
</tr>
<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>69.4</td>
</tr>
<tr>
<td><strong>Total (ex Double Glazing)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (ex Drapes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

Note that energy bill savings are based on a gas tariff of 1.75c/MJ, and electricity tariffs of 28c/kWh (peak) and 18c/kWh (off peak). Savings for low flow shower rose, washing machine and dishwasher also include water bill savings. The upgrade measures have been costed based on commercial rates and do not include any government incentives which might be available.
The next phase of Sustainability Victoria’s work on existing houses has been to trial retrofit measures 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 impacts to assess actual costs and savings, the impact of the upgrades on the level of energy service provided, and householder 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 investigated pump-in cavity wall insulation. Key reasons to investigate this retrofit measure were that wall insulation has wide applicability across the existing Victorian housing stock and cavity wall insulation can be applied to existing houses which are not undergoing a major renovation2. The OGA study showed that the application of cavity wall insulation could significantly improve the House Energy Rating, and therefore the thermal comfort, of the house as well as providing significant energy savings. The results from the OGA study suggest that if pump-in cavity wall insulation was applied to all uninsulated pre-2005 Victorian houses, this would give total annual energy bill savings of around $200 Million per year, reduce greenhouse gas emissions by around 647 kT per year, reduce total residential gas consumption by around 8.4% and reduce total residential electricity consumption by around 0.6%.

How the trial was undertaken

The Cavity Wall Insulation Retrofit Trial was undertaken in two stages, with 8 houses retrofitted in 2012 (Houses WI1 to WI8) and a further 7 houses retrofitted in 2013 (Houses WI9 to WI15)3. All 15 houses were located in Melbourne. The intention was to conduct the trials during the main winter heating period from June to August, with the retrofits undertaken in late June or early July. In practice, logistical issues arranging the retrofits meant that the 2012 trials were conducted mainly over the July to September period, with the retrofits undertaken around mid-August. The 2013 trials were conducted mainly over the June to September period. However, significant issues were experienced in arranging the retrofits and most retrofits were undertaken from late July to early August. This required the meters which were used to monitor the electricity consumption of the gas ducted heaters to be removed from most houses shortly after the retrofits had been undertaken and the data downloaded4. Unfortunately, the meters were not then replaced until around 10 days after their removal, and warmer weather from late August into September 2013 meant that heating use in the trial houses was reduced. For some houses this reduced the amount and quality of the data that was available to estimate the energy savings achieved by the retrofit.

1 To end 2015 we have trialled halogen downlight replacements, comprehensive draught sealing, pump-in cavity wall insulation, gas heating ductwork upgrades, gas heating ductwork upgrades combined with gas furnace upgrades, window film secondary glazing, solar air heaters, heat pump clothes dryers, pool pump replacements, gas water heater upgrades, halogen downlight replacements combined with ceiling insulation remediation, and some comprehensive whole house retrofits.
2 Where a major renovation is being undertaken and internal wall linings removed, wall insulation bats can be installed before the wall linings are re-instated. In weatherboard houses the removal and replacement of the external weatherboards as part of the renovation also provides the opportunity to install insulation bats. This is likely to be more straightforward and cheaper than pump-in cavity wall insulation.
3 Our intention was to retrofit 8 houses in 2013 – 8 houses were recruited to participate in the study, however one house withdrew at the installation stage as significant drilling was required to install the insulation.
4 The meters were set to a 1 minute logging interval, which meant that they could only store around 3 months of data on their internal memory cards.

The Cavity Wall Insulation Retrofit Trial involved a number of key steps:

- The wall insulation type and installation companies to be used in the trial were selected by MEFL in consultation with Sustainability Victoria. While a number of pump-in cavity wall insulation products are available, it was decided to use hydrophobic (water resistant) granulated rockwool5 for the retrofit trials as this product has been in use in Australia since the 1980s and has been installed successfully in a significant number of houses in the ACT as part of a government rebate program [MEFL 2012]. MEFL subcontracted two companies to install the cavity wall insulation for stage 1 of the trial, and one company for stage 2 of the trial [MEFL 2012 & 2013].
- Houses were recruited by MEFL to participate in the trial. The key target was houses which had uninsulated walls with a wall type that was suitable for the installation of the granulated rockwool cavity wall insulation and which used gas ducted heating as the main form of heating. Houses with gas ducted heating were chosen as these would be expected to have a higher energy use for heating, and this should make it easier to estimate the energy savings achieved.

For stage 1 of the trial participation was limited to houses which had either brick-veneer or cavity brick walls, as the installation companies had more experience installing the insulation in these wall constructions and installation generally requires less drilling than for houses with weatherboard walls. For stage 2 of the trial no limitations were placed on the type of wall construction and these weatherboard houses were selected to participate in the trial. No houses with cavity brick walls were selected to participate in the trials. This was partly because only a fairly small proportion (<11%) of houses in Victoria have cavity brick walls and so only a few households with this type of wall construction registered their interest to participate in the trials. Of the cavity brick houses which did express an interest some had a wall cavity that was too narrow to install the insulation5. In another house the pitch of the roof was quite steep and it would not have been possible to install the insulation without special, and more expensive, safety procedures. [MEFL 2012]

In addition to the wall construction type, preference was given to [MEFL 2012]:

- houses with tiled roofs as it is less complex and costly to install the insulation, as the installer can simply lift the outer layer of roof tiles to access the top of the wall cavity. For houses with corrugated iron roofs a roof plumber needs to be hired to lift the roofing iron to provide access to the wall cavity and this adds extra cost and can create scheduling issues;
- houses with the same wall and roof construction type throughout. Houses with a mixture of roof and wall types are harder to retrofit or there may be certain areas that cannot be retrofitted (e.g. an extension with a skillion roof);
- single storey houses over double storey houses, as it is generally more expensive to insulate double storey houses.

Shortlisted houses were inspected by both the insulation installation company and an electrician before the final selection was made. An assessor from the installation company inspected each house to ensure it was suitable for installing the pump-in cavity wall insulation, and to gather the necessary information to prepare a quotation.

5 Granulated rockwool manufactured by CSR Bradford was used. This had been accredited by the Victorian Building Commission’s Building Regulations Advisory Panel (http://www.vba.vic.gov.au/practitioners/building-product-accrreditation) in 2007 V07/05, 21/11/07).
6 A standard cavity should be around 50 mm thick. However, the cavity is often narrower than this and may contain mortar, meaning that it is not possible to install the pump-in granulated rockwool. In one house the cavity was found to be only 10 mm thick meaning that it was not possible for a hose to be dropped into this space or for the walls to be drilled [MEFL 2012, Pears 2007].
An inspection was undertaken by a licensed electrician to ensure that the electrical wiring was suitable for the installation of the wall insulation. Any electrical wiring installed in the external wall cavity will be covered by the insulation which is pumped in, meaning that the rated current carrying capacity of the wiring needs to be reduced so that it won’t overheat. In most houses only minor modifications were required – the circuit breakers installed in the switchboard were reduced from 20 Amps to 16 Amps. (MEFL 2012)

› Metering equipment was installed at the houses to assist us to monitor the impact of the cavity wall insulation retrofits. Small stand-alone battery operated temperature sensors and data loggers were installed outside the houses (1 logger) as well as in the main living areas which were heated (3 to 4 loggers). These recorded both external and internal temperatures at 10 minute intervals during the day. A small plug-in electrical power meter and data logger was also installed on the electrical supply to the gas ducted heater. This was set to record the average power consumption of the gas ducted heater at one-minute intervals during the day, allowing us to identify the times when the gas ducted heaters were operating, as well as to measure the electricity consumption of the heaters. We used the electricity consumption of the heaters as a proxy for their gas consumption. The metering equipment was installed around one month prior to the cavity wall insulation retrofits and left in place for around four to six weeks after the retrofits9.

› Historical gas billing data was obtained from the houses which participated in the study and was used to estimate their gas use for heating prior to the retrofits. As gas is used for only a limited number of end uses – heating, water heating and sometimes cooking – and as the heating energy use is concentrated during the cooler months, it is possible to use the bi-monthly gas billing data to estimate the annual energy use of the gas heating10. Where possible, estimates were undertaken for a number of recent years for each house, temperature corrected11 using Bureau of Meteorology (BoM) data, and then the average annual gas use for heating calculated.

› Brief householder surveys were conducted before and after the retrofits. The aim was to assess people’s perceptions of the thermal comfort of their houses before and after the retrofits, as well as their perceptions of any changes in the difficulty heating the house;

› An infrared camera was used to obtain thermal images of the inside of the external walls while the heating was in operation, before and after the retrofits were undertaken. The thermal camera generates colour coded images with different colours representing the temperature of the surfaces imaged. If taken under the correct conditions the uninsulated sections of the internal walls should have a lower temperature than the insulated sections of the internal walls. The use of thermal imaging was trialled to: (1) explore the extent to which this technique can be used to verify the coverage of the wall insulation after retrofit; and (2) provide a visual indication of the impact of the wall insulation at reducing heat losses through the walls during winter;

› The selected insulation companies installed the cavity wall insulation. Photographs were taken of the walls after the retrofits, to provide an indication of the visual impact of the installation process;

› All surveys, data and images collected during the Cavity Wall Insulation Retrofit Trials were provided to Sustainability Victoria and analysed to determine the impacts of the retrofits. The results of the analysis are presented in this report.

Overview of the report

In Chapter 2 we give a general overview of residential cavity wall insulation. This covers the benefits of wall insulation and approaches to insulating walls in existing houses. It also discusses the different types of pump-in cavity wall insulation which are available and provides more detail on the installation of granulated rockwool cavity wall insulation. This is intended to aid the understanding of the results achieved during this Trial.

In Chapter 3 we provide an overview of the houses which were recruited for the Cavity Wall Insulation Retrofit Trial, and present the results of our analysis. In particular we look at householder perceptions of any changes in thermal comfort and difficulty heating, the way in which the heating was operated before and after the retrofits, the evidence that the cavity wall insulation is reducing winter heat losses through the walls, the energy savings achieved by the retrofits in practice, and the economics of the retrofits. We also discuss some of the practical issues associated with the cavity wall insulation retrofits and the ways in which these can be overcome.

In Chapter 4 we present our summary and conclusions.

More detailed data and analysis is presented in the Appendices. In Appendix A1 we provide pictures of the walls of some of the houses following the retrofits to give an indication of the visual impact of installing the insulation. In Appendix A2 we provide the detailed responses from the householder surveys undertaken before and after the retrofits and in Appendix A3 we present the results of the monitoring which was undertaken in each house as part of the Trial to assess the quantitative impact of the cavity wall insulation.

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9 While it would have been possible to install a separate gas meter with a pulsed output and a pulse logger to measure the gas consumption of the gas ducted heater, this is considerably more complicated and expensive than installing a simple plug-in power meter as the gas line needs to be cut and it requires a gas fitter. Gas ducted heaters can have quite a high electricity consumption when operating, typically in the range of 300 to 800 Watts, with the electricity used mainly to power the main air circulation fan and combustion fan. Typically the electricity consumption is around 2% of the gas consumption.

10 Due to logistical issues many of the electrical power meters in the stage 2 houses had to be removed shortly after the retrofits and the data downloaded. The meters were not replaced until around 10 days after their removal, leaving a gap in the data for these houses.

11 Daily gas use during the summer months was assumed to be entirely due to water heating and cooking. Except where gas-boosted solar water heating was present, annual average daily use for water heating and cooking was taken to be 1.2 times the summer use. This was used to estimate annual use for water heating and cooking, and then subtracted from the total annual gas use to estimate gas use for heating.

12 The length and severity of winters varies from year-to-year, and so gas heating energy use also shows significant annual variability. BoM data was obtained for relevant locations for the period 2000 to 2013, and the number of Heating Degree Days (18ºC base) calculated for each year. The average number of Heating Degree Days was calculated for 2000 to 2013 and used as the reference. The number of Heating Degree Days was then calculated for each year of billing data and used to derive an index to temperature correct the gas heating use for that year.
2 Cavity wall insulation

The benefits of wall insulation

Walls can be a significant source of heat loss from a home in winter and a significant source of heat gain in summer. Figure 1 shows the range of heat loss and heat gain expected from an uninsulated house in Melbourne during the winter and summer months. In both seasons the walls are expected to be responsible for 15 to 25% of the heat transfer through the external building shell of the house. In winter, the walls – along with air leakage - represent the second highest source of heat losses from the home, behind ceilings.

If the home has an insulated ceiling, which is quite common in Victoria13, the percentage of heat loss and heat gain through the walls is likely to be somewhat higher than indicated in Figure 1.

FIGURE 1: TYPICAL HEAT LOSSES AND GAINS FROM AN UNINSULATED HOUSE14

Walls 25–35%
Ceiling 15–25%
Air leakage 15–25%
10–20%

WINTER HEAT LOSS

Walls 10–20%
Ceiling 25–35%
Air leakage 15–25%

SUMMER HEAT GAINS

In Victoria the most common types of wall construction are brick-veneer, weatherboard and cavity brick (sometimes referred to as double brick). In 2005, at the time of the introduction of more stringent energy efficiency standards for new houses, these wall construction types accounted for 61.3%, 17.5% and 11.0% respectively of the 1.9 million houses then standing15. The introduction of mandatory insulation standards in Victoria in 1991 meant that between 1991 and 2005 all houses constructed with brick-veneer and weatherboard walls would have had to install insulation, although in some cases this may have only been a reflective foil laminate (RFL) sarking. Prior to the 1990s many houses would have been built with little or no wall insulation. A 2012 report for ICANZ estimated that there were 1,195,000 class 1 dwellings – stand-alone, terrace or semi-detached houses – which did not have wall insulation, or around half of the existing Victorian housing stock. [ICANZ 2010]

The main wall construction types found in Victorian houses have a low resistance to heat flow when they are uninsulated. R-value is a measure of the thermal resistance (or resistance to heat flow) of individual insulation products and also of composite building sections such as ceilings, floors and walls. The typical R-values of uninsulated external wall sections range from R0.45 (weatherboard and brick-veneer) to R0.50 (cavity brick). [DOI 2013] In all cases the R-value of the walls can be significantly increased by the addition of insulation to the wall cavity, thereby reducing the heat transfer across the walls during winter and summer. The addition of the insulation to the wall cavity has a number of other beneficial impacts on the thermal performance of the house [Pears 2007]:

- The temperature of the internal wall surfaces will be much closer to the ambient room temperature, improving occupant comfort by reducing radiative heat losses15 to walls in winter and increasing radiative heat gains from (or reducing radiative heat losses to) walls in summer;
- It increases the impact of any ceiling insulation. If only the ceiling is insulated, the temperature of the room air near to the external walls is higher in winter and lower in summer, meaning that the heat losses/gains through the walls are increased, undermining the impact of the ceiling insulation to some extent.

Cavity brick walls have overall better thermal performance compared to brick-veneer or weatherboard walls, due to their slightly higher R-value and also due to the increased thermal mass of the inner leaf of brickwork. However, if these walls are uninsulated cavity brick houses will become too cold in winter and they can become too hot in summer if the house is exposed to prolonged heat wave conditions. In this case the inner leaf of brickwork heats up and can make the house hot and uncomfortable, especially during the night time hours. If the wall cavity is insulated the heat transfer through the cavity is significantly reduced and the thermal mass of the internal leaf of brickwork helps to stabilise internal temperatures in both summer and winter, improving thermal comfort. [DOI 2013]

13 ABS data suggests that around 88% of houses had ceiling insulation in 2014. See ABS4602.055001, Dec 3, 2014.
15 ABS 4602.0 Environmental Issues: People’s Views and Practices, March 2005
16 Warmer surfaces radiate heat to cooler surfaces and the greater the temperature difference the greater the rate of heat transfer. This means that heat is lost from your body to a cold inner wall surface in winter – increasing the wall temperature reduces this rate of heat loss. In summer wall surface temperatures are likely to be lower than body surface temperatures in most cases so there will still be some heat loss. Insulation will lower the surface temperature of the internal wall and improve comfort by increasing the rate of heat loss from your body.
The installation of wall insulation to an uninsulated wall results in a range of benefits for house occupants [EST 2002, HEAT 2010]:

- A house that is naturally warmer in winter and cooler in summer without supplementary heating and cooling;
- A house that retains the heat longer in winter once the heating is turned off, and remains cooler for longer in summer once the air conditioning is turned off;
- Reduced condensation on internal walls in winter and reduced (or eliminated) mould growth;
- Fewer draughts;
- Reduced energy bills for heating and cooling; and
- A reduction of external noise coming into the home.

**Insulating walls in existing houses**

Current housing energy efficiency standards mean that new houses have well insulated walls and this insulation is easily installed during the construction phase. This is also the case where an upstairs addition or an extension means that new walls are added to a house as part of a major renovation.

During a major renovation of houses with brick-veneer or weatherboard walls the internal wall linings of some existing external walls may also be removed17, and this provides an easy and cost effective opportunity to insulate any uninsulated wall sections. Insulation batts can be installed between the wall studs in the normal manner to achieve the desired level of insulation – if fibreglass batts are used either R2.0 (70 mm) or R2.5 (90 mm) can usually be added. A higher R-value would be possible if rock wool insulation batts are installed. It is important that the insulation batts are not compressed, as this reduces their insulating effect, and that the insulation does not come into contact with the outer leaf of brickwork. The batts can be held in place using RFL or fishing line. [DOI 2013]

In some cases houses with weatherboard walls may have the weatherboards removed and replaced as part of a renovation. This also provides an easy opportunity to install insulation batts.

The installation of wall insulation to an existing external wall when the internal wall lining is not being removed is more complicated. There are a range of possible options, depending on the wall construction type [Pears 2007, HEAT 2010, DOI 2013]. Weatherboard walls can be insulated by removing some of the external boards to allow insulation batts to be installed between the wall studs, and then replacing them afterwards. Alternatively, foam insulation boards (e.g. polystyrene boards) can be fixed to the outside of the weatherboards and then rendered. The R-value which can be achieved will depend on the type and thickness of the foam board used.

Where houses have brick-veneer, cavity brick or weatherboard walls, the walls can also be insulated using pump-in cavity wall insulation (see below). This can be pumped into the wall cavity without removing either the internal or external wall cladding – access is usually gained either through the roof by lifting the tiles or roofing iron above the wall cavity, drilling holes through the mortar between bricks, removing individual bricks or, in some cases, by drilling holes through the internal wall linings. The R-value which can be achieved depends on the type of insulation used and the thickness of the wall cavity.

**Pump-in cavity wall insulation**

The main materials used for cavity wall insulation in Australia and internationally are granulated mineral fibre (either rockwool or glass mineral wool), expanded polystyrene beads, or polyurethane or urea-formaldehyde foams. It is important that the insulation material does not absorb any moisture that passes through the external wall cladding and does not transport water across the wall cavity to the internal wall cladding via capillary action. This means that the materials must be water repellent or ‘hydrophobic’. The material should also have a relatively low resistance to water vapour diffusion18. [EST 2002, Wigger et al 2011, Maksay 2013, DOI 2013]

**Granulated rockwool**

Rockwool is made from molten rock and recycled glass furnace slag, which is extruded into fine fibres and felted into a mat. The fibres are specifically manufactured to suit the machines which are used to granulate the rockwool and inject the granulated rockwool into wall cavities, and have a different length and diameter compared to those which are used in insulation batts. During manufacture, the rockwool fibres are impregnated with a silicon-based water repellent to make them hydrophobic. In Australia the CSIRO has tested this type of insulation under extreme rain conditions and found that it generally did not increase the risk of water penetration. [Pears 2007, HEAT 2010, Maksay 2013] According to the ACT Government’s advisory service the granulated rockwool is “rot proof, odourless and will not sustain vermin or fungal growth. Once, installed, it does not release dust or fibres and is not known to have any ill effects on health. It also settles very little over time.” [HEAT 2010]

**Polystyrene beads**

Small spherical expanded polystyrene (EPS) beads with diameters in the range of 2 mm to 8 mm are used. As the beads are very free flowing they are coated with a non-toxic binding agent when they are injected into the wall cavity. The bonding agent solidifies and locks the beads in place to avoid the insulation escaping through the inner wall cladding or around wall penetrations. The polystyrene beads should not come into contact with PVC-coated electric wiring as this may make the insulation around the wiring brittle. [DOE 1997, DOI 2013]

**Expandable foams**

Urea formaldehyde (UF) foam consists of a resin and hardener solution which is injected into the wall cavity using compressed air. After injection the foam hardens and dries, and is subject to some shrinkage and fissuring. The UF foam releases a small amount of formaldehyde vapour as it hardens and this may enter the house if the inner wall cladding is not well sealed, and because of this there are some health concerns relating to this type of insulation. Allergic skin reactions are possible, but considered unlikely at the concentrations of formaldehyde used. However, some people may suffer irritation to the eyes and upper respiratory tract. Ventilation of the house should remove this vapour, but if in doubt people are advised to seek medical advice. [DOE 1997, EST 2002]

Polyurethane foam consists of liquids which are mixed together and injected into the wall cavity via small diameter (around 12 mm) holes through either the external or the internal wall cladding. The mixture expands into the wall cavity and a rigid foam is produced in a few minutes. [DOE 1997]

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17 Upstairs additions often require extra structural support to be included in the ground floor walls, requiring the removal of the wall linings from some sections of the ground floor walls.

18 In a German study which compared the properties of 7 different cavity wall insulation products the granulated rockwool product had the lowest resistance to water vapour (Wigger et al 2011)
The wall cavity was introduced into house construction to separate the internal wall cladding from the external cladding to avoid dampness problems which are experienced in older solid-walled dwellings. [EST 2002] Two critical issues need to be addressed when using any type of pump-in cavity wall insulation: (1) rain penetration, or the risk of moisture being transported across the wall cavity to the inner wall cladding causing dampness and mould problems; and, (2) the safety of any electrical wiring which is located in the wall cavity.

Pears has noted that the greatest risk of water penetration occurs when raked mortar joints are used between the bricks instead of flush or ironed mortar joints (see Figure 2). “Raked mortar can be recognised because the mortar surface is recessed back from the surface of the bricks (by around 10 mm), leaving a shallow flat strip of the brick sides visible. This creates two problems. First, water can pool on top of the exposed bricks, unlike flush or ironed mortar where the water has nowhere to sit, and runs off. Second, the surface of the mortar is porous and can easily absorb water (unlike ironed joins, where the process of ‘ironing’ the mortar compresses the surface, reducing its porosity).” [Pears 2007] Cracks in walls or degraded mortar joints (pointing) also increase the risk of water penetration, and should be repaired before cavity wall insulation is installed.

FIGURE 2: TYPES OF MORTAR JOINTS

As noted above, pump-in cavity wall insulation must be hydrophobic to reduce the risk of moisture being transported across the wall cavity. A number of studies undertaken in the UK during the 1990s focussing on houses with cavity brick walls provide good evidence that the use of pump-in cavity wall insulation creates little additional risk of rain penetration and dampness when it has been properly installed. The Northern Ireland Housing Executive, the main public sector housing authority, installed cavity wall insulation in over 100,000 dwellings. There were no reports of rain penetration problems with these houses, a result which is attributed partly to the high quality of house construction and partly due to the fact that the use of cavity wall insulation was restricted to two storeys height. Before the program severe condensation problems were a regular occurrence in these houses, causing the rotting of building components such as timber window frames. The combination of cavity wall insulation, central heating and controlled ventilation was found to have virtually eliminated these problems. An additional benefit of the reduced condensation was that the life of building components such as timber windows was increased. [DOE 1996b]

A second study of over 13,000 houses in England and Wales found that there “was no evidence … that filling the cavity with insulation resulted in any greater incidence of damp problems than occurred in cavity walls that had not been filled with insulation”. The results of this study are presented in Figure 3. The incidence of rain penetration in both types of houses was very low, and almost identical (0.26% vs 0.22%). The houses which had cavity wall insulation experienced fewer issues - 84% vs 78% of households reporting that there were not problems - mainly due to a lower incidence of condensation and damp in the insulated houses. The study found that the structural condition of the existing walls was critical in avoiding rain penetration: “Any cavity wall, if not correctly built, e.g. with poorly filled mortar joints or mortar droppings on wall ties, would be likely to have problems”. [DOE 1998, EST 2002] The study concluded that “Most of the rain penetration problems reported in homes could have been avoided if a more thorough pre-fill inspection had been carried out by the contractor prior to installation. Other rain penetration problems were often a result of the contractor’s failure, in the pre-fill inspection, to identify existing building defects such as failed pointing, broken guttering, and breach of a damp-proof course or bridged cavities.” [DOE 1998]
An investigation by the UK consumer organisation Which found that “some assessors aren’t carrying out pre-installation checks that we consider crucial and which could have costly consequences for consumers with homes unsuitable for” cavity wall insulation. They estimated that there could be thousands of British homes that were not suitable for the installation of cavity wall insulation, and noted that it could cause serious damp problems if wrongly installed. [Which 2011]

Insulation which is pumped into a wall cavity could cover any electrical wiring which is run through the cavity. This reduces the rate of heat loss from the wiring when it is carrying a current, which can result in the wire overheating if it is heavily loaded for long periods. In some cases this could result in a fire. Before the insulation is installed, an electrician should check that the house’s wiring will still comply with the Australian Wiring Rules when covered with insulation. Where the wiring would not comply, the electrician can usually install current limiting circuit breakers at the electrical switchboard to reduce the maximum current carrying capacity of the electrical wiring, and keep it within safe temperature limits. This may mean that wiring does not have the current carrying capacity required to meet the electricity requirements of the household, and in this case rewiring may be necessary. Households considering the installation of cavity wall insulation should discuss these issues with an electrician. It is recommended that they have an electrician issue a Certificate of Electrical Safety to certify the wiring system is safe and compliant, before the insulation is installed. [Pears 2007, HEAT 2010, ACT Gov 2012, DOI 2013]

Only a small cavity wall insulation retrofit industry currently exists in Australia. A recent report noted that there were only four or five companies operating in this area. Most activity has been undertaken in the ACT, where a government rebate scheme operated for a number of years with the main focus being on insulating houses with cavity brick and brick-veneer walls with granulated rockwool. [Maksay 2013]. A survey conducted for the ACT government of 72 houses which participated in this program found that total energy savings (electricity and gas) of 15% were achieved. [ICANZ 2012]

In contrast to Australia, a significant cavity wall insulation industry has operated in the UK since the early 1970s focussing on the insulation of cavity brick walls, which comprise around 70% of the housing stock. This industry expanded from the mid-1990s, driven by government energy efficiency policies which provided a financial incentive to install the insulation. Over the last four decades around 11 million houses have been insulated. [Maksay 2013] The scale of the industry in the UK seems to have led to significantly lower installation costs compared to the current situation in Australia. In November 2014 the average cost for insulating a detached house in the UK was around 720 Pounds Sterling (around A$1,400).[23] This compares with an average cost of $4,268 found in this study. The increased cost in Victoria might also be due to the use of a greater volume of cavity fill insulation, as the cavities in brick-veneer and weatherboard walls are wider than in cavity brick walls, and to a difference in house size.

A UK study of mineral wool cavity wall insulation installed in three separate local authority housing estates found actual savings in gas bills of between 20% to 29% following the installation of the cavity wall insulation (DOE 1996a).

Maksay [2013], who recently undertook a detailed study of the UK cavity wall industry as part of a study tour, has noted that a “unique approach has developed in the UK with the focus being not on CWI insulation products but rather on CWI Systems”.

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[22] The “Other issues” (2.4%) in the insulated houses were due to the cavity fill insulation or wall vents that were blocked because sleeves had not been properly fitted. [DOE 1998]

[23] www.energysavingtrust.org.uk(domestic/content/cavity-wall
In the UK, an independent not-for-profit organisation called the British Board of Agrément (BBA) plays a key role in the industry by accrediting the products and installation systems for mineral wool and expanded polystyrene foam cavity wall insulation marketed by different companies. The BBA awards an Agrément Certificate for a particular installation system if it has passed a comprehensive assessment involving laboratory testing, and inspection of the production process and an on-site evaluation of the installation process. The main factors taken into consideration during this assessment are (Maksay 2013):

- The water resistance of a cavity wall filled with the insulation, to help ensure that rain penetration will not be an issue;
- The adequacy of fill achieved in a wall cavity using the specified installation machinery and drilling patterns;
- The thermal properties of the insulation;
- The toxicity and fire retardant properties of the insulation;
- A site visit to ensure that the installation procedure is satisfactory; and,
- A review of the insulation manufacturer’s training arrangements for the system.

The BBA also approves each installation firm, and regularly assesses and monitors the performance of the Approved Installers. There is an obligation on these companies to properly train and regularly inspect the work of their site assessors and installation technicians, and keep written records as evidence. In addition to this the BBA requires the cavity wall insulation system providers, usually the companies which manufacture the insulation products, to monitor the work of the installers which are using their system. [EST 2002, Maksay 2013].

Another important element of the UK cavity wall insulation industry is the Cavity Insulation Guarantee Agency (CIGA), which issues 25 year guarantees to households which have installed cavity wall insulation. All Approved Installers are required to be a member of this organisation and pay a small fee to CIGA for each completed installation. In 2010 the CIGA was issuing around half a million guarantees each year and had a claim rate of less than 1,000 (or 0.2%) per annum. [Maksay 2013]

**Installation of granulated rockwool cavity wall insulation**

In the Cavity Wall Insulation Retrofit Trial we have used granulated rockwool to insulate the walls of all houses which participated in the trial. This can be installed into many existing brick-veneer, weatherboard and cavity-brick walls although, as shown by the UK experience, the condition of the external wall cladding and the wall cavity, and the thickness of the wall cavity also need to be taken into consideration.

The experience of the UK industry has highlighted the importance of the pre-retrofit assessment in helping to ensure a successful installation. The Energy Savings Trust has identified key elements of an appropriate assessment process [EST 2002, DOE 1997]:

- Determining that the existing wall cavity is not already filled with insulation;
- Finding out if the cavity of any adjacent house in a row of terraced houses or in a semi-detached house has already been filled;
- Determining that the wall cavity is suitable to be filled with insulation. For example, if a cavity brick wall has a cavity of less than 40 mm or if bricks have been used as wall ties and bridge the cavity, it is unsuitable for filling;
- Inspecting the general condition of the external wall cladding. The wall should be inspected for cracking and the causes ascertained, and mortar joints in brick walls should be inspected for excessive cracking and defective pointing.Lintels and windows should also be checked to see if they are out of plumb. Any defects in wall construction should be rectified;
- Checking the external walls from inside the house to identify any existing damp problems that need to be repaired, e.g. leaking gutters or downpipes, rising damp;
- Identifying any wall penetrations, e.g. flues, wall vents and exhaust fans, which require protective barriers to be installed prior to the cavity fill insulation being installed. Any holes in the inner wall cladding will need to be sealed. Where houses have suspended floors and the wall cavity is open to the sub-floor space it will also need to be sealed to prevent the escape of insulation;
- Checking the rain exposure of the wall, to ensure that insulation product and installation system are suitable;

The installation process involves a number of steps including: creating access points to inject the insulation; installing barriers and sleeving to prevent the insulation entering adjacent properties, to protect wall vents, exhaust fans and power outlets, and ensuring the wall cavity will not allow insulation to escape in to the sub-floor space; injecting the insulation into the wall cavity; making good any access points; and, undertaking quality checks. [EST 2002, HEAT 2010, Knauf 2012]

If the house has a suspended floor and there is adequate access to the sub-floor space, the bottom of the wall cavity is usually blocked by stuffing insulation batts into the gap to ensure that the cavity insulation does not leak from the wall cavity. In cases where access is not possible the cavity fill insulation is allowed to spill into the sub-floor space but will soon bridge the gap and prevent any more insulation material escaping. [MEFL 2012]

Special equipment is used to granulate the rockwool prior to installation and to pump the granulated rockwool into the wall cavity. This equipment is quite expensive and is one reason for the relatively small size of the industry in Australia at the moment. The installation equipment of one UK supplier [Knauf 2012] is likely to be representative of most equipment used. The equipment is operated remotely by the installer. Bales of the rockwool insulation are put into a hopper and then feed into a pelleting unit, where it is cut into shorter lengths by shredder bars and circulated within a pelleting chamber to form insulation pellets of the desired size and shape. It then passes through a rotary valve and is blown through a hose into the wall cavity. A special nozzle is used to inject it through holes in the wall. The filling process is controlled by a pressure switch, which stops the equipment when the cavity wall has been filled to the required density.

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24 UF foam systems are covered by British Standards, BS5167 and BS5168. [EST 2002]

25 The site assessors are responsible for assessing the suitability of a property for the installation of cavity wall insulation and providing a quotation. The installation technicians install the insulation.

26 At the time of Maksay’s visit in 2010 a fee of 5.11 pounds plus VAT was applied to each installation.

27 Mineral wool and EPS systems are considered to be suitable for use in all parts of the UK. [EST 2002]
In houses with tiled roofs access to the wall cavity can usually be achieved by removing the second row of tiles to expose the top of the external wall cavity. A special lay-flat hose is then inserted into the cavity between the wall studs and dropped to the bottom of the wall cavity, and the insulation pumped in from the bottom up as the hose is slowly withdrawn (see Figure 4). In houses with metal roofs the sheets of iron over the wall cavity can also be lifted by a roof plumber, but this is a more expensive process. In this case, or where insulation needs to be installed under windows, in brick-veneer or cavity brick houses small injection holes (around 25 mm) can be drilled through the mortar joints between the brickwork or individual bricks can be removed (see Figure 5). The holes are filled or the bricks replaced after the insulation has been installed, and it is important that the mortar is matched closely with the existing mortar.

In weatherboard houses injection holes can either be drilled through the weatherboards or through the internal wall lining. For two storey houses, the ground floor walls are usually insulated through injection holes in either the external or internal wall cladding. [HEAT 2010, EST 2002, MEFL 2012] A summary of the usual approaches to installing cavity wall insulation for different wall and roof construction types is provided in Table 2.

The installation process is more complicated in brick-veneer houses where the wall framing is wrapped in RFL sarking or wall wrap. If the house has a tiled roof the hose can be inserted behind the sarking to insulate the space between the sarking and the plasterboard (around 90 mm) down to the level of the middle nogging. The hose can then be dropped down between the sarking and the external brickwork to insulate this space (generally 40 to 50 mm) for the full wall height. This means that the top section of wall has a much better insulation fill than the bottom section. An alternative approach employed by one company in the Retrofit Trial was to remove bricks at regular intervals below the middle noggings, cut a hole in the sarking and then use the hose to fill the space between the plasterboard and the sarking. [MEFL 2012]

Pictures showing the visual impact of installing the cavity wall insulation are provided in Appendix A1.
FIGURE 5: INSTALLATION OF CAVITY WALL INSULATION BY REMOVING INDIVIDUAL BRICKS

Bricks removed under windows

Pumping insulation into wall cavity under windows

FIGURE 6: EQUIPMENT USED TO INJECT INSULATION INTO WALL CAVITY

Hose to fill wall cavity through roof tiles

Nozzle to fill wall cavity through holes between bricks

TABLE 2: INSTALLATION OF CAVITY WALL INSULATION IN DIFFERENT WALL AND ROOF CONSTRUCTION TYPES

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Roof Type</th>
<th>Tiled Roof</th>
<th>Metal Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick-veneer</td>
<td></td>
<td>Except under windows, installation by lifting roof tiles. Under windows either drill holes through mortar or remove bricks.</td>
<td>Installation by drilling holes through mortar or removing bricks.</td>
</tr>
<tr>
<td>Weatherboard</td>
<td></td>
<td>Lift roof tiles to insulate the top half of the wall. Drill holes through weatherboards to insulate bottom half of wall or drill holes through the internal wall lining.</td>
<td>Drill holes through weatherboards to insulate the top and bottom half of wall or drill holes through the internal wall lining.</td>
</tr>
<tr>
<td>Cavity brick</td>
<td></td>
<td>Except under windows, installation by lifting roof tiles. Under windows either drill holes through mortar or remove bricks.</td>
<td>Installation by drilling holes through mortar or removing bricks.</td>
</tr>
</tbody>
</table>

Information from MEFL based on advice from the insulation contractors.
The way in which the majority of brick-veneer walls are constructed means that the top plate of the timber frame is somewhat higher than the top of the external brickwork. This means that once the cavity between the brick and the timber frame has been filled with insulation, the section of timber frame above the top of the brickwork still needs to be insulated (see Figure 7 (a)). This can be done by cutting an insulation batt to size and fitting it between the wall studs, as shown in Figure 7 (b). [MEFL 2012]

**FIGURE 7: INSULATION REQUIREMENTS ABOVE TOP OF BRICKWORK**

Insulation gap above the brickwork

Gap filled with insulation batt cut to size

An important consideration with the installation of cavity wall insulation is that good insulation coverage is achieved, with the insulation installed to the correct density and no gaps or voids in the insulation. The spacing of the injection points for the insulation and the condition of the wall cavity - especially for cavity brick walls - play an important role in determining the quality of the insulation fill which is achieved. Kingspan Insulation undertook thermographic surveys of 84 houses in the UK at which cavity wall insulation had been installed in cavity brick walls, and followed this up with endoscopic investigations at 20 properties at which potential installation defects were identified. Of the 84 houses involved in the thermographic survey, 34 showed evidence of missing or low density insulation in some sections of the wall and this was subsequently confirmed in the endoscopic surveys. [Kingspan]

The study concluded that “The condition of the wall cavity prior to installation is critical to the success of injected mineral fibre full cavity wall insulation”. Critical issues identified in the Kingspan study include:

- Most of the defects were located between window positions and within smaller wall panel sections between building components such as windows and doors, equidistant between injection holes and at wall penetrations;
- Dirty wall ties or mortar “snots” on the inner face of either leaf of brickwork can result in voids once the insulation is installed. There is little scope to rectify these issues once wall construction is complete;
- The width of the wall cavity. Because the installation equipment is sensitive to back pressure a wall cavity that is too narrow (less than 40 mm) can be difficult to fill properly;

The level of insulation which can be achieved depends on the type of wall construction and the width of the cavity. For cavity brick walls an overall installed R-value of R1.3 to R1.5 is expected, while for weatherboard walls an overall installed R-value of R2.5 could be achieved. [HEAT 2010, DoI 2013]. For brick-veneer walls the insulation level which can be achieved will depend on the width of the wall studs, the width of the cavity between the brickwork and the framing, and on whether or not sarking has been fixed to the outside of the wall frame. In this case installed R-values of between R1.9 to R3.4 would be expected. [ICANZ 2012, HEAT 2010] The highest value will be achieved where there is no sarking and the overall cavity width is around 130 mm. The lowest value will be achieved where sarking is fixed to the outside of the frame and the top half of the wall (e.g. above the nogging) filled to the full cavity width via the roof while in the lower half only the cavity between the brickwork and sarking (around 40 to 50 mm) is filled. In this latter case an installed R-value of around R2.9 could be achieved if the insulation was installed via holes drilled in the internal wall lining so that the insulation filled the space between the wall studs.

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30 This involved drilling holes in the walls of the properties near the site of suspected defects identified in the thermographic surveys and inserting an endoscope into the wall cavity. [Kingspan]

31 It is assumed that the values quoted in [ICANZ 2012] are the added R-value which can be achieved and not the overall R-value of the wall section.
3 Results of the cavity wall insulation retrofit trials

Housing Sample

Details of the 15 houses which participated in the Cavity Wall Insulation Retrofit Trial are shown in Table 3. Eight houses (WI1 to WI8) were retrofitted in 2012. The other seven houses (WI9 to WI15) were retrofitted in 2013\(^\text{32}\). The estimated average annual gas use for heating for the houses was 47,585 MJ/Yr. This is lower than the average gas use for gas ducted heating in the OGA study houses (62,689 MJ/Yr). The average cost for installing the cavity wall insulation was $4,286, consistent with an average cost of $4,167 estimated for this upgrade in the OGA study houses.

\[32\text{ Eight houses were recruited to participate in this trial, but one pulled out as they were concerned about the visual impact of installing the insulation.}\]

<table>
<thead>
<tr>
<th>House No</th>
<th>Decade Built</th>
<th>Construction Details*</th>
<th>Floor Area (m(^2))</th>
<th>Heating Gas Use (MJ/Yr)</th>
<th>Retrofit Cost ($)</th>
<th>Start Date</th>
<th>Retrofit Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>1950s</td>
<td>Walls - BV; Floor – ST; Insulated ceiling</td>
<td>122</td>
<td>45,268</td>
<td>$3,704</td>
<td>14/7/12</td>
<td>10/8/12</td>
<td>10/9/12</td>
</tr>
<tr>
<td>WI2</td>
<td>1970s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>150</td>
<td>63,897</td>
<td>$5,153</td>
<td>14/7/12</td>
<td>12/8/12</td>
<td>17/9/12</td>
</tr>
<tr>
<td>WI3</td>
<td>1980s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>185</td>
<td>35,383</td>
<td>$4,565</td>
<td>14/7/12</td>
<td>20/8/12</td>
<td>25/9/12</td>
</tr>
<tr>
<td>WI4</td>
<td>1960s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>102</td>
<td>37,702</td>
<td>$4,199</td>
<td>14/7/12</td>
<td>21/8/12</td>
<td>26/9/12</td>
</tr>
<tr>
<td>WI5</td>
<td>1960s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>113</td>
<td>52,821</td>
<td>$3,630</td>
<td>14/7/12</td>
<td>7/8/12</td>
<td>17/9/12</td>
</tr>
<tr>
<td>WI6</td>
<td>1950s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>146</td>
<td>41,194</td>
<td>$4,250</td>
<td>14/7/12</td>
<td>14/8/12</td>
<td>25/9/12</td>
</tr>
<tr>
<td>WI7</td>
<td>1960s</td>
<td>Wall – BV; Floor – ST; Insulated ceiling</td>
<td>97</td>
<td>25,080</td>
<td>$3,222</td>
<td>17/7/12</td>
<td>20/8/12</td>
<td>17/9/12</td>
</tr>
<tr>
<td>WI8</td>
<td>1960s</td>
<td>Wall - BV; Floor – ST; Insulated ceiling</td>
<td>129</td>
<td>59,775</td>
<td>$4,809</td>
<td>20/7/12</td>
<td>21/8/12</td>
<td>26/9/12</td>
</tr>
<tr>
<td>WI9</td>
<td>1940s</td>
<td>Wall - WB; Floor – ST; Insulated ceiling</td>
<td>200</td>
<td>65,171</td>
<td>$3,034</td>
<td>14/6/13</td>
<td>8/7/13</td>
<td>14/8/13</td>
</tr>
<tr>
<td>WI10</td>
<td>1970s</td>
<td>Wall – BV; Floor – ST; Insulated ceiling</td>
<td>160</td>
<td>30,945</td>
<td>$3,885</td>
<td>28/5/13</td>
<td>31/7/13</td>
<td>11/9/13</td>
</tr>
<tr>
<td>WI11</td>
<td>1950s</td>
<td>Walls - WB; Floor – ST; Insulated ceiling</td>
<td>65</td>
<td>43,064</td>
<td>$3,032</td>
<td>13/6/13</td>
<td>1/8/13</td>
<td>11/9/13</td>
</tr>
<tr>
<td>WI12</td>
<td>2000s</td>
<td>Walls - BV; Floor – ST; Insulated ceiling; 1st floor walls insulated</td>
<td>185</td>
<td>53,150</td>
<td>$4,862</td>
<td>7/6/13</td>
<td>4/7/13</td>
<td>23/9/13</td>
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<tr>
<td>WI13</td>
<td>1980s</td>
<td>Walls - BV; Floor – ST; Insulated ceiling; Some wall insulation</td>
<td>210</td>
<td>66,576</td>
<td>$5,792</td>
<td>29/6/13</td>
<td>25/7/13</td>
<td>30/8/13</td>
</tr>
<tr>
<td>WI14</td>
<td>1940s</td>
<td>Wall - WB; Floor – ST; Insulated ceiling</td>
<td>120</td>
<td>38,966</td>
<td>$3,621</td>
<td>7/6/13</td>
<td>26/7/13</td>
<td>10/9/13</td>
</tr>
<tr>
<td>WI15</td>
<td>1940s</td>
<td>Wall – BV; Floor – ST; Insulation status unknown</td>
<td>205</td>
<td>54,781</td>
<td>$6,527</td>
<td>8/6/13</td>
<td>27/6/13</td>
<td>11/9/13</td>
</tr>
</tbody>
</table>

Average 146 47,585 $4,286

* S = storey; Walls: BV = brick veneer; WB = weatherboard; Floors: ST = suspended timber; CS = concrete slab on ground.
Householder perceptions

Surveys were conducted before and after the cavity wall insulation retrofits were undertaken to identify any changes in householder perceptions of the level of thermal comfort in their houses and the difficulty of heating the houses. The results of these surveys are summarised in Figure 8 and the detailed results for each house are provided in Appendix A2.

FIGURE 8: SUMMARY OF HOUSEHOLDER SURVEY RESULTS

Overall the householders reported that the level of comfort of their houses increased after the cavity wall insulation retrofits had been undertaken (from an average score of 3.3 to 3.9)\(^\text{33}\). This corresponded with a reduction in the difficulty of heating their homes (from an average score of 1.8 to 1.3)\(^\text{34}\).

Thermal comfort

All houses which participated in the study used gas ducted heating as the main form of heating, so not surprisingly all houses had a reasonable level of thermal comfort (average rating of 3.3) prior to the retrofits. Overall the retrofits resulted in an increase in the perceived level of comfort to an average rating of 3.9. The majority of households (67%) rated their houses as being more comfortable after the retrofit had been undertaken. The ratings for three of the houses (WI9, WI10 & WI14) suggested that there had been no changes in thermal comfort, although in all cases their more detailed comments indicated that either the heater was now working less or that comfort had improved but there were still issues with draughts which needed to be addressed. House WI14 had wall vents, and these can be a major source of draughts. The ratings for two of the houses (WI11 and WI15) suggested that there had been a decrease in comfort after the retrofit. In both cases their more detailed comments indicated that there had been some improvements in thermal comfort, and the main issue seemed to be that the unseasonably warm weather after the retrofits in 2013 made it difficult to tell what the impact had been.

Below we provide a selection of comments from householders concerning the impact of the cavity wall insulation retrofits on their level of thermal comfort. The improvement in thermal comfort was linked to better retention of heat and higher internal temperatures when the heating was switched off, especially during the night time, and a more even distribution of heat throughout the house. In some cases households were able to reduce the thermostat setting of their heater and still maintain comfort conditions or even switch off secondary heating which was used to supplement the gas ducted heating in the colder areas of the house.

\[^{33}\] The level of winter comfort was ranked on a scale from 1 (extremely uncomfortable) to 5 (extremely comfortable).

\[^{34}\] The difficulty of heating was ranked on a scale from 1 (small difficulty) to 5 (extremely difficult).
Difficulty heating

Most households which participated in the study had little difficulty heating their house. Again, this may be due to the fact that they all used gas ducted heating. Overall the occupants reported that their houses were easier to heat after the retrofits (average rating decreased from 1.8 to 1.3), although 6 (40.0%) of the houses did not perceive any change in the difficulty of heating their house. In two of the cases (WI1 and WI8) this seems to have been because the existing heater was more than sufficient to heat the house to the required comfort conditions. In two of the houses (WI5 and WI10) the more detailed comments indicated either that it was now easier to heat certain parts of the house or that the house now heated more quickly and retained the heat better. House W115 noted that the warmer weather since the retrofit made it hard to tell whether the difficulty of heating had been reduced.

A selection of comments from householders concerning the impact of the cavity wall insulation retrofits on the difficulty of heating their homes is provided below. Where an improvement was noticed this was often linked to the better distribution of heat throughout the house, better heat retention in the house and the house heating up more quickly than before.

Comments on the difficulty of heating the home

Before – The heater can deliver the required amount of heat but the main problem is the distribution of the heat. It is harder to regulate and control the temperature in [the kitchen].

After – The distribution of the heat is better since the retrofit. It is easier to heat the kitchen. (WI2)

Before – The house is easy to heat with the central heater. The bedroom on the south side is harder to heat than the rest of the house.

After – Very slight improvement in the ease of heating the house. The bedroom on the south side is heating up quicker and holds its heat better. (WI3)

Before – House heats up quite easily, not difficult. Harder to heat the home office and bedroom on the south side.

After – The house heated up easily in the past so there has not been a huge change, but it seems to hold its heat for longer and not take quite as long in the morning to heat up. Easier to heat [the home office and bedroom on the south side] since the retrofit. (WI6)

Before – [The house] cools very quickly. Means we basically have to heat all of the time.

After – House heating has been straight forward. The kitchen was previously hard to heat. Seems easier now. (WI13)

Visual impact of the retrofit

In many cases the installation of the cavity wall insulation requires a hole to be drilled through the wall, usually through the mortar between the external bricks for cavity brick or brick-veneer walls or through the weatherboards. In some cases bricks are removed to allow the insulation to be installed. The holes are filled following the installation of the insulation and the bricks replaced. The drill holes are usually around 25 mm in diameter, meaning that both the mortar and some of the brickwork are removed. In this case the visual impact will depend on the level of contrast between the bricks and the mortar and how well the mortar used for patching matches the existing mortar. In the case of removed bricks the visual impact depends on how closely the replacement mortar matches the existing mortar. Holes drilled through internal walls or weatherboards need to be filled and repainted.

The type of the drill bit used when drilling the holes can potentially affect the visual impact as in some cases chipping of the brickwork occurs around the drill holes. A drill bit with a pilot point can create less damage to the brickwork and reduce the visual impact. [MEFL 2012]

A selection of post-installation photos from houses which either had holes drilled through the external or internal walls or bricks removed are provided in Appendix A1, and examples are provided in Figure 9. It is important to keep in mind that these photographs were taken shortly after installation so the mortar may not have had time to cure to its final colour.
Following the retrofits householders were asked if they noticed any issues created by the installation of the cavity wall insulation, including the visual impact. A selection of the comments concerning the visual impact is provided below. In general householders either noticed little impact or were not concerned with the visual impact. In a number of houses the mortar was not initially well matched, but this was either rectified or was expected to improve over time as the mortar cured and weathered. A number of householders felt there could have been a more comprehensive clean up after the installation.

**Comments on the visual impact of the retrofit**

No problems. The visual impact was quite minimal. (WI1)

No, everything was all fine. The visual impact is not a big concern, but if the house was newer it might have been more of a concern. (WI2)

Happy with the result and not really concerned about the visual impact where the drilling needed to take place. The removal of the bricks is better visually than the drilling into the wall. There was a lot of dust after the retrofit was completed that had to be hosed away. (WI3)

It is not a major problem but the mortar could have been matched better in the drill holes. Also, it would have been nice if there was a more comprehensive clean at the end of the installation process. (WI4)

Overall very happy with the retrofit. The visual impact is quite minimal and the bricks were replaced in a neat manner. (WI5)

The new mortar doesn’t match the old colour but it should fade over time. (WI9)

There was an issue with the brick colour – mortar not matching. This has now been resolved. (WI12)
Thermal Imaging

Thermal images were taken of the external walls in the trial houses both prior to and after the cavity wall insulation was installed. Our aim was to see if these images provided a good indication of the impact of the wall insulation on heat losses through the walls in winter, and whether or not this would be an effective technique for checking the quality of the installation, by identifying areas of wall that had either not been insulated or where adequate fill had not been achieved. Once installed, the cavity wall insulation is impossible to inspect by visual means unless wall linings are removed.

The images taken by thermal imaging (or infrared) cameras show the temperature of building surfaces and other objects in the image, based on a colour coded scale. The thermal images in Figure 10 demonstrate the effect that installing cavity wall insulation can have on heat transfer through an external wall. Before the retrofit the uninsulated sections of wall between the wall studs (purple) are at a much lower temperature (around 13 to 14°C) than the side internal wall (orange/yellow) shown on the left of the image (around 18 to 19°C). They are also colder than the wall studs (around 15°C) which are visible as a faint grid pattern. This is because the heat losses from the uninsulated external wall sections mean that the temperature of the internal plasterboard is much closer to the outside air temperature. The small insulating effect of the wooden studs mean that the internal plasterboard in front of these is at a slightly higher temperature, while elsewhere the temperature of the plasterboard lining the external wall is much closer to the outside air temperature.

After the insulation is installed the situation is quite different. The insulated external wall panels are now around the same temperature as the side internal wall (both now yellow and around 18 to 19°C) because much less heat is being lost through the external walls and the internal plasterboard is much closer to the internal air temperature. This increase in temperature of the internal wall surfaces increases occupant comfort as it lowers the radiant heat losses from people’s bodies to cold wall surfaces. The wall studs – visible as a faint pink grid pattern – are now colder (around 15°C) than the insulated sections of the external walls.

A recent BRANZ study report [Cox-Smith 2010] provides a useful overview of the use of thermal imaging cameras to identify issues relating to the installation of cavity wall insulation. It concluded that the cameras are a useful tool for auditing the quality of an installation but that “success requires not only the correct choice of camera capabilities and settings but also the temperature conditions must be right as well.”

Cox-Smith noted that in the northern hemisphere it is common to undertake thermal imaging surveys of external walls from outside the house. However, in New Zealand (and even more so in Australia) the more temperate climate and smaller temperature difference experienced across the external walls means that it is better to undertake the thermal imaging surveys from inside the home. He notes that “with claddings such as brick veneer, the thermal resistance, thermal mass and vented cavity behind the bricks means that the thermal characteristics of the exterior face of the bricks is significantly isolated from the thermal behaviour of the insulated framing.” [Cox-Smith 2010]
Cox-Smith has identified a range of conditions which need to be satisfied to achieve good quality thermal images which can be used to assess the quality of a wall insulation installation during the winter months [Cox-Smith 2010]:

- A minimum temperature difference of 10K\(^\circ\) is required between the interior and exterior wall surface or internal and external ambient air temperatures for a period of 4 hours prior to conducting the survey. A temperature difference higher than this (e.g. 15K\(^\circ\)) will give a better result;
- There should be no direct sunlight on the external wall surfaces to be surveyed for approximately 3 hours prior to the survey for lightweight wall construction (e.g. weatherboard) and approximately 8 hours for brick-veneer construction. If the temperature difference across the wall is greater than 10K these times can be reduced. This means that internal wall surveys are best undertaken in the very early morning up to an hour or two after sunrise. Any external wall surveys should be undertaken at night or in the early morning before dawn;
- For exterior surveys, the wind speed should be less than 6.7 m/s and the external walls should be dry.

The ideal conditions identified by Cox-Smith are fairly difficult to achieve in practice. While a range of images were taken in all houses which participated in this retrofit trial, the majority of the images were not of a suitable quality to allow a straightforward comparison between the pre- and post-retrofit situation to be made, or allow the quality of the installation to be assessed. This is clearly an area where further work is required if a cavity wall insulation retrofit industry is to be developed in Australia in future.

### Economics of retrofitting

Installing cavity wall insulation into the external walls of the 15 houses which participated in the Cavity Wall Insulation Retrofit Trials should have reduced the heat losses through the external walls when the heating was operating, increased heat retention in the houses after the heating was switched off, increased the temperature of internal walls, and contributed to higher temperatures during the daytime when the heating was not operating\(^{36}\). The householders have experienced this as an increase in the thermal comfort of their houses and reduction in the difficulty of heating the houses. By reducing the heat losses through external walls when the heating is operating the installation of the cavity wall insulation was also expected to lead to heating energy savings, and therefore reduced heating costs.

All houses which participated in the study used gas ducted (or central) heating as their main form of heating. The annual gas use for heating the houses, estimated from their previous gas bills, is shown in Table 3 above. In addition to this the gas ducted heating systems consume a significant amount of electricity when they are operating, mainly to operate the air circulation fan and combustion air fan – typically the electricity consumption of the heaters is around 2% of the gas consumption, and is often in the range of 1 to 4 kWh per day\(^{37}\) during the main winter heating months.

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35 This is the scientific way in which temperature differences are expressed, in degrees Kelvin. 1 degree Kelvin is equivalent to 1ºC.

36 The household surveys (see summary above and details in Appendix A2) and internal temperature profiles before and after the retrofits (see Appendix A3) provide evidence of increased heat retention, and the thermal images undertaken in some houses (see Figure 8) provide good evidence that heat losses have been reduced and internal wall temperatures increased.

37 The estimated electricity use as a percentage of gas consumption is based on laboratory testing of gas ducted heaters undertaken for the Equipment Energy Efficiency Program [E3, 2008]. The typical daily electricity consumption of gas ducted heaters is based on monitoring undertaken for the Retrofit Trials.
### TABLE 4: MODELLED ESTIMATES OF SAVINGS FROM THE INSTALLATION OF CAVITY WALL INSULATION

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>45,268</td>
<td>19.5</td>
<td>8,845</td>
<td>49.1</td>
<td>$168.5</td>
<td>$3,704</td>
<td>22.0</td>
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<td>WI2</td>
<td>63,897</td>
<td>17.1</td>
<td>10,928</td>
<td>60.7</td>
<td>$208.2</td>
<td>$5,153</td>
<td>24.7</td>
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<td>35,383</td>
<td>16.1</td>
<td>5,685</td>
<td>31.6</td>
<td>$108.3</td>
<td>$4,565</td>
<td>42.1</td>
</tr>
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<td>37,702</td>
<td>17.1</td>
<td>6,448</td>
<td>35.8</td>
<td>$122.9</td>
<td>$4,199</td>
<td>34.2</td>
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<tr>
<td>WI5</td>
<td>52,821</td>
<td>19.5</td>
<td>10,321</td>
<td>57.3</td>
<td>$196.7</td>
<td>$3,630</td>
<td>18.5</td>
</tr>
<tr>
<td>WI6</td>
<td>41,194</td>
<td>17.1</td>
<td>7,045</td>
<td>59.1</td>
<td>$134.2</td>
<td>$4,250</td>
<td>31.7</td>
</tr>
<tr>
<td>WI7</td>
<td>25,080</td>
<td>19.5</td>
<td>4,900</td>
<td>27.2</td>
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<td>11,680</td>
<td>64.9</td>
<td>$222.6</td>
<td>$4,809</td>
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<td>WI9*</td>
<td>65,171</td>
<td>25.3</td>
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<td>$313.7</td>
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<td>$100.8</td>
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<td>$218.2</td>
<td>$3,032</td>
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<td>$6,527</td>
<td>25.8</td>
</tr>
<tr>
<td>Stock Av.</td>
<td>47,187</td>
<td>19.3</td>
<td>9,130</td>
<td>50.7</td>
<td>$174.0</td>
<td>$4,245</td>
<td>27.2</td>
</tr>
</tbody>
</table>

* These houses had weatherboard walls. All other houses had brick veneer walls.

In the first instance we used data on the house size, construction and insulation status (see Table 3) and estimated annual gas heating energy use to prepare a theoretical estimate of the energy savings which could be achieved when the wall insulation is installed. For this we used the Victorian housing model, which allows the floor area, wall and floor construction type and insulation status of the ceilings and walls to be entered for a number of different climate zones, and which produces annual heating and cooling load estimates for heating and cooling an entire house or the main living areas. The heating and cooling loads are estimated for a number of different occupancy profiles. The model was used to estimate the percentage saving for the heating when wall insulation was added, and this was combined with the estimated annual gas use for heating to estimate annual gas and electricity savings for the houses. For most houses it was assumed that there was no wall insulation to start with and that the wall insulation achieved 100% coverage.

The results of this analysis are shown in Table 4 for the 14 houses for which a complete set of monitoring data was obtained during the trials. Using the housing model it was estimated that the installation of the cavity wall insulation could result in average gas savings of 9,130 MJ/Yr, average electricity savings of 50.7 kWh/Yr and annual heating energy bill savings of $174 per year. Based on the average installation cost of $4,245 for these 14 houses this would give a payback of 27.2 years for the heating energy savings. This compares with an estimated annual energy bill saving of $157 and a payback of 28 years for the gas ducted heating houses which participated in the OGA study, although in this case the energy savings are based on both heating and cooling energy use.

The modelling suggests that the heating energy saving for houses with brick veneer walls is typically in the range of 16% to 20% and is somewhat lower than the savings expected for houses which have weatherboard walls (24% to 27%). This effect may be partly due to the insulation assumptions for the brick-veneer walls used in the Victorian housing model. In practice the level of insulation in brick-veneer walls depends on the thickness of the wall cavity and framing, whether or not the frame is wrapped in sarking and on the method used to insulate the walls. Where there was no sarking in these walls a higher R-value may have been achieved and so the housing model is likely to have underestimated the saving.

### Notes

38 This model was developed by Tony Isaacs for Sustainability Victoria in 2008 to assist with the development of the Victorian Residential Energy End-Use Model.

39 This includes heating or cooling all day, in the morning and evening or just in the evening.

40 House WI13 already had some walls insulated. In this case we assumed that 30% of the walls were initially insulated.

41 The metering equipment was not installed correctly on the gas ducted heater in house WI12 and so no data on the operation of the heater was obtained for this house.

42 For houses which used air conditioning during the summer months the total energy bill savings would be larger than this and the payback would be shorter.
As part of the Cavity Wall Insulation Retrofit Trials we sought to more directly estimate the heating energy savings which were achieved from the cavity wall insulation retrofits, by monitoring the energy use of the heating, and internal and external temperatures in the participating houses for around a month before and after the retrofits were undertaken. The electricity consumption of the gas ducted heaters in the houses was monitored using a plug-in power meter/logger. In addition to allowing an estimate of the electricity savings achieved by the retrofits to be made, it was assumed that the electricity consumption of the gas ducted heaters was a reasonable proxy for the gas consumption and would therefore allow an estimate of the gas saving to be made – if there was a 10% reduction in electricity use, it was assumed that this would correspond to a 10% reduction in gas use.

The meters installed on the electricity supply to the gas ducted heaters were set to measure the average electricity use over each 1 minute interval throughout the day. In addition to allowing the daily electricity consumption of the heaters to be calculated, this enabled us to identify those times of the day that the heater was operating to heat the house. Gas ducted heaters are operated by a thermostat. When switched on both the gas burner and air circulation fan operate to heat air and circulate the heated air through the house via the ductwork. Once the internal air temperature has reached the thermostat setting, the gas burner and air circulation fan switch off, and will remain off until the internal air temperature falls below the thermostat setting by a certain amount. When operating, the gas ducted heater will cycle on and off to maintain the internal temperature at the thermostat setting.

In addition to monitoring the electricity use of the gas ducted heaters, small stand-alone temperature loggers were used to record the outside temperature (1 logger) and the inside temperature (3 to 4 loggers) in the heated areas of the house. The loggers were set to measure the average temperature over a 10 minute interval throughout the day. The data from the internal temperature loggers was averaged to produce an estimate of the average temperature in the heated areas of the house. This allowed us to obtain an understanding of the temperatures that the house was being heated to when the heater was operating. Combined with the outside temperature data, this also allowed us to calculate the average temperature difference between the inside and outside of the house when the heater was operating. This temperature difference is related to the heating load (or amount of heating) that the heater has to provide to achieve the observed internal temperatures. When the temperature difference is higher the rate of heat loss from the house is higher, and so the larger the heat output that is required from the heater to maintain the thermostat setting.

An example of the data collected is provided in Figure 11. The graphs show the data collected by the meters throughout the day for House WI2 on 10 August, 2012, with the time during which the gas ducted heater was operating indicated by green shading. The first graph shows the electricity consumption of the gas ducted heater. In this case the heater has an electrical power consumption of around 350 Watts when it is operating and an electrical power consumption of around 1.3 Watts when it is in standby mode. The heater was switched on twice during the day: it first operated from 8:04 am to 9:54 am; it operated for a second time from 3:28 pm (15:28) to 11:50 pm (23:50). The heater was switched on for a total of 10.4 hours on this day, with the heater fan operating for a total of 7.3 hours during this period. The daily electricity consumption of the heater was 2.32 kWh, with 2.30 kWh of this consumed when the heater fan was operating.

The second graph shows the average temperature in the heated areas of the home. The temperature increases when the heating is first switched on and then alternates around the thermostat setting once the heater has brought the house up to the required temperature. It appears that the thermostat was set to around 16 to 17ºC in the morning and to around 20ºC in the afternoon. The final graph shows the average temperature difference between the inside of the house and outside. The average temperature difference during the time that the heater was operating was 8.9ºC. The largest temperature difference occurred later in the evening, due to the higher thermostat setting and the relatively low outside air temperature.

The monitoring results for all houses which participated in the Cavity Wall Insulation Retrofit Trial are summarised in Appendix A3. The average results for the pre-retrofit and post-retrofit monitoring period are provided for each house for internal and external daily temperature profiles, the daily temperature difference profile and for the daily electricity consumption profile of the gas ducted heater. The daily electricity use of the gas ducted heater when operating is also shown plotted against the outside temperature for the entire monitoring period.

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43 In a number of its comprehensive retrofit trials Sustainability Victoria has monitored both the gas and electricity consumption of the gas ducted heaters. This has confirmed that there is essentially a linear relationship between the gas and electricity consumption.

44 The data was used to estimate both the total daily electricity consumption of the heaters in kWh, and also to estimate the daily electricity consumption during those times that the heater fan was operating. Even when gas ducted heaters are not operating they consume a small amount of electricity as standby power, typically in the range of 2 to 10 Watts.

45 This is simplified explanation of how the gas duct heater works. In practice the gas burner usually comes on before the air circulation fan to heat the heat exchanger, and the air circulation fan starts to operate once the heated air in the gas furnace has reached an adequate temperature. At the end of the heating cycle the gas burner switches off, but the air circulation fan will continue to operate for a short time to extract heat from the heat exchanger.
FIGURE 11: METER DATA FOR HOUSE WI2, 10 AUGUST, 2012

Electricity consumption of gas ducted heater

Average internal temperature in heated area

Average temperature difference – heated area to outside
The ‘raw’ results for the Cavity Wall Insulation Retrofit Trial are provided in Table 5. This shows the average temperature difference when the heating is operating, average heater operating time and average heater electricity consumption before and after the retrofits, for those days on which the heater was operated. Taken on face value, this data suggests that an average heating energy saving of 42.5% was achieved across the 14 houses which participated in the trial and for which gas ducted heater data is available. However, some caution needs to be used when interpreting this result as it is influenced by a range of factors:

- The heating was operated could change between the pre- and post-retrofit period. The times of day at which the heaters are operated could change, the heating could be operated for longer or shorter periods each day during the post-retrofit period, or the thermostat settings used after the retrofits could be different to those used before – in this case there could be either an increase or a decrease in the usual thermostat settings. These changes in user behaviour have implications for the time that the heater operates and/or the temperature difference during the times the heater operates, both of which can affect the energy consumption of the heater.

- Coupled with the relatively short pre- and post-retrofit monitoring period these factors mean that the ‘raw’ results are not necessarily a good guide to the energy savings which were achieved in practice.

The raw data collected during the Cavity Wall Insulation Retrofit Trials was further analysed to obtain a more accurate estimate of the energy savings achieved. The methodology used seeks to estimate the “technical” energy saving which was achieved. This is the saving which is relatively independent of the climatic conditions in the pre- and post-retrofit periods, and also independent of user behaviour, for example, whether or not the heater is run for shorter or longer periods and whether or not the thermostat settings are increased or decreased.

### TABLE 5: RAW MONITORING RESULTS, BEFORE AND AFTER RETROFIT

<table>
<thead>
<tr>
<th>House</th>
<th>Before</th>
<th>After</th>
<th>% Change</th>
<th>Before</th>
<th>After</th>
<th>% Change</th>
<th>Before</th>
<th>After</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>6.80</td>
<td>6.09</td>
<td>-10.5%</td>
<td>17.14</td>
<td>7.04</td>
<td>-58.9%</td>
<td>1.83</td>
<td>0.81</td>
<td>-56.0%</td>
</tr>
<tr>
<td>WI2</td>
<td>8.13</td>
<td>8.09</td>
<td>-0.4%</td>
<td>8.72</td>
<td>6.78</td>
<td>-22.2%</td>
<td>1.78</td>
<td>1.14</td>
<td>-35.9%</td>
</tr>
<tr>
<td>WI3</td>
<td>5.92</td>
<td>5.91</td>
<td>-0.1%</td>
<td>11.02</td>
<td>4.99</td>
<td>-54.7%</td>
<td>1.35</td>
<td>0.63</td>
<td>-53.1%</td>
</tr>
<tr>
<td>WI4</td>
<td>9.30</td>
<td>7.44</td>
<td>-20.0%</td>
<td>6.98</td>
<td>3.40</td>
<td>-51.3%</td>
<td>1.54</td>
<td>0.66</td>
<td>-57.1%</td>
</tr>
<tr>
<td>WI5</td>
<td>8.79</td>
<td>9.03</td>
<td>2.7%</td>
<td>11.77</td>
<td>8.56</td>
<td>-27.3%</td>
<td>1.21</td>
<td>0.70</td>
<td>-42.4%</td>
</tr>
<tr>
<td>WI6</td>
<td>7.29</td>
<td>6.55</td>
<td>-10.2%</td>
<td>10.70</td>
<td>6.63</td>
<td>-38.0%</td>
<td>2.39</td>
<td>1.32</td>
<td>-44.6%</td>
</tr>
<tr>
<td>WI7</td>
<td>8.51</td>
<td>9.31</td>
<td>9.4%</td>
<td>7.03</td>
<td>3.61</td>
<td>-48.7%</td>
<td>1.91</td>
<td>0.92</td>
<td>-52.0%</td>
</tr>
<tr>
<td>WI8</td>
<td>7.46</td>
<td>6.33</td>
<td>-15.2%</td>
<td>13.74</td>
<td>7.09</td>
<td>-48.4%</td>
<td>2.82</td>
<td>1.31</td>
<td>-53.5%</td>
</tr>
<tr>
<td>WI9</td>
<td>6.53</td>
<td>7.13</td>
<td>9.2%</td>
<td>9.52</td>
<td>9.23</td>
<td>-3.1%</td>
<td>4.43</td>
<td>3.49</td>
<td>-21.1%</td>
</tr>
<tr>
<td>WI10</td>
<td>6.75</td>
<td>5.91</td>
<td>-12.5%</td>
<td>4.76</td>
<td>3.97</td>
<td>-16.5%</td>
<td>0.67</td>
<td>0.58</td>
<td>-13.3%</td>
</tr>
<tr>
<td>WI11</td>
<td>8.46</td>
<td>7.24</td>
<td>-14.4%</td>
<td>14.84</td>
<td>6.41</td>
<td>-56.8%</td>
<td>1.51</td>
<td>0.70</td>
<td>-53.6%</td>
</tr>
<tr>
<td>WI12</td>
<td>8.95</td>
<td>8.26</td>
<td>-7.7%</td>
<td>10.80</td>
<td>7.86</td>
<td>-27.2%</td>
<td>2.04</td>
<td>1.46</td>
<td>-28.4%</td>
</tr>
<tr>
<td>WI13</td>
<td>7.49</td>
<td>6.38</td>
<td>-14.9%</td>
<td>10.46</td>
<td>7.14</td>
<td>-31.7%</td>
<td>1.38</td>
<td>0.68</td>
<td>-50.4%</td>
</tr>
<tr>
<td>WI14</td>
<td>6.26</td>
<td>5.81</td>
<td>-7.3%</td>
<td>10.12</td>
<td>6.27</td>
<td>-38.1%</td>
<td>3.51</td>
<td>1.90</td>
<td>-45.7%</td>
</tr>
<tr>
<td>WI15</td>
<td>7.11</td>
<td>6.63</td>
<td>-6.7%</td>
<td>9.84</td>
<td>5.93</td>
<td>-39.7%</td>
<td>1.89</td>
<td>1.09</td>
<td>-42.5%</td>
</tr>
</tbody>
</table>

The way in which the heating was operated could change between the pre- and post-retrofit period. The times of day at which the heaters were operated could change, the heating could be operated for longer or shorter periods each day during the post-retrofit period, or the thermostat settings used after the retrofits could be different to those used before – in this case there could be either an increase or a decrease in the usual thermostat settings. These changes in user behaviour have implications for the time that the heater operates and/or the temperature difference during the times the heater operates, both of which can affect the energy consumption of the heater.

For House WI12 the power meter on the gas ducted heater seems to have been installed incorrectly and no useful data on heater electricity consumption was obtained.

The meters were installed in early June, but logistical delays meant that the retrofits were not undertaken until August and the meters were left in place for longer than was intended. As the power meters had a data storage capacity of only 3 months, this lead to the first month of data being overwritten.
The analysis methodology used was based on advice provided by Energy Efficient Strategies (EES)\(^4\) and sought to estimate the average power consumption of the heater during times of steady state operation, when the heater was cycling on and off. The approach was to manually isolate sections of data when the heater was cycling on and off in a relatively uniform manner, and the internal and external temperature profiles indicated that the heater was displaying steady state operation\(^5\). In this case the temperature difference profile was fairly flat and tended to oscillate around a certain value. These packets of data were analysed to calculate the average electrical power consumption of the heater and the average temperature difference during this time, the data points plotted on a scatter diagram, and a linear regression analysis (with intercept set to zero) used to calculate the slope of the line of best fit for the data sets before and after the retrofit was undertaken. A comparison of the slope of the two lines was then used to estimate the technical energy saving achieved. A lower slope after the retrofits indicates that an energy saving has been achieved, as the heater power consumption is lower for the same temperature difference.

This approach seems to work best when the heating is operating relatively long periods each day at a constant thermostat setting and displays fairly uniform cycling behaviour. It is also necessary to have enough data points for both the pre- and post-retrofit periods to allow a useful comparison to be made. In some cases heating is only operated in short bursts so that the heater either does not display any cycling behaviour or only cycles for a short period—generally a period of cycling of at least 2 hours is necessary to obtain a useful data point. In some cases the heaters monitored showed little or no cycling behaviour on some (or in some cases many) days, meaning that few useful data points could be obtained.

An example of the type of graph obtained is shown in Figure 12, and the graphs for all houses are provided in Appendix A3. In this example the estimated energy saving resulting from the cavity wall insulation retrofit is 19.8\(^%\)\(^5\).

As noted previously we are using the electricity consumption of the gas ducted heater as a proxy for the gas consumption of the heater, so in Figure 12 the average heater electrical power consumption over the heating period (measured in Watts) is a proxy for the average gas consumption rate of the heater over the heating period (measured in MJ/hr). This gas consumption rate is, in turn, directly related to the rate of heat output of the heater.

When operating under steady state conditions, the average rate of heat output from the heater should equal the average rate of heat loss from the house. As the temperature difference between inside and outside the house increases, the rate of heat loss from the house increases and the heater needs to provide more heat energy to achieve the same temperature setting, increasing the rate of energy consumption (or power consumption) of the heater over the heating period. Similarly, if the temperature difference decreases the rate of heat loss decreases, decreasing the rate of energy consumption (or power consumption) of the heater over the heating period. When the temperature difference is zero, the heat losses will be zero, and therefore no heat input is required from the heater. As is evident from Figure 12, a given temperature difference does not always correspond to the same average power consumption—this is likely to be due mainly to different wind and rain conditions\(^5\) on different days and also to changes in user behaviour (e.g., having some windows or doors open, closing off some heating vents, changing heater settings) on different days.

![FIGURE 12: SCATTER DIAGRAMS FOR HOUSE WI2](image)

Installing cavity wall insulation into uninsulated walls makes the building shell of the houses more energy efficient by reducing the rate heat loss from the houses when the heating is operating\(^5\)\(^2\). For given climatic conditions and a given temperature difference this should reduce the rate of heat output required from the heater. The slope of the lines of best fit on the scatter diagrams is equal to the average heater power consumption for a 1ºC temperature difference, and should therefore be lower following the cavity wall insulation retrofit. Thus, the slope of the lines of best fit before and after the retrofits can be used to estimate the technical energy saving achieved.

It is important to note that the methodology used will estimate the energy saving when the heater is operating. In some cases the installation of the cavity wall insulation may mean that it is no longer necessary to operate the heating during certain times of the day or night\(^5\)\(^3\). For example, on sunny winter days when the sun is shining through windows the wall insulation should lead to higher internal temperatures, meaning that it might be possible to delay switching on the heating in the evening. Also, for those houses which normally operate their heating overnight\(^5\)\(^1\), better heat retention overnight might also mean that it is no longer necessary to operate the heating overnight or that there is a longer delay before the heater resumes operating in the early hours of the morning. This may mean that the “technical” energy saving underestimates the heating energy savings which were achieved.

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\(^{48}\) EES were provided with data files for a number of houses which participated in draught sealing, wall insulation and ductwork upgrade retrofit trials and asked to provide advice on the best metric to use to derive the technical savings and the methodology to use to derive this metric. The results presented in this report were calculated by Sustainability Victoria.

\(^{49}\) In Figure 9 this corresponds to the period of operation between 19:20 and 22:00.

\(^{50}\) The estimated saving is \(s = \frac{1}{1} - \frac{17.075}{17.075} \times 100\% = 19.8\%\)

\(^{51}\) The wind speed can impact on the rate of heat loss from a house. The higher the wind speed the higher the general heat loss from building surfaces. Also, higher wind speeds will increase the pressure differential across the building and increase the air leakage rate of the houses. We did not collect any data on wind speed or pressure differential as part of the Retrofit Trial. In the case of external walls, factors such as rain and the amount of daily sunshine will also impact on the rate of heat loss from the house.

\(^{52}\) It will also reduce the rate of heat entry though walls during the summer months when it is warmer outside than inside.

\(^{53}\) The occupants of house WI13 noted that they no longer needed to operate an oil filled column heater in a bedroom overnight following the installation of the cavity wall insulation. The load profile data for house WI1 (Appendix A3) shows that the heater was no longer operated overnight following the retrofit. Similarly, the load profile data for houses W55, W6, W18, W11 and W15 all show significantly less heater use during the night time hours after the retrofits.

\(^{54}\) It is quite common for a night setback to be used, where the thermostat setting is reduced from say 20 to 21ºC during the evening to 14 to 15ºC during the night. In this case the heater will stop operating and stay off until the internal temperatures drop down to the lower setting, and the heater will come back on during the early hours of the morning.
The result of applying this methodology to all houses is provided in Table 6. This shows the estimated average annual gas energy use for heating prior to the retrofits, the estimated "technical" heating energy saving, the estimated annual gas and electricity savings and resulting annual energy bill saving55, retrofit cost and payback.

The estimates for houses WI1, WI10 and WI11 have produced a negative result, suggesting increased heater energy use after the retrofits for any given temperature difference. Given that the thermal imaging undertaken for these houses indicates that reasonable insulation coverage had been achieved, increased energy use is highly unlikely and these anomalous results may be explained by a number of factors:

› For house WI1 the monitoring results presented in Appendix A3 suggest that a significant energy saving has in fact been achieved. The daily electricity use of the heater was significantly lower after the retrofit was undertaken, even when the higher outside temperatures during this time are taken into consideration. The graph of the average daily load profile of the heater shows that it was no longer run overnight and was also used much less during the morning and into the late afternoon after the retrofit – the heater is now mainly being used in the evening. This means that after the retrofit internal temperatures were lower overnight and until the heater switched on in the evening and this may partly account for the higher energy use when the heater is operating as some heat will be absorbed by the house’s thermal mass when it is first switched on. Also, for this house only a few useful data points were obtained before and after the retrofit, and this could reduce the accuracy of the estimate;

› For house WI10 the householder comments (Appendix A2) suggest that the insulation did in fact have a reasonable impact ("Insulation made a big difference"), with the house heating more quickly, holding its temperature better and a reduced operating time for the gas ducted heater. This house also used an air conditioner to supplement the gas heating, and in the post-retrofit survey the householder notes that they “rarely had to use the air conditioner to boost the temperature”. This may explain the anomalous result, as only the operation of the gas ducted heater was monitored. If both the operation of the gas ducted heater and the air conditioner were monitored we may have identified an energy saving for the overall heating energy use;

› For house WI11 an 18 day gap in metering coverage after the retrofits had been undertaken meant that data was collected for only a fairly small number of days, and most of these were relatively warm days towards the end of the monitoring period. This meant that the heater was operating for only a short period each day, reducing the quality of the data collected after the retrofit.

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55 The bill saving is based on a natural gas tariff of 1.75 c/MJ and an electricity tariff of 28 c/kWh.

### Table 6: Estimated Technical Savings for the Cavity Wall Insulation Retrofit Trial Houses

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1*</td>
<td>45,268</td>
<td>-7.2%</td>
<td>-3,257</td>
<td>-25.0</td>
<td>-$64.0</td>
<td>$3,704</td>
<td>-57.9</td>
</tr>
<tr>
<td>WI2</td>
<td>63,897</td>
<td>19.8%</td>
<td>12,626</td>
<td>69.9</td>
<td>$240.5</td>
<td>$5,135</td>
<td>21.4</td>
</tr>
<tr>
<td>WI3</td>
<td>35,383</td>
<td>24.9%</td>
<td>8,805</td>
<td>64.8</td>
<td>$172.2</td>
<td>$4,565</td>
<td>26.5</td>
</tr>
<tr>
<td>WI4</td>
<td>37,702</td>
<td>21.1%</td>
<td>7,937</td>
<td>65.7</td>
<td>$157.3</td>
<td>$4,199</td>
<td>26.7</td>
</tr>
<tr>
<td>WI5</td>
<td>52,821</td>
<td>26.8%</td>
<td>14,136</td>
<td>63.6</td>
<td>$265.2</td>
<td>$3,630</td>
<td>13.7</td>
</tr>
<tr>
<td>WI6</td>
<td>41,194</td>
<td>13.1%</td>
<td>5,398</td>
<td>62.2</td>
<td>$111.9</td>
<td>$4,250</td>
<td>38.0</td>
</tr>
<tr>
<td>WI7</td>
<td>25,080</td>
<td>11.3%</td>
<td>2,837</td>
<td>41.0</td>
<td>$61.1</td>
<td>$3,222</td>
<td>52.7</td>
</tr>
<tr>
<td>WI8</td>
<td>59,775</td>
<td>12.1%</td>
<td>7,243</td>
<td>71.9</td>
<td>$146.9</td>
<td>$4,809</td>
<td>32.7</td>
</tr>
<tr>
<td>WI9</td>
<td>65,171</td>
<td>15.0%</td>
<td>9,765</td>
<td>115.9</td>
<td>$203.3</td>
<td>$3,034</td>
<td>14.9</td>
</tr>
<tr>
<td>WI10*</td>
<td>30,945</td>
<td>-13.8%</td>
<td>-4,260</td>
<td>-15.8</td>
<td>-$79.0</td>
<td>$3,885</td>
<td>-49.2</td>
</tr>
<tr>
<td>WI11*</td>
<td>43,064</td>
<td>-34.1%</td>
<td>-14,673</td>
<td>-91.1</td>
<td>-$282.3</td>
<td>$3,032</td>
<td>-10.7</td>
</tr>
<tr>
<td>WI13</td>
<td>66,576</td>
<td>3.8%</td>
<td>2,536</td>
<td>14.1</td>
<td>$48.3</td>
<td>$5,792</td>
<td>119.9</td>
</tr>
<tr>
<td>WI14</td>
<td>38,966</td>
<td>16.6%</td>
<td>6,460</td>
<td>41.6</td>
<td>$124.7</td>
<td>$3,621</td>
<td>29.0</td>
</tr>
<tr>
<td>WI15</td>
<td>54,781</td>
<td>11.4%</td>
<td>6,224</td>
<td>71.2</td>
<td>$128.9</td>
<td>$6,527</td>
<td>50.6</td>
</tr>
<tr>
<td>Av. – All</td>
<td>47,187</td>
<td>9.4%</td>
<td>4,412</td>
<td>39.3</td>
<td>$88.2</td>
<td>$4,245</td>
<td>48.1</td>
</tr>
<tr>
<td>Av. – Ex WI1, 10 &amp; 11</td>
<td>49,213</td>
<td>15.5%</td>
<td>7,633</td>
<td>62.0</td>
<td>$150.9</td>
<td>$4,437</td>
<td>29.4</td>
</tr>
</tbody>
</table>

The result of applying this methodology to all houses is provided in Table 6. This shows the estimated average annual gas energy use for heating prior to the retrofits, the estimated "technical" heating energy saving, the estimated annual gas and electricity savings and resulting annual energy bill saving55, retrofit cost and payback.

The estimates for houses WI1, WI10 and WI11 have produced a negative result, suggesting increased heater energy use after the retrofits for any given temperature difference. Given that the thermal imaging undertaken for these houses indicates that reasonable insulation coverage had been achieved, increased energy use is highly unlikely and these anomalous results may be explained by a number of factors:
The estimated technical energy saving for house WI13 (3.8%) is also somewhat lower than expected. This household also noted improvements (e.g. better heat retention) after the insulation had been installed, and found that they no longer had to use an oil filled heater in one bedroom after the retrofit. The house had its insulation installed in two stages, the first on 25 July and the second on 30 August, and very little usable data was available for the period after the walls had been fully insulated due to warmer weather in the latter part of the monitoring period. This may explain the relatively low energy saving estimate.

Excluding the data from houses W1, WI10 and WI11, we estimate that the cavity wall insulation has achieved an average technical energy saving of at least 15.5%, resulting in an average annual gas saving of 7,633 MJ per year, an electricity saving of 66.8 kWh per year, and an average heating bill saving of $150.9 per year. The average installation cost for these houses was $4,437, giving an average payback on this investment of 29.4 years on the heating energy saving. This result is reasonably consistent with the results of the modelling in the OGA study houses – in this case we found an average 13.1% heating energy saving, and an average energy bill saving of $157 per year in houses with gas ducted heating resulting in a payback of 28 years, although for the OGA study the cooling savings were also included in the calculation.

The majority (67%) of the Retrofit Trial houses had an estimated technical energy saving in the range of 11% to 27%, and four of these (27%) had an estimated saving in the range of 19% to 27%. It is clear that for some houses the addition of cavity wall insulation can lead to a very significant reduction in heating energy consumption.

The technical saving estimate is lower than the modelled estimate presented in Table 4 (19.3%). This may be because complete insulation coverage was not achieved in the trial, because our methodology may be underestimating the saving, or a combination of both factors. In some houses (WI10 and WI13) it is clear that there were some additional savings from supplementary electrical heating, but this was not captured as part of our monitoring. In other houses it is clear that heating was no longer used, or usage significantly reduced, overnight and during the middle of the day, but this additional energy saving will not be captured by our estimation methodology.

### Impact on usage of heating

As part of the study we investigated whether the cavity wall insulation retrofits had an impact on the way in which the households used their heating. In particular, we investigated whether or not there was a rebound effect associated with the wall insulation retrofits. This is sometimes also called the take-back effect. Some economists argue that energy efficiency measures result in lower energy savings than expected (anywhere between 10 to 50% less), because consumers choose to take some of the energy savings as a higher level of energy service. For example the Productivity Commission’s report on its inquiry into energy efficiency [PC 2005] 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". In the context of the cavity wall insulation retrofits the presence of rebound would mean that householders chose to operate their heating for longer hours and/or operate their heating at a higher thermostat setting after the retrofits.

We have used data collected on the average daily internal temperature profile of the houses to gain an understanding of how people operated their heating before and after the retrofits. The combined average temperature profile of all 15 houses which participated in the Trial for those days on which the heating was operated is provided in Figure 13 (a), and the average daily electrical load profile of the heaters in these houses is shown in Figure 13 (b) to give an idea of the main times during which the heating was operating. In general, the average internal temperatures in the heated areas of the houses were higher during most times of the day – especially during the late evening and early morning periods when the heating was much less likely to be operating – and during the middle parts of the day, when the heating was also less likely to be operating. The temperature profiles are a much closer match during the main operating times of the heater in the morning and evening. The average increase in internal temperature in the heated areas across the day was 0.53°C. If all of this increase was all interpreted as being due to the impact of a rebound effect, this would correspond to a reduction in the expected saving of around 7.4% (based on an average temperature difference when heating of 7.11°C before the retrofit).

However, it seems likely that not all of the observed increase in average internal temperatures following the retrofits is due to householders increasing the thermostat setting of the heating. The higher temperatures which are observed in the houses during the late evening and early morning reflect the lower rate of heat loss from the houses when the heating is no longer operating, keeping the internal temperatures higher than they would otherwise be. This is an expected impact of insulating the walls and is well illustrated by the data from houses W13, W14, W15, W17, W18 and W114 (see Appendix A3). Similarly, the higher internal temperatures which are evident during the initial stages of the morning heating peak (approx. 5:30 to 9:00 am) largely reflect the higher initial temperature in the pre-retrofit houses prior to the heating being switched on and possibly also better heat retention during the initial warm up. This effect is well illustrated by houses W13, W15 and W114 (Appendix A3). The higher temperatures which were observed during the daylight hours (10:00 to 16:30) are also likely to reflect the better heat retention of the houses once the wall insulation has been installed, and may also reflect the insulated houses’ ability to retain heat which enters the houses through the windows during the day when it is warmer outside than inside. This effect is well illustrated by houses W13, W14, W17 and W115 (Appendix A3).
Practical issues

As part of the Cavity Wall Insulation Retrofit Trials, MEFL documented a range of issues relating to the installation of the cavity wall insulation. Below we have summarised the issues documented in the project reports [MEFL 2012, MEFL 2013].

Narrow wall cavities and obstructions in the cavity

The standard approach to installing granulated rockwool cavity wall insulation in a framed wall via lifting roof tiles (see Chapter 2) requires that the wall cavity is wide enough to drop the lay-flat hose to the bottom of the cavity. A minimum cavity width of around 40 mm is required for the hose to deliver the granulated rockwool effectively.

In this Trial it was found that it was not possible to insulate some cavity-brick walls of houses which expressed an interest in the study as the cavity was not wide enough or was blocked by obstructions. Even with timber framed walls the cavity needs to be relatively free of obstructions, such as pieces of timber or extra wide noggins that may block access to the cavity further down the wall. [MEFL 2012]

House WI2 had a tiled roof, but the wall cavity was too narrow to allow the hose to be dropped down the cavity. This meant that all walls needed to be drilled in order to install the insulation, instead of just drilling under windows. Two lines of holes were drilled, one line approximately half-way down the wall and the second line near the top of the wall, as shown in Figure 14. One of the insulation installers reported that it was not as easy to install the insulation in brick-veneer walls in Victoria, as the cavities tended to be narrower and there were more obstructions than in similar walls in the ACT. They felt it would be simpler and more reliable to drill through the walls in all brick-veneer houses rather dropping the lay-flat hose down the wall cavity. [MEFL 2012]

When obstructions are found in the wall cavity the installers need to spend time trying to find ways to pass the hose around these obstructions. Even where a way around the obstruction can be found the hose is constricted and it can take longer to install the insulation as it is harder to pump in. Where it is not possible to find a way around the obstruction the installer needs to drill through these sections of wall in order to install the insulation. House WI4 had quite a few obstructions in the wall cavity making it difficult to install the insulation by lifting roof tiles. In some parts of the house the installer was only able to fill the top of the half of the wall cavity by dropping the lay-flat hose from above and had to drill through lower sections of the wall in order to fill below these obstructions. Figure 15 shows an example of such a section of wall at this house. It can be seen (circled in red) that there are only four holes that have been drilled and patched in the lower section of the wall. [MEFL 2012]
Sections of walls which are difficult to insulate

The insulation installers reported that at some houses there were certain sections of walls that could not be filled with insulation for a range of reasons or where alternative approaches needed to be found [MEFL 2012]:

- Water tanks against walls: These can prevent the access required to install the insulation. This issue was encountered at Houses WI1 and WI2. In the case of WI1 the water tank was up against a section of wall with a flat metal roof. Installing the insulation would have required drilling through the wall, but the position of the rain water tank prevented this. In the case of WI3 the timber frame was wrapped in foil. Where the water tank was located it was possible to insulate the section of wall between wall studs down to the middle nogging by lifting tiles, but it was not possible to access the lower section of the wall.

- Pipes and cables in walls: At house WI7 the installer was not able to install insulation in a section of wall approximately half a metre wide because this section had a significant number of pipes and cables running through it. Electrical cables in the wall which run into the switchboard can also be an issue. One of the companies did not install insulation around the electrical switchboard area in order to make any future electrical modifications easier. The other company did install insulation in this area as long as it was approved by an electrician, as this allows greater insulation coverage and if electrical work needs to be undertaken in the future cabling can be fed-down through the insulation to the switchboard using electrical conduit.

- Wasp nests in walls: At house WI4 there was a section of wall where there were a number of paper wasps nests obstructing the wall cavity and this section of wall was not filled.

- Access problems caused by construction characteristics: In house WI8 there was a section of the flat metal roof where access to the wall cavity was blocked by an intersecting eave from the adjoining wall (see Figure 16). This section of wall was not insulated.

- Access problems caused by solar systems: A number of houses involved in the trials had PV panels and/or a solar hot water system. If either of these systems were installed over the second row of roof tiles this meant that the wall cavity could not be accessed from the roof. In these instances the wall underneath the PV panels or solar hot water system needed to be drilled or brick removed to allow for the wall insulation to be installed.

Other issues

In a number of cases the householders and/or insulation installers expressed concerns that the assessor did not undertake a proper assessment when initially inspecting the house, so the installer was not as well prepared for the installation work as they should be. For instance, issues such as the presence of PV panels or solar water heaters, a roof with a steep pitch, and narrow wall cavities may have not been correctly identified. This highlights the importance of good training and thorough pre-installation assessment processes. [MEFL 2012]

Wet weather can lead to delays in installing the insulation if the insulation is being installed via the roof. It is not possible for installation to proceed on wet days because firstly it is dangerous to work on the roof in such conditions, and secondly water will run into the wall cavity while the tiles are lifted.
4 Summary and Conclusions

Summary

Through the Cavity Wall Insulation Retrofit Trials Sustainability Victoria investigated the use of pump-in granulated rock wool cavity wall insulation to improve the energy efficiency of existing Victorian houses with uninsulated external walls. Key reasons to investigate this retrofit were that previous work undertaken by Sustainability Victoria [SV 2015] found that insulating existing wall cavities can significantly improve the thermal performance of houses, it has wide applicability across the existing Victorian housing stock, and it can result in significant energy and greenhouse savings. Insulating existing external walls also has the potential to significantly improve occupant comfort in both winter and summer months.

The results from the OGA study [SV 2015] suggest that if pump-in cavity wall insulation was applied to all pre-2005 Victorian houses with uninsulated walls, this would give total annual energy bill savings of around $200 Million per year, total greenhouse savings of 647 kT per year, reduce total residential gas consumption by around 8.4% and total residential electricity consumption by around 0.6%.

A total of 15 houses were recruited to participate in Sustainability Victoria’s Cavity Wall Retrofit Trial, which was run in two stages over the main winter heating period: 8 houses in 2012 and 7 houses in 2013. Thermal imaging surveys of the external walls were undertaken before and after the retrofits to assess the impact of the insulation in reducing heat losses from the homes during winter. In addition to this householder surveys, and metering of gas ducted heater electricity use and internal and external temperatures, were used to assess the qualitative and quantitative impacts of the cavity wall insulation retrofits.

The average cost of installing the cavity wall insulation in the 15 houses which participated in the Retrofit Trial was $4,286, quite close to the average estimated cost of $4,167 found in the OGA study. The householders experienced the cavity wall insulation retrofits as an increase in the thermal comfort of their houses and reduction in the difficulty of heating the houses. Many houses also reported that their house now retained heat better during the night and/or during the day when the heating was turned off, and some noted that they no longer had to use other heaters to supplement their gas ducted heating in some areas of their homes or could turn their thermostat setting down. While the installation of the cavity wall insulation has the potential to create some visual impacts – due to the need to drill through external or internal walls, or remove and replace bricks for installation in some sections of the wall – in general the householders either did not notice any significant impact from this or were not concerned by the visual impact.

While a total of 15 houses participated in the retrofit trial a full set of metering data was available for only 14 of these houses, and our analysis of the energy saving impact of the retrofits was based on these 14 houses.

By reducing heat losses from the houses both when the heating was operating and when the heating was switched off the cavity wall insulation retrofits were expected to lead to heating energy savings, and therefore reduced heating costs. Two approaches were used to estimate the energy savings which resulted from the draught sealing retrofits: modelling using the Victorian housing model; and, analysis of the energy and temperature data collected during the pre- and post-retrofit monitoring periods.

Data on house size, construction type and initial insulation status for the 14 houses was input into the Victorian housing model and used to estimate the percentage energy saving for a centrally heated home resulting from the addition of wall insulation (see Table 4).

This data was combined with estimated annual gas heating energy use to estimate the energy savings which were expected to result from insulating the wall cavities. This modelling suggested an average annual heating gas energy saving of 9,130 MJ per year (or 19.3% of heating energy use) and annual electricity savings of $50.7/kWh per year for an overall average energy bill saving of $174 per year. Based on an average installation cost of $4,245 for these 14 houses this would give an average payback of 27.2 years.

Metering data collected during the pre- and post-retrofit period for all 14 houses was analysed to obtain plots of the average heater electrical power consumption against the average temperature difference between inside and outside the house during those times when the heater was operating under steady state conditions. Comparison of the lines of best fit for this data enabled an estimate of the heating energy saving to be obtained. Estimates for three of the houses were anomalous and these were eliminated from the analysis. This suggested an average heating energy saving of at least 15.5% was achieved across the houses, giving average annual gas heating energy savings of 7,633 MJ per year, and annual average electricity savings of 62.0 kWh per year for an average annual energy bill saving of $150.9 per year. The average installation cost for these 11 houses was $4,437 giving an average payback of 29.4 years. Four of the houses (27%) had an estimated energy saving in the range of 19 to 27%.

The overall energy savings may well have been greater than estimated by this second approach because the estimated saving for one house (W113 – 3.8%) was quite low, most probably because this house was not fully insulated until towards the end of the trial. Also, this methodology estimates the heating energy savings of only the main gas heating when the heating was operating. A number of the participating houses noted that the installation of the cavity wall insulation allowed them to reduce or eliminate the use of supplementary electric heating but the energy use of these heating devices was not monitored. Also, the householder surveys and monitoring of internal temperatures suggested that internal temperatures were generally higher when the heating was no longer operating, reducing or eliminating heating use overnight and during the day, and also possibly pushing back the time that the heater was turned on in the evening. This is likely to have resulted in some additional energy savings which were not recognised by our analysis methodology.

It is also relevant to note that in this study we only estimated only the heating energy saving resulting from the cavity wall insulation retrofit. In those houses with supplementary cooling, such as refrigerative air conditioners and ducted evaporative cooling, the installation of the wall insulation should also improve summer comfort and reduce summer cooling energy use, resulting in additional energy and monetary savings.

The energy bill savings are based on the energy tariffs that applied at the time the analysis was undertaken. It seems likely that energy costs will continue to rise, especially for gas in the short to medium term56. This means that the energy bill savings derived from this retrofit will increase over coming years and this, in turn, will improve the cost effectiveness of this retrofit.

56 Residential electricity prices in Melbourne increased by 88% in real terms over the period 2006/07 to 2013/14 and residential gas prices increased by 45% in real terms over the same period. Electricity prices are expected to remain relatively flat in the short term while gas prices are expected to continue to increase. State of the Energy Markets 2014, Australian Energy Regulator 2014. The original source for this data is ABS Consumer price index, cat. No 6401.0.
Further, the savings documented in the report are based only on the energy bill savings which result directly from the installation of the cavity wall insulation. We have not included any value associated with the greenhouse gas savings resulting from the upgrade, or comfort or health improvements which could result from the upgrade. Currently, there is not widespread agreement on how to include the value of greenhouse abatement in such analysis, and as yet there is no evidence base which would allow the comfort and health benefits for households in Victoria to be included. While some of these benefits might accrue directly to the households, they will be shared with governments and society more broadly.

As part of the study we collected internal temperature data to help assess the impact of the cavity wall insulation retrofits on household behaviour. Some economists argue that a rebound effect exists, which in the context of cavity wall insulation retrofits would mean that householders increased the operating time of the heater and/or increased thermostat settings after the retrofits, thereby reducing the energy savings achieved as some of the energy saving was taken up as increased thermal comfort. To explore this issue, the average daily internal temperature profiles of the houses on days on which the heating was operating were compared before and after the retrofit. In general the internal temperatures of the homes were higher after the retrofit, especially during the night time hours and during the middle parts of the day when the heating was much less likely to be operating. Internal temperatures were much closer during the main times the heaters were operating.

If all of this temperature difference was attributed to a rebound effect this suggests a rebound of around 7%. However, it seems likely that the increased internal temperatures simply reflect the better heat retention of the houses once they are insulated, and may also reflect the ability of the insulated houses to capture and retain heat which enters the house during the day. While some change in behaviour may have taken place after the cavity wall insulation was installed we believe that much of the observed temperature difference can be explained by the better heat retention when the heater was not operating.

Householder surveys identified a number of issues which need to be addressed when cavity wall insulation is installed:

- In some cases the mortar which was used to patch the drill holes or to replace bricks which were removed was not a good match to the existing mortar. In most cases this was expected to improve over time as the new mortar cured and weathered. It is important that householders have a good understanding of what to expect during the retrofit process and, where possible, to make sure the replacement mortar is a close match.
- Drilling holes and/or removing bricks can create a certain amount of dust and rubble and in some cases householders felt that this was not adequately cleaned up after the installation was completed.

Feedback from MEFL and the insulation installers identified a number of issues that are relevant to the wider implementation of cavity wall insulation in Victorian houses. The cavities in cavity brick walls seemed to be narrow in Victorian houses compared to the ACT, and this meant that not all houses with this type of wall construction could be included in the trial. In general where the cavity is less than 40 mm wide and/or where the cavity is obstructed it is not possible to insulate the houses.

Installers reported that the cavities in some brick-veneer houses were too narrow or were blocked with obstructions such as pieces of timber or extra wide noggings, which can obstruct access to the lower part of the cavity when the installation is via lifting tiles (or metal sheeting) above the external wall cavity and dropping the hose to the bottom of the cavity. In this case the insulation needs to be installed by drilling through the external brickwork or removing some bricks – this is the approach which is commonly used in the UK for insulating cavity brick walls, and in Australia for insulating under windows.

It was also found that that it is difficult or impossible to insulate some wall sections. Water tanks up against external walls, a concentration of pipes or cabling in walls, wasps nests, some construction characteristics, or solar or PV systems installed directly above the wall cavity can mean that it is impossible to insulate the wall section or that installation needs to be via through the external wall.

In some cases the initial pre-installation assessment of the houses had not identified issues which needed to be taken into account when the installation commenced. This highlights the importance of good training and thorough pre-installation inspection processes.

Conclusions

The Cavity Wall Insulation Retrofit Trial has shown that insulating existing external wall cavities is an effective strategy to reduce energy consumption in existing Victorian houses. It led to an average estimated energy saving of at least 15.5% of heating energy use for an average commercial cost of around $4,440. Estimated annual energy bill savings were at least $150.9 per year, giving a payback on the investment in cavity wall insulation of around 29 years. The insulation has improved occupant comfort in winter, reduced the difficulty of heating the houses and led to greater heat retention which, in turn, has increased internal temperatures overnight and during the day when the heater was generally not operating.

Savings are likely to be larger than estimated from this trial as our analysis methodology has not allowed us to capture all of the heating energy saving, and houses with supplementary cooling would also get additional cooling energy savings during summer.

The cavity wall insulation industry in Australia is currently quite small, with only around 4 or 5 companies operating and only able to service a fairly low level of demand. Average insulation costs in Australia are considerably higher than in the UK where government incentives have led to over 11 million homes being insulated in this way. The high cost in Australia is likely to be due partly to the level of demand and competition, but is also probably due to the higher width of the wall cavities (brick veneer and weatherboard vs cavity brick) and possibly also due to larger house sizes. A significant increase in demand for cavity wall insulation should result in a reduction in the average cost of installing the insulation, which would improve the cost-effectiveness of this retrofit.

Energy prices, particularly gas, seem likely to continue to increase in coming years. Higher energy prices, combined with a lower installation cost could significantly improve the economics of retrofitting cavity wall insulation.

The cavity wall insulation industry in the UK is supported by formal accreditation of insulation products, installation processes and of the insulation installers, with training required for both the pre-installation assessors and installation technicians. The industry is also supported by a levy on each installation, and this is used to provide a 25 year guarantee of the quality of the installation work. The UK industry provides a useful model which could be followed in Australia to help facilitate the expansion of this industry.
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A1: Visual Impact of the Cavity Wall Insulation Retrofits

In many of the houses photographs were taken after the retrofits to show the visual impact of installing the cavity wall insulation. In some houses this required drilling through the mortar between bricks and patching the drill holes afterwards, and in other houses this involved removing some bricks and replacing them afterwards. Below we have provided a selection of these photographs for those houses where they are available.

**House WI1**

- Drill holes through wall
- Drill hole under window

**House WI2**

- Drill holes under windows and in wall
- Close up of drill hole

**House WI3**

- Drill holes under window
- Bricks replaced under window
House WI4

Drill holes in wall

Close up of drill hole

House WI5

Section of wall following retrofit

Replaced brick

House WI6

Section of wall following retrofit

Drill holes under window
House WI7

Section of wall after retrofit

Close up of drill hole

House WI8

Section of retrofitted external wall

Drill holes through internal plasterboard

House WI9

No photographs available

House WI10

Brick replaced under window

Brick replaced in wall
House WI11
No photographs available

House WI12
No photographs available.

House WI13
No photographs available

House WI14
Drill holes in external wall

House WI15
No photographs available
A2: Detailed householder survey results for each house

Surveys were conducted before and after the cavity wall insulation retrofits were undertaken to identify any changes in householder perceptions of the level of thermal comfort in their houses and the difficulty of heating the houses. Householders were also asked a number of questions towards the end of the monitoring period to obtain a deeper insight into their experience of the retrofits. The detailed results for each household which participated in the study are provided below.

<table>
<thead>
<tr>
<th>Householder Rating (1 to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>House No</td>
</tr>
<tr>
<td>WI1</td>
</tr>
<tr>
<td>WI2</td>
</tr>
<tr>
<td>WI3</td>
</tr>
<tr>
<td>WI4</td>
</tr>
<tr>
<td>WI5</td>
</tr>
<tr>
<td>WI6</td>
</tr>
<tr>
<td>WI7</td>
</tr>
<tr>
<td>WI8</td>
</tr>
</tbody>
</table>

Table A1: Householder responses to thermal comfort question, before and after retrofit

Thermal comfort

Householders were asked to rate the comfort of their home on a scale of 1 (extremely uncomfortable) to 5 (extremely comfortable) during the winter months and also invited to comment on the comfort level. The detailed results are provided in Table A1.
### Householder Rating (1 to 5)

<table>
<thead>
<tr>
<th>House No</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI9</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td><strong>Before</strong> – It could be comfortable if turn the heat up, but have a massive bill.&lt;br&gt;<strong>After</strong> – It feels like the heater is working less than previously.</td>
</tr>
<tr>
<td>WI10</td>
<td>3.5</td>
<td>3.5</td>
<td>0</td>
<td><strong>Before</strong> – Heats up and cools down too quickly.&lt;br&gt;<strong>After</strong> – Insulation made a big difference but we still need to do some work on draft proofing and glazing to get better control.</td>
</tr>
<tr>
<td>WI11</td>
<td>4</td>
<td>3</td>
<td>-1</td>
<td><strong>Before</strong> – In general great.&lt;br&gt;<strong>After</strong> – Comfortable. The weather has been warmer so we haven’t had to use the heater.</td>
</tr>
<tr>
<td>WI12</td>
<td>2.5</td>
<td>3</td>
<td>0.5</td>
<td><strong>Before</strong> – It’s tough to get the right temperature. The temperature fluctuates too much.&lt;br&gt;<strong>After</strong> – Finding that it is surprisingly draughty - gets cold very quickly.</td>
</tr>
<tr>
<td>WI13</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td><strong>Before</strong> – Notice that it cools very quickly. Heat the [bedroom at the end of the house] separately at night with an oil filled heater.&lt;br&gt;<strong>After</strong> – We still heat the house to 20ºC according to the thermostat. The house seems to retain heat better and requires less heating. The oil filled heater has not been required since the retrofit.</td>
</tr>
<tr>
<td>WI14</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td><strong>Before</strong> – Don’t like ducted heating.&lt;br&gt;<strong>After</strong> – Heating seems to be coming on less. [The lounge] still has open grilles allowing outside air in and warmer air out.</td>
</tr>
<tr>
<td>WI15</td>
<td>4</td>
<td>3</td>
<td>-1</td>
<td><strong>After</strong> – Hard to tell as it has been warmer. House is quieter. Passageway is warmer than the rest of the house. Affects the rest of the house as this is where to thermostat is.</td>
</tr>
</tbody>
</table>

| Average  | 3.3    | 3.9   | 0.6    |

Following the retrofits the householders were asked to comment on whether or not there had been any changes in the comfort of their houses since the retrofits. The responses are provided in Table A2.
### Table A2: Householder Perceptions of Changes in Thermal Comfort Since the Retrofit

<table>
<thead>
<tr>
<th>House No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>Comfort has improved in the house. It seems to hold heat better overnight. The heater does not seem to be running as much in the evening.</td>
</tr>
<tr>
<td>WI2</td>
<td>Have noticed a definite improvement. The heater seems to be not working as much, and the heat is better distributed.</td>
</tr>
<tr>
<td>WI3</td>
<td>It is not as cold in the morning and the children’s bedroom (on the southern side) seems to heat better.</td>
</tr>
<tr>
<td>WI4</td>
<td>The house does not get majorly cold any more, and the temperature seems to be more consistent. The house does not get as cold when it is left unattended and it does not cool down as much overnight when the heater is turned off.</td>
</tr>
<tr>
<td>WI5</td>
<td>A definite improvement in the house since the retrofit. The house seems to hold the heat longer.</td>
</tr>
<tr>
<td>WI6</td>
<td>The house is not as cold in the mornings. The thermostat has been reduced to 18°C since the retrofit. Definite changes have been noticed.</td>
</tr>
<tr>
<td>WI7</td>
<td>The difference is noticeable in the morning. It is not as cold as the house seems to heat its heat better. The house is definitely more comfortable.</td>
</tr>
<tr>
<td>WI8</td>
<td>The peripheral rooms are warmer now and easier to heat. The house does not get as cold overnight. The heater seems to not need to run as much throughout the night (they set the heater at 15°C during the night). It does not feel so cold sitting next to the wall in the lounge since the retrofit. Wall seems not to be so cold.</td>
</tr>
<tr>
<td>WI11</td>
<td>Overnight the house loses less heat. Previously it was dropping as low as 12°C but now it averages 16°C.</td>
</tr>
<tr>
<td>WI13</td>
<td>The house generally seems to retain heat better and seems to require less heating. Better heat retention in the living room, play room and bedroom.</td>
</tr>
<tr>
<td>WI14</td>
<td>Unable to say as house still needs heating, just unsure how much. The house doesn’t seem to cool down as much at night when the heating is switched off.</td>
</tr>
<tr>
<td>WI15</td>
<td>Hard to tell as the weather has been unseasonably warm.</td>
</tr>
</tbody>
</table>
Difficulty heating

Householders were asked to rate the difficulty of heating their home on a scale of 1 (small difficulty) to 5 (extremely difficult) during the winter months, and also invited to comment on the difficulty of heating, before and after the retrofits had been undertaken. The detailed results are provided in Table A3.

### TABLE A3: HOUSEHOLDER RESPONSES TO DIFFICULTY OF HEATING QUESTION, BEFORE AND AFTER RETROFIT

<table>
<thead>
<tr>
<th>Householder Rating (1 to 5)</th>
<th>House No</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WI1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td><strong>Before</strong> – Central heater can deliver the required heat to the house quite easily. <strong>After</strong> – No change.</td>
</tr>
<tr>
<td></td>
<td>WI2</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td><strong>Before</strong> – The heater can deliver the required amount of heat but the main problem is the distribution of the heat. It is harder to regulate and control the temperature in [the kitchen]. <strong>After</strong> – The distribution of the heat is better since the retrofit. It is easier to heat the kitchen.</td>
</tr>
<tr>
<td></td>
<td>WI3</td>
<td>2</td>
<td>1.75</td>
<td>-0.25</td>
<td><strong>Before</strong> – The house is easy to heat with the central heater. The bedroom on the south side is harder to heat than the rest of the house. <strong>After</strong> – Very slight improvement in the ease of heating the house. The bedroom on the south side is heating up quicker and holds its heat better.</td>
</tr>
<tr>
<td></td>
<td>WI4</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td><strong>Before</strong> – It is generally not too difficult to heat this house. The only difficulty is in the peripheral areas of the house. [The lounge is] always harder to heat. Always harder to get the desired temperature [in the back bedroom]. <strong>After</strong> – The difficulty of heating has definitely dropped now. It wasn’t hard before but things are better now. Improvement noted [in the lounge and back bedroom].</td>
</tr>
<tr>
<td></td>
<td>WI5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td><strong>Before</strong> – The heater can easily deliver the heat required for the house. A bit harder to heat the north east corner of the lounge and the two bedrooms on the north side. <strong>After</strong> – Same as before. The north east corner of the lounge is easier to heat since the retrofit. Easier to heat the bedrooms.</td>
</tr>
<tr>
<td></td>
<td>WI6</td>
<td>2</td>
<td>1.5</td>
<td>-0.5</td>
<td><strong>Before</strong> – House heats up quite easily, not difficult. Harder to heat the home office and bedroom on the south side. <strong>After</strong> – The house heated up easily in the past so there has not been a huge change, but it seems to hold its heat for longer and not take quite as long in the morning to heat up. Easier to heat [the home office and bedroom on the south side] since the retrofit.</td>
</tr>
<tr>
<td></td>
<td>WI7</td>
<td>3.5</td>
<td>2</td>
<td>-1.5</td>
<td><strong>Before</strong> – The house heats up ok but it does not seem to hold its heat very well. <strong>After</strong> – The house is holding its heat much better since the retrofit.</td>
</tr>
<tr>
<td></td>
<td>WI8</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td><strong>Before</strong> – The house is easy to heat. The heater is powerful and can deliver the required load. <strong>After</strong> – No change to difficulty of heating.</td>
</tr>
<tr>
<td></td>
<td>WI9</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td><strong>Before</strong> – 10 minute response time. <strong>After</strong> – Reduced thermostat setting, using the heater less.</td>
</tr>
</tbody>
</table>
## Householder Rating (1 to 5)

<table>
<thead>
<tr>
<th>House No</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>Comments</th>
</tr>
</thead>
</table>
| WI10     | 2      | 2     | 0      | **Before** – Cools down really quickly.  
**After** – Heats quickly and temperature is maintained pretty well. Reduced ‘on’ periods for the gas system, lowered temperature, and rarely had to use the air conditioner to boost the temperature. |
| WI11     | 2      | 1     | -1     | **After** – No difficulties but haven’t used the heater much. |
| WI12     | 2      | 2     | 0      | |
| WI13     | 4      | 1     | -3     | **Before** – cools very quickly. Means we basically have to heat all of the time.  
**After** – House heating has been straightforward. The kitchen was previously hard to heat. Seems easier now. |
| WI14     | 4      | 1     | -3     | **Before** – Heat is lost very quickly.  
**After** – Will need next year’s winter bill to compare first. |
| WI15     | 2      | 2     | 0      | **After** – All appears normal. Hard to tell as the weather has been warmer during the period after the insulation was installed. |
| **Average** | 1.8 | 1.3 | -0.5 |
Issues

In the post-retrofit survey householders were asked if they had noticed any issues created by the installation of the cavity wall insulation, including the visual impact of the retrofit. The responses for those houses in which an issue was identified are provided in Table A4.

<table>
<thead>
<tr>
<th>House No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>No problems. The visual impact is quite minimal.</td>
</tr>
<tr>
<td>WI2</td>
<td>No, everything was all fine. The visual impact is not a big concern, but if the house was newer it might have been more of a concern.</td>
</tr>
<tr>
<td>WI3</td>
<td>Happy with the result and not really concerned about the visual impact where the drilling needed to take place. The removal of the bricks is better visually than the drilling into the wall. There was a lot of dust after the retrofit was completed that had to be hosed away.</td>
</tr>
<tr>
<td>WI4</td>
<td>It is not a major problem but the mortar could have been matched better in the drill holes. Also, it would have been nice if there was a more comprehensive clean at the end of the installation process.</td>
</tr>
<tr>
<td>WI5</td>
<td>Overall very happy with the retrofit. The visual impact is quite minimal and the bricks were replaced in a neat manner.</td>
</tr>
<tr>
<td>WI6</td>
<td>No, happy with the process and no problems. This visual impact is not a concern.</td>
</tr>
<tr>
<td>WI7</td>
<td>There was a crack in the brickwork near where the drilling was done, but not sure if this was already there or caused by the drilling.</td>
</tr>
<tr>
<td>WI8</td>
<td>No problems.</td>
</tr>
<tr>
<td>WI9</td>
<td>The new mortar doesn’t match the old colour but it should fade to match over time.</td>
</tr>
<tr>
<td>WI10</td>
<td>Installation process needs work. Gaps under the house were not filled and it took ages for the bricks to be replaced. Installers were also unsure how to deal with the solar panels restricting access to one side of the house. None of these were big problems, but it seemed strange that the holes were missed.</td>
</tr>
<tr>
<td>WI11</td>
<td>There were few problems, but a couple of appointments with the installers were not kept. Information regarding the fitting of the product was not given by the man who gave the quote.</td>
</tr>
<tr>
<td>WI12</td>
<td>There was an issue with the brick colour – mortar not matching. This has now been resolved.</td>
</tr>
<tr>
<td>WI13</td>
<td>The only problem was that one drill hole pierced the plaster. As it was partially behind the laundry sink we have ignored it. Scheduling was a little problematic. The installation hasn’t had any negative impact on the look of the house.</td>
</tr>
<tr>
<td>WI14</td>
<td>No aside from rendering and painting touch ups. There were a few missed sections and all ceiling vents are still open to the outside air. I felt those should have been blocked.</td>
</tr>
<tr>
<td>WI15</td>
<td>Drilling holes worked better than removing bricks.</td>
</tr>
</tbody>
</table>
A3: Monitoring results for each house

Below we provide a summary of the data collected from the metering equipment which was installed for each of the houses which participated in the Cavity Wall Insulation Retrofit Trial. In addition to some basic information about each of the houses – monitoring dates and retrofit dates – we provide the following information:

› Average daily heater electricity use and operating time, and average temperature difference when the heater is operating for the pre- and post-retrofit monitoring periods;

› A graph which shows the daily electricity consumption of the gas ducted heater (when the fan is operating) throughout the entire monitoring period, plotted against the average daily outside temperature. The daily electricity consumption before the retrofit is shown in blue and the daily electricity consumption after the retrofit is shown in green. On days of higher outside temperature less heating is required, and so the daily electricity consumption is generally lower on these days;

› A graph which shows the average daily internal and external temperature profiles of the houses before the retrofits. The profiles show how the temperatures vary throughout the day, based on the 10 minute sampling interval that was used. The average daily profile is the average of all of the individual daily profiles for those days on which the gas ducted heater was operating;

› A graph which shows the average daily internal and external temperature profiles of the houses after the retrofits for those days on which the heating was operating;

› A graph which compares the average daily internal temperature profiles of the houses before and after the retrofits were undertaken. This gives an indication of whether the householders have made any changes to the operation of their heating system after the retrofits were undertaken;

› A graph which compares the average daily profile of the temperature difference – the difference between the internal temperature and the outside temperature – before and after the retrofits were undertaken, on those days on which the heating was operated. This gives an indication of the heating task which is faced by the gas ducted heating system before and after the retrofit. The larger the temperature difference, the larger the ‘heating task’ and therefore the larger the energy consumption of the heater needs to be to achieve the observed internal temperatures;

› A graph which compares the average daily load profile of the gas ducted heater before and after the retrofits. This shows the way in which the electricity consumption of the gas ducted heater (measured in Watts) changes throughout the day, based on the 1 minute sampling interval that was used. To produce the average daily load profile the individual daily load profiles have been averaged for all days on which the gas ducted heater was operating;

› A scatter diagram which plots data points showing the average heater electrical power consumption (Watts) during times when the heater is operating under steady state conditions against the average temperature difference during these times, both before and after the retrofits. The slopes of the lines of best fit were used to estimate the technical energy saving achieved by the retrofit.
House WI1

Monitoring started: 14/7/12
Retrofit completed: 10/8/12
Monitoring ended: 10/9/12

Av. daily electricity consumption of heater fan –
Before (1.83 kWh/day), After (0.81 kWh/day)

Av. daily operating time of heater –
Before (17.14 hrs/day), After (7.04 hrs/day)

Av. temperature difference when heater operating –
Before (6.80°C), After (6.09°C)

W1 - Temperature Profile Before & After Retrofit

W1 - Relationship Between Heater Elec Power and Temp Difference

y = 15.16x
y = 16.182x
House WI2

Monitoring started: 14/7/12
Retrofit completed: 12/8/12
Monitoring ended: 17/9/12

Av. daily electricity consumption of heater fan –
Before (1.78 kWh/day), After (1.14 kWh/day)

Av. daily operating time of heater –
Before (8.72 hrs/day), After (6.78 hrs/day)

Av. temperature difference when heater operating –
Before (8.13ºC), After (8.09ºC)
House WI3

Monitoring started: 14/7/12
Retrofit completed: 20/8/12
Monitoring ended: 25/9/12

Av. daily electricity consumption of heater fan –
Before (1.35 kWh/day), After (0.63 kWh/day)

Av. daily operating time of heater –
Before (11.02 hrs/day), After (4.99 hrs/day)

Av. temperature difference when heater operating –
Before (5.92°C), After (5.91°C)
House WI4

Monitoring started: 14/7/12
Retrofit completed: 21/8/12
Monitoring ended: 26/9/12

Av. daily electricity consumption of heater fan –
Before (1.54 kWh/day), After (0.66 kWh/day)

Av. daily operating time of heater –
Before (6.98hrs/day), After (3.40 hrs/day)

Av. temperature difference when heater operating –
Before (9.30ºC), After (7.44ºC)
House WI5

Monitoring started: 14/7/12
Retrofit completed: 7/8/12
Monitoring ended: 17/9/12

Av. daily electricity consumption of heater fan –
Before (1.21 kWh/day), After (0.70 kWh/day)

Av. daily operating time of heater –
Before (11.77hrs/day), After (8.56hrs/day)

Av. temperature difference when heater operating –
Before (8.79ºC), After (9.03ºC)
House WI6

Monitoring started: 14/7/12
Retrofit completed: 14/8/12
Monitoring ended: 25/9/12

Av. daily electricity consumption of heater fan –
Before (2.39 kWh/day), After (1.32 kWh/day)

Av. daily operating time of heater –
Before (10.70 hrs/day), After (6.63 hrs/day)

Av. temperature difference when heater operating –
Before (7.29ºC), After (6.55ºC)
House WI7

Monitoring started: 17/7/12
Retrofit completed: 20/8/12
Monitoring ended: 17/9/12

Av. daily electricity consumption of heater fan –
Before (1.91 kWh/day), After (0.92 kWh/day)

Av. daily operating time of heater –
Before (7.03 hrs/day), After (3.61 hrs/day)

Av. temperature difference when heater operating –
Before (8.51ºC), After (9.31ºC)
House WI8

Monitoring started: 20/7/12
Retrofit completed: 21/8/12
Monitoring ended: 26/9/12

Av. daily electricity consumption of heater fan –
Before (2.82 kWh/day), After (1.31 kWh/day)

Av. daily operating time of heater –
Before (13.74 hrs/day), After (7.09 hrs/day)

Av. temperature difference when heater operating –
Before (7.46ºC), After (6.33ºC)
House WI9

Monitoring started: 14/6/13
Retrofit completed: 8/7/13
Monitoring ended: 14/8/13

Av. daily electricity consumption of heater fan –
Before (4.43 kWh/day), After (3.49 kWh/day)

Av. daily operating time of heater –
Before (9.52 hrs/day), After (9.23 hrs/day)

Av. temperature difference when heater operating –
Before (6.53ºC), After (7.13ºC)
House WI10

Monitoring started: 28/5/13
Retrofit completed: 31/7/13
Monitoring ended: 11/9/13

Av. daily electricity consumption of heater fan –
Before (0.67 kWh/day), After (0.58 kWh/day)

Av. daily operating time of heater –
Before (4.76 hrs/day), After (3.97 hrs/day)

Av. temperature difference when heater operating –
Before (6.75°C), After (5.91°C)

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House WI11

Monitoring started: 13/6/13
Retrofit completed: 1/8/13
Monitoring ended: 11/9/13

Av. daily electricity consumption of heater fan –
Before (1.51 kWh/day), After (0.70 kWh/day)

Av. daily operating time of heater –
Before (14.84 hrs/day), After (6.41 hrs/day)

Av. temperature difference when heater operating –
Before (8.46°C), After (7.24°C)
House WI12

Monitoring started: 7/6/13
Retrofit completed: 4/7/13
Monitoring ended: 23/9/13

The power meter was not correctly installed at this house, so no metrics relating to the operation of the heater are available. Temperature profile graphs have been provided below, but note that these are for all days during the monitoring period and not just those days on which the heater was operating.
House WI13

Monitoring started: 29/6/13
Retrofit completed: 25/7/13 & 30/8/13
Monitoring ended: 12/9/13

Av. daily electricity consumption of heater fan –
Before (2.04 kWh/day), After (1.46 kWh/day)

Av. daily operating time of heater –
Before (10.80 hrs/day), After (7.86 hrs/day)

Av. temperature difference when heater operating –
Before (8.95ºC), After (8.26ºC)
House WI14

Monitoring started: 7/6/13
Retrofit completed: 26/7/13
Monitoring ended: 10/9/13

Av. daily electricity consumption of heater fan –
Before (1.38 kWh/day), After (0.68 kWh/day)

Av. daily operating time of heater –
Before (10.46 hrs/day), After (7.14 hrs/day)

Av. temperature difference when heater operating –
Before (7.49°C), After (6.38°C)
House WI15

Monitoring started: 8/6/13
Retrofit completed: 27/6/13
Monitoring ended: 11/9/13

Av. daily electricity consumption of heater fan –
Before (3.51 kWh/day), After (1.90 kWh/day)

Av. daily operating time of heater –
Before (10.12 hrs/day), After (6.27 hrs/day)

Av. temperature difference when heater operating –
Before (6.26ºC), After (5.81ºC)