Gas Heating Ductwork Retrofit Trial
REPORT Gas Heating Ductwork Retrofit Trial

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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 (OGA) study data was collected from a reasonably representative sample of 60 existing (pre-2005) Victorian houses and used to: determine the energy efficiency status of the houses; identify the energy efficiency upgrades which could be practically applied to the houses; and, to estimate the upgrade costs and energy bill savings which could be achieved. The results of this initial work are published as The Energy Efficiency Upgrade Potential of Existing Victorian Houses [SV 2015].

The results presented in the On-Ground Assessment study report are estimates based on modelling, using data collected from real houses and focussing on energy efficiency upgrades which could be practically applied to the houses. The next phase of our work on the existing housing stock is to implement energy efficiency upgrades in houses and assess the actual impacts achieved. Through the Residential Energy Efficiency Retrofit Trials, we are implementing key energy efficiency retrofits1 in existing houses and monitoring the impact to assess actual costs and savings, the impact of the upgrades on the level of energy service provided, and 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.

In this report we present the results of our initial Gas Heating Ductwork Retrofit Trial2, which was undertaken in 8 houses in 2013. Infrared thermal imaging was used to assess the heat losses from the old existing ductwork prior to retrofit, and compare this with the heat losses from the new high efficiency ductwork following the retrofit. 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 ductwork upgrades.

Gas ducted heating is now the main form of heating used in Victoria; it is currently used in around 915,000 homes, with around 550,000 of these systems being installed prior to 2000. We estimate that these houses have an average annual gas use for heating of around 60,000 MJ per year at an energy cost of around $1,000. Gas ducted heaters are a heating system comprising a gas furnace and the gas heating ductwork. Previous work in both Australia and the US has shown that heat losses from older ductwork can be quite high and result in overall low system efficiencies.

Studies undertaken by Graham Palmer in ten Victorian houses suggested that these heat losses could be reduced from around 35% prior to retrofit to around 17% after retrofit. The results of the Palmer study combined with data collected during Sustainability Victoria’s OGA study, suggest that retrofitting old gas heating ductwork in pre-2000 houses could achieve average annual energy bill savings of around $235 per year and average annual greenhouse savings of 745 kg per year. Victoria-wide this represents a potential annual energy bill saving of around $129 Million per year and annual greenhouse savings of 409 kT per year.

Gas heating ductwork is located either under the house or in the roof space, so is “out of sight, out of mind”. This means that the energy losses from the ductwork are largely a hidden problem which the majority of householders are likely to be unaware of.

The Gas Heating Ductwork Retrofit Trial has shown that the replacement of old existing ductwork with new high efficiency ductwork can be an effective strategy to reduce heating energy consumption in existing Victorian houses. It reduced heat losses through the walls of the ductwork by around a half and eliminated heat losses through holes and tears in the ductwork. Average heating energy savings of around 14.1% were achieved in this trial, giving average annual energy bill savings of $177 per year and average greenhouse savings of 570 kg per year. The average cost of the ductwork retrofits was $2,849, giving an average payback of around 16.1 years. As this measure is an eligible activity under Victoria’s Energy Saver Incentive Scheme, both the installation costs and the paybacks are likely to be lower than this in practice.

Savings in the range of 15% to 23% were achieved in 4 out of the 8 houses which participated in the trial, and in houses with high annual heating energy use this makes a ductwork retrofit quite an attractive investment. It is clear that in some houses the ductwork retrofit can result in very substantial energy savings, although detailed investigative work is likely to be required to identify those houses which will give such large savings. This might require a combination of visual inspection and thermal imaging to identify the extent to which the external cover of the ductwork has been degraded (e.g. holes and tears), and possibly air pressurisation testing to measure the air leakage rate from the ductwork.

Residential energy prices have risen significantly in Victoria since 2007 and seem likely to continue to increase in future, especially for natural gas. Continued price rises for natural gas will improve the payback on gas heating ductwork retrofits.

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1 To end 2015 we have trialled halogen downlight replacements, comprehensive draught sealing, pump-in cavity wall insulation, gas heating ductwork upgrades, combined ductwork and gas heating 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 A second trial was conducted in 2014. This involved replacing both the existing ductwork and the gas ducted heater in 5 houses. In addition to thermal imaging, air pressurisation testing was undertaken on the ductwork to assess the extent to which the ductwork retrofit reduces air leakage from the ductwork. The results of this trial will be published in a future report.
Acknowledgements

This study is based on the analysis of data and information collected from gas heating ductwork retrofit trials undertaken in 8 Victorian houses. We would like to especially thank these households for their participation in the study by allowing access to their houses to enable monitoring and data collection to be undertaken, the replacement of existing old gas heating ductwork with new high efficiency ductwork, providing access to their gas billing data, and for participating in qualitative surveys before and after the retrofits were undertaken.

Sustainability Victoria contracted EnviroGroup Australia Pty Ltd to manage household recruitment and liaison, on-site data collection, manage the ductwork retrofits and to prepare a brief project report. In particular we would like to thank Ryan Mosby, who was EnviroGroup’s project manager for this work. We have acknowledged the different organisations which were involved in the Gas Heating Ductwork Retrofit Trial below.

<table>
<thead>
<tr>
<th>Project</th>
<th>Organisation</th>
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</thead>
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<tr>
<td>Project conception, design &amp; funding, and project oversight</td>
<td>Sustainability Victoria</td>
</tr>
<tr>
<td>Lead contractor / project manager</td>
<td>EnviroGroup Australia Pty Ltd</td>
</tr>
<tr>
<td>Household recruitment and liaison</td>
<td>EnviroGroup Australia Pty Ltd</td>
</tr>
<tr>
<td>Data collection, surveys, and meter installation</td>
<td>EnviroGroup Australia Pty Ltd</td>
</tr>
<tr>
<td>Gas heating ductwork retrofits</td>
<td>Sub-contractors engaged by EnviroGroup Australia Pty Ltd</td>
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<tr>
<td>Project report</td>
<td>EnviroGroup Australia Pty Ltd</td>
</tr>
<tr>
<td>Analysis of data from 8 houses and final report</td>
<td>Sustainability Victoria</td>
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### Abbreviations and Acronyms

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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Approx.</td>
<td>Approximately</td>
</tr>
<tr>
<td>Av.</td>
<td>Average</td>
</tr>
<tr>
<td>BoM</td>
<td>Bureau of Meteorology</td>
</tr>
<tr>
<td>Diff.</td>
<td>Difference</td>
</tr>
<tr>
<td>DIY</td>
<td>Do it yourself</td>
</tr>
<tr>
<td>Elec.</td>
<td>Electricity</td>
</tr>
<tr>
<td>Ex.</td>
<td>Excluding</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>HER</td>
<td>House Energy Rating</td>
</tr>
<tr>
<td>kT</td>
<td>Kilotonne</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour, used to measure electrical energy consumption, 1 kWh = 3.6 MJ</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoule</td>
</tr>
<tr>
<td>No.</td>
<td>Number</td>
</tr>
<tr>
<td>OGA</td>
<td>On-Ground Assessment</td>
</tr>
<tr>
<td>SV</td>
<td>Sustainability Victoria</td>
</tr>
<tr>
<td>Temp.</td>
<td>Temperature</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
</tbody>
</table>

### Glossary and definitions

**Boot**
A plastic or metal fitting which is used to connect the gas heating ductwork to the outlet register.

**Branch take-off**
A plastic or metal fitting which is used to join a main branch of the gas heating ductwork to two or three smaller branches of ductwork.

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

**Outlet register**
A plastic or metal fitting which directs the heated air from the gas heating ductwork into a room. The outlet registers are usually fitted with adjustable louvers to modify the angle at which the air is blown, and can be located at either floor (ductwork under the floor) or ceiling (ductwork in the roof) level.

**Plenum**
A box like structure, usually constructed of metal, which can be used as the initial distribution point for the heated air which is blown out of the gas ducted heating furnace. The plenum has a number of outlets which connect to the main branches of the gas heating ductwork.

**R-value**
Measure of the thermal resistance of a building material or building element, and is also used to indicate the performance of insulation batts and blankets. The higher the R-value (e.g. R1.0 or R1.5) the higher the level of insulation.
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.

Through the OGA study we assessed the cost-effectiveness of a total of 21 different building shell, lighting and appliance upgrades which could be applied to the 60 existing houses which participated in the study. The results of this analysis are summarised in Table 1 [SV 2015] – the results have been normalised to show the estimated average savings and costs for the 60 houses studied. The replacement of existing heating systems with high efficiency heating systems was one of the more significant and cost effective upgrades identified, however in the OGA study this was limited to upgrading the heating system only. Where houses had an existing gas ducted heating system it was assumed that the existing ductwork remained in place when a new gas heating furnace was installed3. In this case it was estimated that the gas ducted heating upgrade would lead to average annual energy bill savings of around $236 per year and annual greenhouse savings of 745 kg per year in the houses it was implemented, based on current energy tariffs.

FIGURE 1: STOCK OF GAS DUCTED HEATERS IN VICTORIAN HOMES

3 This approach was taken for the OGA study because detailed on-site measurements need to be undertaken to determine the heat losses from existing ductwork.
4 ABS 4602 Environmental Issues: Energy Use and Conservation, various years.
### 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 ($/Yr)</th>
<th>Av. Cost ($/Yr)</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>$535.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Draught Sealing</td>
<td>98.3%</td>
<td>7,809</td>
<td>221</td>
<td>8,030</td>
<td>496</td>
<td>$153.9</td>
<td>$1,019.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>55.0%</td>
<td>135</td>
<td>16</td>
<td>152</td>
<td>12</td>
<td>$24.9</td>
<td>$190.9</td>
<td>7.7</td>
</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; Pelmels</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>270</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>694</td>
</tr>
<tr>
<td><strong>Total (ex Double Glazing)</strong></td>
<td></td>
<td>30,203</td>
<td>5,610</td>
<td>35,813</td>
<td>3,434</td>
<td>$989</td>
<td>$15,274</td>
<td>15.4</td>
</tr>
<tr>
<td><strong>Total (ex Drapes)</strong></td>
<td></td>
<td>30,273</td>
<td>5,621</td>
<td>35,894</td>
<td>3,441</td>
<td>$991</td>
<td>$25,383</td>
<td>25.6</td>
</tr>
</tbody>
</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.
Figure 1 above shows how the stock of gas ducted heaters in Victorian homes has changed since 1999. The stock has increased steadily, so that gas ducted heating is now the dominant form of heating used in Victorian homes. It is used as the main form of heating in around 41.9% of homes, compared to gas room heating – the next main form of heating – which is used in around 24.3% of homes.

In comparison to gas room heaters, gas ducted heating is a heating system – it is comprised of a gas heating furnace which heats the air and circulates it via an air distribution fan, plenums, insulated ductwork and branch take-offs to distribute the heated air throughout the house5, boots and outlet registers to transfer the heated air from the ductwork into the house, and a return air grille and return air ductwork to bring the air inside the house back to the gas furnace to be reheated. The overall efficiency of the gas ducted heating system is determined by both the efficiency of the gas furnace and the efficiency of the ductwork. Studies in both Australia [Palmer 2008] and the United States [DoE 2004] have found that the efficiency of the ductwork used with gas ducted heating systems can be quite low, due to the high energy losses which can occur in old ductwork, meaning that the overall efficiency older gas ducted heating systems is also quite low.

Energy losses in gas heating ductwork occur through two main mechanisms [Palmer 2008; DoE 2004]:

- Leakage of heated air from the ductwork at poor or degraded joins
- Poor connections between the ductwork and other fittings such as plenums, branch take-offs and boots. The ductwork is usually connected to these fittings by duct tape and in older systems this tape was found to have degraded;
- Poor connections between the ductwork and other fittings such as plenums, branch take-offs and boots. The ductwork is usually connected to these fittings by duct tape and in older systems this tape was found to have degraded;
- Thermal conduction losses through the ductwork casing and uninsulated or poorly insulated plenums, branch take-offs and boots. Older ductwork is likely to have a lower level of insulation6 and the insulation is more likely to be degraded in some way, increasing these losses.

In 2008 Graham Palmer undertook a study of the energy losses from gas heating ductwork in 10 houses located in Melbourne which had ductwork that was between 9 and 30 years old7. Based on on-site testing, Palmer found that the energy losses from the existing ductwork varied from 26% to 58%, with average losses of around 35%. The average energy losses from ductwork greater than 15 years old (39%) was significantly higher than the average energy losses from ductwork 15 years old or less (24%). When this old ductwork was replaced with a new high quality ductwork installation - with an R-value of either R1.0 or R1.5 - it was found that these energy losses could be reduced to 10% to 18%, or average losses of around 17%. [Palmer 2008]

Palmer found that upgrading the old existing ductwork resulted in a significant improvement to the overall efficiency of the gas ducted heating system. He found an improvement in the overall system efficiency of 30% where the existing ductwork was greater than 15 years old and 14% for systems where the existing ductwork was less than 15 years old, which suggests that significant energy savings are possible. [Palmer 2008]

Palmer’s report notes a number of reasons for the high level of energy losses observed in his study [Palmer 2008]:

- Semi-rigid aluminium duct was used widely from the early 1970’s to mid-1980’s. This ductwork “is prone to substantial leakage through the breakdown of the polyethylene sleeve, and at the duct-to-fitting connections”. The air leakage results from perforations along the length of the ductwork, which are intended to reduce the audible noise through the duct, but lead to substantial air leakage if the outer sleeve breaks down or is torn;
- Thermal conduction losses through the ductwork casing and uninsulated or poorly insulated plenums, branch take-offs and boots. The ductwork is usually connected to these fittings by duct tape and in older systems this tape was found to have degraded;
- Poor connections between the ductwork and other fittings such as plenums, branch take-offs and boots. The ductwork is usually connected to these fittings by duct tape and in older systems this tape was found to have degraded;
- In some cases poor initial installation was found to have resulted in damaged ductwork.

The next phase of Sustainability Victoria’s work on existing houses has been to trial retrofit measures and assesses the actual impacts achieved. Through the Residential Energy Efficiency Retrofit Trials we are implementing key energy efficiency retrofits8 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 are investigating the replacement of old existing gas heating ductwork with new high efficiency ductwork. This is intended to build on the initial work undertaken by Graham Palmer, to identify the current costs and savings which can be achieved when a commercial ductwork upgrade is undertaken in Victorian homes9.

Gas heating ductwork is located either under the house or in the roof space, so is “out of sight, out of mind”. This means that the energy losses from the ductwork are largely a hidden problem which the majority of householders are likely to be unaware of. Based on the average efficiency of the gas ducted heating furnaces found in houses in SV’s On-Ground Assessment study, and the pre- and post-retrofit energy losses measured by Palmer, we estimate that poor quality older gas heating ductwork could result in increased energy bills of around $235 per year, based on current gas tariffs, and increased greenhouse emissions of around 745 kg per year compared to a house with good quality ductwork. This suggests that if the ductwork in all pre-2000 gas ducted heating systems was upgraded with high quality ductwork this would generate total energy bill savings of around $129 Million per year and total greenhouse savings of around 409 kT per year, across the Victorian residential sector10.

9 To end 2015 we have trialled halogen downlight replacements, comprehensive draught sealing, pump-in cavity wall insulation, gas heating ductwork upgrades, combined ductwork and gas heating 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.

10 Palmer notes that the reduction in energy losses achieved in his study might be higher than can be achieved in a commercial retrofit, as the quality of the new ductwork installation might not be as high.

11 There were 548,300 gas ducted heating systems installed in 1999. In the OGA study we found that gas ducted heaters in pre-2005 houses consumed an average of 62.689 MJ/yr, and that the average conversion efficiency of the heaters was 70.8%. Based on the average energy loss figures from the Palmer study we estimate an overall efficiency for the gas ducted heater system of 46.3% prior to retrofit and 59.0% after retrofit, giving an annual gas saving of 13,471 MJ/yr, or around 21%.

5 The plenum takes the heated air from the furnace and channels it into the main duct branches. Branch take-offs may also be used to split the main ducts into a number of duct branches to distribute the air to different rooms. The ducts then connect to boots which channel the heated air in to the house, where it is distributed via an outlet registers. In older houses with suspended timber floors the ductwork is often under the house and the gas furnace is located outside. In some houses the gas furnace and the ductwork are located in the roof space.

6 Older ductwork is likely to be insulated only to R0.6, although ductwork with this level of insulation was still quite common well into the 2000’s. Recent ductwork installations are more likely to be insulated to R1.0 or higher.

7 This study received funding support from Sustainability Victoria.

8 A good summary of Palmer’s report is provided in [McGowan 2009].
Significant energy savings might also be achieved from the gas ducted heating systems installed during the 2000’s, during which time the stock of heaters increased by around 350,000. While Palmer found that the plastic fittings (branch take-offs and boots) used in more recent ductwork installations led to better connections and lower leakage losses, he cites figures that suggest that in the late 2000’s the market was still dominated by ductwork with a low level of insulation: R0.6 (85 to 90%), R1.0 (10 to 15%) and R1.5 (0 to 2%). [Palmer 2008].

How the trial was undertaken

The Gas Heating Ductwork Retrofit Trial was undertaken in 2013 and involved the retrofit of 8 houses located in Melbourne. The trials were undertaken over the main winter heating period (June to August), to make it easier to assess the impact of the retrofit on the energy consumption of the heater.

The Gas Heating Ductwork Retrofit Trial involved a number of key steps:

- Houses were recruited by EnviroGroup to participate in the trial.
- The key target was houses which had older gas ducted heating systems, and a reasonably high level of gas consumption during winter months – to be accepted into the trial houses had to have a winter gas consumption of at least 300 MJ/day. Details of the houses which participated in the trials are provided in Chapter 2;
- The ductwork retrofits were generally undertaken around the end of June, to coincide with the middle of the monitoring period. The existing ductwork was removed and replaced with new ductwork with an overall R-value of R1.65;¹²
- EnviroGroup took photographs and thermal images of the ductwork before and after the retrofits were undertaken, to help identify the main heat loss sites and the causes of the heat loss. Examples of these photographs and thermal images are provided in Chapter 2, and the images and photographs from all houses are provided in Appendix A.1;
- Metering equipment was installed at the houses to assist us to monitor the impact of the gas heating ductwork 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 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. This allowed us to identify the times when the gas ducted heater was 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 consumption¹³. The metering equipment was installed around one month prior to the ductwork retrofits and left in place for around one month after the retrofits were completed;
- 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 heating¹⁴. Where possible, estimates were undertaken for a number of recent years for each house, temperature corrected¹⁵ 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 effectiveness of their gas ducted heating system;
- All surveys, data and images collected during the Gas Heating Ductwork Retrofit Trial were provided to Sustainability Victoria and analysed to determine the impacts of the draught sealing retrofits. The results of this analysis are presented in this report.

Overview of the report

In Chapter 2 we provide an overview of the houses which were recruited for the Gas Heating Ductwork Retrofit Trial, and present the results of our analysis. In particular we look at the impact of the gas heating ductwork retrofits on the heat losses from the ductwork, householder perceptions of any changes in thermal comfort and the effectiveness of their gas ducted heating systems, the way in which the heating was operated before and after the retrofits, the energy savings achieved by the retrofits, and the economics of the retrofits. We also look at some of the practical issues associated with the ductwork retrofits, and the ways in which these can be overcome.

In Chapter 3 we present our summary and conclusions. More detailed data and analysis is presented in the Appendices. In Appendix A1 we provide copies of the photographs and thermal images that were taken of the ductwork for each house before and after the retrofits were undertaken. In Appendix A2 we present the detailed results of the householder surveys which were used to assess the qualitative impacts of the ductwork retrofits. 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 ductwork retrofits.

¹² The product used in this trial was Green duct 1.65 Ultimate, which incorporates an R1.5 polyester insulation blanket and has a claimed overall R-value of R1.65. To be used in the trial the product needed to meet the eligibility requirements of the Energy Saver Incentive Scheme.

¹³ 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 of the gas ducted heater is around 2% of the gas consumption.

¹⁴ Daily gas use during the summer months was assumed to be entirely due to water heating and cooking. Annual average daily gas 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.

¹⁵ 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 (18°C base) calculated for each month and 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. Results of the gas heating ductwork retrofit trials

### Housing Sample

Details of the 8 houses which participated in the initial Gas Heating Ductwork Retrofit Trial are shown in Table 2. The estimated annual gas use for heating of the houses which participated in the Trial was 59,868 MJ per year. This is slightly lower than the average gas use for gas ducted heating in the OGA study houses (62,689 MJ per year).

#### Table 2: Details of the Houses which Participated in the Retrofit Trial

<table>
<thead>
<tr>
<th>House No.</th>
<th>No. of People</th>
<th>Approx. Age of House (Yrs)</th>
<th>Construction Details*</th>
<th>Floor Area (m²)</th>
<th>Gas Ducted Heater Details</th>
<th>Age &amp; Condition of Ductwork</th>
<th>Est. Gas Use for Heating (MJ/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>4</td>
<td>70</td>
<td>Wall - WB; Floor - ST; Ceiling insulated</td>
<td>200</td>
<td>Brivis Buffalo 120; &gt; 20 yrs old Underfloor ducts</td>
<td>&gt; 20 yrs Reasonable condition, some tears</td>
<td>117,541</td>
</tr>
<tr>
<td>DR2</td>
<td>2</td>
<td>40</td>
<td>Wall - CB; Floor - ST; Ceiling insulated</td>
<td>170</td>
<td>Brivis 92 Downflow, 35 yrs old Underfloor ducts</td>
<td>35 yrs Reasonable condition, some tears &amp; holes</td>
<td>53,812</td>
</tr>
<tr>
<td>DR3</td>
<td>4</td>
<td>50</td>
<td>Wall - WB; Floor - ST; Ceiling insulated</td>
<td>185</td>
<td>Stadt RR20i, 10 yrs old Underfloor ducts</td>
<td>&gt; 20 yrs Reasonable condition</td>
<td>35,011</td>
</tr>
<tr>
<td>DR4</td>
<td>2</td>
<td>75</td>
<td>Wall - WB; Floor - WB &amp; CSOG; Ceiling insulated</td>
<td>90</td>
<td>Brivis Wombat 92; &gt; 15 years old Ducts in roof</td>
<td>Very old, age unknown, Poor condition, multiple tears in plastic covering</td>
<td>32,475</td>
</tr>
<tr>
<td>DR5</td>
<td>3</td>
<td>60</td>
<td>Walls - CB; Floor - ST; Ceiling insulated</td>
<td>160</td>
<td>Brivis Buffalo 85, 23 yrs old Underfloor ducts</td>
<td>23 yrs Reasonable condition</td>
<td>44,025</td>
</tr>
<tr>
<td>DR6</td>
<td>4</td>
<td>30</td>
<td>Wall - CG; Floor - ST; Ceiling insulated</td>
<td>230</td>
<td>Braemar TH3, 6 yrs old Underfloor ducts</td>
<td>&gt; 20 yrs Poor condition, multiple tears in plastic covering</td>
<td>74,690</td>
</tr>
<tr>
<td>DR7</td>
<td>2</td>
<td>70</td>
<td>Wall - CB; Floor - ST; Ceiling insulated</td>
<td>150</td>
<td>Initial - Vulcan CX 901, 30 yrs old; New - Braemar TH523N Underfloor ducts</td>
<td>30 yrs Reasonable condition, some holes in plastic covering</td>
<td>45,650</td>
</tr>
<tr>
<td>DR8</td>
<td>3</td>
<td>90</td>
<td>Wall - WB; Floor - ST; Ceiling insulated</td>
<td>180</td>
<td>Brivis 2P Wombat 26, 15 yrs old Ducts in roof</td>
<td>Very old, age unknown, Reasonable condition</td>
<td>75,741</td>
</tr>
<tr>
<td><strong>Av</strong></td>
<td>3.0</td>
<td>61</td>
<td><strong>171</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>59,868</strong></td>
</tr>
</tbody>
</table>

* Walls: WB = weatherboard; CB = cavity brick; Floors: ST = suspended timber; CSOG = concrete slab on ground.
Reduction of heat losses from the ductwork

Photographs and infrared thermal images of the ductwork were obtained before and after the retrofits were undertaken. All images taken for the different houses are provided in Appendix A1. The thermal images are colour coded and show the temperature on the surface of the ductwork and other objects in the images. Where available, the photographs of the ductwork are provided next to the corresponding thermal images, making it possible to relate features that are visible on the ductwork (e.g. ductwork joins, tears and holes in the external plastic sleeve, strapping or tape which compresses the ductwork insulation, boots, etc) with the surface temperature of the ductwork.

The air which is blown through the ductwork is typically heated to a temperature in the range of 50ºC to 60ºC. Some of the heat from this air will conduct through the insulated walls of the ductwork, raising the temperature of the outer surface of the ductwork, and is ultimately lost to the cold ambient air (under the floor or in the roof space) and surrounding surfaces via a combination of convection and radiation. Better insulated ductwork will have lower conducted heat losses through the walls of the ductwork, and so the temperature of the outer surface of the ductwork will also be lower. Compression of the ductwork’s insulation tends to reduce the performance of the insulation and will therefore result in higher heat losses around the compressed area. Holes in the insulation and/or the duct’s outer plastic sleeve which covers the insulation will allow heated air to escape, and act as another source of heat loss from the ductwork.

| Table 3: Average Surface Temperature of Ductwork Before and After Retrofit |
|---------------------------------|----------------|----------------|----------------|
| **House Number** | **Average Duct Surface Temperature (ºC)** | **Pre-Retrofit** | **Post-Retrofit** | **Difference** |
| DR1 | 19.7 | 14.3 | 5.3 |
| DR2 | 22.7 | N/A | N/A |
| DR3 | 25.1 | 11.9 | 13.3 |
| DR4 | 21.5 | 15.9 | 5.6 |
| DR5 | 20.6 | 15.9 | 4.7 |
| DR6 | 20.1 | 14.0 | 6.2 |
| DR7 | 21.2 | 13.7 | 7.6 |
| DR8 | 26.8 | 19.1 | 7.7 |
| **Average** | 22.2 | 14.9 | 7.2 |

We have analysed the thermal imaging data provided in Appendix A1 to estimate the surface temperature of the ductwork before and after retrofit in those areas where the ductwork is not compressed and where there are no holes, tears or joins. The results of this analysis are provided in Table 3. While only a few spot temperature measurements were undertaken for each house and these were not undertaken under standard conditions, it is clear that the surface temperature of the retrofitted ductwork is substantially lower than the surface temperature of the old existing ductwork. This suggests that the new ductwork has resulted in a substantial reduction in heat losses through the walls of the ductwork. Based on an average surface temperature of 22.2ºC before the retrofit and an average surface temperature of 14.9ºC after the retrofit, we estimate that these losses have been reduced by around 55%.

One of the more spectacular examples of the reduction in heat losses through the walls of the ductwork was provided by House DR8 – see Figures 2a and 2b below. In this case the surface temperature of the original ductwork was very high, around 29ºC. This is likely to be due to the ductwork being poorly insulated and perhaps also to the dark and dust covered nature of the ductwork; it probably also reflects a high temperature of the heated air being transported through the ductwork. Following retrofit (Figure 2b, point M2) the surface temperature has dropped by around 10ºC.

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The bulk insulation used in the walls of the ductwork derives its insulation effect from the many small air pockets trapped between the insulation fibres. Compressing the ductwork reduces the number and size of the air pockets, and therefore reduces the insulation effect.

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17 To ensure standard results the temperature of the heated air in the ductwork would need to be the same, the ambient air temperature around the ductwork would need to be the same and the heaters would need to be operating for the same period before the measurements were made. We would also need to undertake more spot temperature measurements using.

18 Based on an assumed R-value of 0.6 before the retrofit and 1.65 after the retrofit, we estimate the heat loss through the walls of the ductwork have been reduced by an average of 54.1% to 56.7% for heated air temperatures in the range of 50ºC to 60ºC.
FIGURE 2: SURFACE TEMPERATURE OF DUCTWORK BEFORE AND AFTER RETROFIT, HOUSE DR8

(a) Pre-retrofit

M1 (28.5°C)

(b) Post-retrofit

M1 (21.8°C), M2 (18.9°C), M3 (22.2°C)

Inspection of the thermal images and photographs in Appendix A1 shows that there are a number of other significant sources of heat losses from the existing ductwork installations:

1. Rips and holes in the outer plastic sleeve;
2. Ductwork joins;
3. Strapping which compresses the insulation; and
4. Boots.

Rips and holes in the outer plastic sleeve can be a major source of heat loss in older ductwork - see Figures 3a and 3b for examples - particularly if the ductwork has suffered extensive degradation over much of its surface area. This source of heat loss is fairly straightforward to identify from a visual inspection of the ductwork. Tears in the plastic sleeve are easy to identify, and even small holes in the sleeve can be recognised by the dark patches which often surround them, presumably caused by dust expelled in the air which escapes through the holes (see Figure 3b). In the thermal images the tears and holes appear as easily recognised bright spots, with temperatures typically in the range of 40°C to 60°C, closely matching the temperature of the heated air in the duct.
Ductwork joins were found to be a common source of heat losses in the existing ductwork installations, both joins between single sections of ductwork and branch take-offs where several sections of ductwork were joined – see Figures 4a and 4b for examples. The surface temperature of these joins was typically in the range of 30°C to 50°C, with older uninsulated metal joins having the highest level of heat loss.
As noted above, compression of the ductwork insulation reduces its insulation effect, and will therefore increase the heat losses in the compressed area. A good example of this can be seen in Figure 4a (see measurement point M2 on the thermal image). Ductwork can be suspended from strapping at multiple points, resulting in multiple sites of increased heat loss.
The boots which link the ductwork to the outlet registers were also found to be a significant source of heat loss. This was the case even after the new ductwork was installed, as the original boots were retained. Figure 5 clearly shows the heat losses from an uninsulated black plastic floor boot in House DR5. While the outer sleeve of the new ductwork has a temperature around 15°C, the temperature of the surface of the boot is in the range of 30°C to 40°C.

As is evident from Table 3, and the photographs and thermal images provided in Appendix A1, the ductwork retrofits have significantly reduced the heat losses through the walls of the ductwork, due to the higher level of insulation of the new ductwork. It is also evident that the new ductwork has eliminated heat losses due to tears and holes in the outer plastic sleeve. The new ductwork installations have used insulated joins and branch take-offs, and this has also reduced heat losses through these elements of the ductwork installation. A good example of this is provided in Figure 6 (House DR8), where the surface temperature of the branch take-off was reduced from around 46°C before retrofit to around 25°C after the retrofit. The ductwork retrofits did not result in a reduction of the heat losses from the boots (see Figure 5), although the use of new insulated boots, or even covering the original boots with a foil-backed insulation blanket, should be able to reduce this source of heat loss substantially.

FIGURE 6: IMPACT OF INSULATED BRANCH TAKE-OFFS

(a) Heat losses from uninsulated branch take-off, House DR8

(b) Heat losses from new insulated branch take-off, House DR8

M1 (45.8°C), M2 (27.1°C), M3 (35.3°C)

M1 (38.7°C), M2 (19.2°C), M3 (24.8°C)
Householder perceptions

Surveys were conducted before and after the gas heating ductwork 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 7, and the detailed results are reported in Appendix A2.

Figure 7: Summary of Householder Survey Results

Overall the households reported that the level of thermal comfort of their houses increased after the gas heating ductwork retrofits had been undertaken (from an average score of 2.4 to 4.0)\(^1\). This corresponded with a slight reduction in the difficulty of heating their homes (from an average score of 2.3 to 1.4)\(^2\).

Thermal comfort

The houses which participated in the study were at least 30 years old, and most were considerably older than this – the average age was just over 60 years. All houses had gas ducted heating. The pre-retrofit rating of thermal comfort suggests that most householders perceived some level of discomfort during winter, and this may be related to the age of the houses as older houses generally have less efficient building shells. Some of the perceived discomfort may have also been due to problems with the existing ductwork – a number houses reported cold rooms where the output from the gas ducted heater was quite low, or that heating was uneven throughout the home. This can be the result of air leakage and other heat loss from the ductwork reducing the heat output at some output registers.

Following the ductwork retrofits the average level of perceived comfort increased from 2.4 to 4.0, with the vast majority (7 out of 8) giving a higher rating for thermal comfort. A selection of comments from the householders on changes to the comfort of their houses following the retrofits is provided below. Most householders reported that their houses were more comfortable after the retrofits. This was often the result of a more even distribution of the heat, greater air flow from the heating vents, or as a result of the houses heating up more quickly when the heater was turned on. In some cases the householders also reported that their houses now retained their heat better. This may be because general air leakage and heat losses can occur from the heating ductwork, even when the heating is not operating. Well sealed new ductwork would reduce this heat loss.

Comments on level of thermal comfort following the retrofit

House warms up quicker and maintains heat, [an] improvement since the ductwork retrofit. (DR1)

[There is a] lot more airflow since [the] new ducting [was] installed. (DR2)

Yes, improved heating and more comfort. House heats up very quickly. Definite improvements since the ducting retrofit. (DR3)

[The lounge and bedrooms are] very comfortable. (DR4)

[The bathroom] is almost overheated as it is a very small room. (DR5)

More comfortable and house heats up quicker. (DR6)

Yes, more comfortable. Better balance and distribution of heat throughout the house. (DR7)

No real change. House heats up quicker. (DR8)

Yes, much more comfortable throughout the whole house now. Previously had rooms that were too hot or too cold, but now rooms are balanced - very happy. (DR8)

Difficulty heating

Most households which participated in the study had little difficulty heating their house. 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 2.3 to 1.4), although half of the householders did not perceive any change in the difficulty of heating their house. When specifically asked if it took less time to heat rooms up since the ductwork retrofit, all houses responded that this was the case. A selection of comments from householders concerning the impact of the ductwork retrofits on the difficulty of heating their homes are provided below.

Comments on the difficulty of heating the home

After - Still some draughts in the house, but house heats up quickly now. (DR1)

Before - Very easy to heat. After - The house heats up quicker than before the ducting retrofit. (DR2)

Before - Heats up fairly quickly. After - Very easy to heat most of the house. (DR3)

Before - With ducted heating it takes a while because it is in the roof space. After - Not now with new ducting. (DR4)

After - Not difficult, but heater can use a lot of energy. (DR5)

Before - Some portion of the house gets more heating. After - Very easy to heat now. (DR6)

Before - No difficulty, except for the front bedroom and hallway. Front bedroom and hallway heat slowly but always feels colder than other rooms. After - Very easy to heat. Front bedroom was very hard to heat previously but [is] now easy to heat. (DR8)

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

\(^2\) The difficulty of heating was ranked on a scale from 1 (small difficulty) to 5 (extremely difficult).
Changes in use of the heater

Following the retrofits householders were asked if there had been any changes in the way they used their heating. Four of the houses reported that there had been some changes (see comments box below). Three of the houses (DR4, DR7 & DR8) reported that they now used a lower thermostat setting, and this in itself could result in an energy saving – every 1°C lower that the thermostat is set to in winter can result in around a 10% reduction in the energy used for heating. One house reported that they were now able to close some of outlet registers, and this could also result in an energy saving.

Comments on changes in the use of the heating

Don’t alter settings but have closed off some of the outlet [registers] in bedrooms now. (DR1)

Have had to start turning [the] thermostat down because of overheating. Have never done that before. (DR4)

Now set the thermostat to 18 to 19°C. [It] used to be 19 to 20°C. (DR7)

Now have to have it at 19°C when it used to be 20°C. (DR8)

Issues

Householders were asked to comment on any issues or problems which arose as a result of the ductwork retrofits. The majority of houses reported that there had been no issues. However, in house DR2 the installation of the new ductwork seems to have resulted in some damage to the old existing heater and this resulted in the heater running at full capacity. The original heater was eventually replaced and the issue rectified.

Economics of retrofitting

Replacing the old existing gas heating ductwork with new high efficiency ductwork in the 8 houses which participated in the initial Gas Heating Ductwork Retrofit Trial has resulted in reduced heat losses from the ductwork: the average temperature on the outer sleeve of the ductwork has been reduced from around 22°C to around 15°C, suggesting that heat losses through the walls of the ductwork have been roughly halved; heat losses from the ductwork joins and branch take-offs have been reduced; and, the new ductwork has eliminated heat losses from tears and holes in the outer sleeve of the ductwork. The majority of households experienced this as an increase in the thermal comfort of their houses and half of the houses reported a reduction in the difficulty of heating their homes. The improvements were linked to a reduction in the time taken to heat up the home, better retention of the heat in rooms and, in some cases, better distribution of the heat throughout the house. A number of houses also reported that they were now able to reduce thermostat settings or close outlet registers in some rooms. By reducing heat losses from the ductwork, thereby increasing the overall energy efficiency of the gas ducted heating system, the ductwork retrofits were 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 2 above. In addition to this the gas ducted heating systems consume a significant amount of electricity when they are operating, primarily to operate the main 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 day21.

As part of the Gas Heating Ductwork Retrofit Trials we sought to estimate the energy savings which were achieved from the ductwork retrofits, by monitoring the energy use of the heating, and internal and external temperatures 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 – if there was a 10% reduction in electricity use, it was assumed that this would correspond to a 10% reduction in gas use22.

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 calculated23 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 amount24. 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 loggers) in the heated areas of the house. The loggers were set to measure the average temperature over each 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 satisfy to achieve the observed internal temperatures.

21 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 a number of Sustainability Victoria’s Retrofit Trials.

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

23 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 3 to 10 Watts.

24 This is simplified explanation of how the gas ducted 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.
An example of the data collected is provided in Figure 8 above. The graphs show the data collected by the meters throughout the day for House DR6 on 14 June, 2013, with the times during which the gas ducted heater was operating indicated by yellow shading – in this case the heater was operated over two separate periods, in the morning from around 5:03 to 8:08 and in the afternoon and evening from around 12:40 to 23:30. The first graph shows the electricity consumption of the gas ducted heater. In this case the heater has an electricity consumption of around 600 Watts when it is operating and an electricity consumption of around 4.2 Watts when it is in standby mode. The heater operated (cycled on and off) for a total of 14.0 hours on this day, with the heater fan operating for a total of 7.6 hours during this period. The daily electricity consumption of the heater was 3.78 kWh, with 3.72 kWh of this consumed when the fan was operating. The second graph shows the average temperature in the heated areas of the home. It appears that the thermostat was set at around 18ºC. The final graph shows the average temperature difference during the time that the heater was operating was 7.4ºC. The largest temperature difference occurred late in the evening and corresponded with a reduction in the outside temperature.

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

The ‘raw’ results for the Gas Heating Ductwork Retrofit Trial are provided in Table 4. Taken on face value, these suggest that an average heating energy saving of 18.2% was achieved across the 8 houses which participated in the trial. In all cases the electricity use and, by implication, the gas use of the gas ducted heaters was lower after the retrofits, with the savings ranging from 3.2% (DR7) to 29.1% (DR4). However, some caution needs to be used when interpreting these results as a range of factors can influence them:

- In general the outside temperatures during the pre-retrofit period were a bit lower than during the post-retrofit period, meaning that there was less need for heating during the post-retrofit period. This could result in the heater operating for less time after the retrofits and/or the temperature difference when heating being lower, both of which would result in lower heater energy use after the retrofits;
- The way in which the heating was operated could have changed between the pre- and post-retrofit period. In some cases the times of day at which the heaters were operated changed, in some cases the heating was operated for longer periods during the post-retrofit period, and in some cases the thermostat settings used after the retrofits were different to those used before – in this case there could have been 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.
### TABLE 4: RAW MONITORING RESULTS, BEFORE AND AFTER RETROFIT

<table>
<thead>
<tr>
<th>House</th>
<th>Weighted Av. Temperature Difference when Heating (ºC)</th>
<th>Av. Heater Operating Time (hrs/day)</th>
<th>Av. Elec. Use of Heater when Operating (kWh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>% Change</td>
</tr>
<tr>
<td>DR1</td>
<td>7.77</td>
<td>7.37</td>
<td>-5.1%</td>
</tr>
<tr>
<td>DR2</td>
<td>12.06</td>
<td>9.57</td>
<td>-20.6%</td>
</tr>
<tr>
<td>DR3</td>
<td>9.06</td>
<td>7.59</td>
<td>-16.3%</td>
</tr>
<tr>
<td>DR4</td>
<td>8.33</td>
<td>7.14</td>
<td>-14.3%</td>
</tr>
<tr>
<td>DR5</td>
<td>6.91</td>
<td>6.79</td>
<td>-1.9%</td>
</tr>
<tr>
<td>DR6</td>
<td>8.51</td>
<td>8.52</td>
<td>0.0%</td>
</tr>
<tr>
<td>DR7</td>
<td>7.48</td>
<td>7.75</td>
<td>3.6%</td>
</tr>
<tr>
<td>DR8</td>
<td>8.64</td>
<td>7.30</td>
<td>-15.5%</td>
</tr>
<tr>
<td>Av. (stock)</td>
<td>8.60</td>
<td>7.75</td>
<td>-9.8%</td>
</tr>
</tbody>
</table>

An inspection of the data in Table 4 shows that House DR7 recorded by far the lowest energy saving after the ductwork retrofits. This can be partly explained by the fact that in this case the temperature difference during those times the heater was operating increased after the retrofit (by 3.6%) and the heater operated for longer (by 13.8%).

The raw data collected during the Gas Heating Ductwork Retrofit Trial 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 is achieved. This is the saving which is 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.

The analysis methodology employed was based on advice provided by Energy Efficient Strategies (EES)

25 EES was provided with data files for a number of houses which participated in draught sealing, wall insulation and gas heating ductwork retrofit trials and asked to provide advice on the best metric to use to identify technical savings and the methodology to derive this metric.

26 In the example provided in Figure 8 this would correspond to the period from around 17:30 to 23:30 in the evening.

The analysis methodology employed was based on advice provided by Energy Efficient Strategies (EES)

27 The estimated saving is \( \frac{(1 - (27.226/32.08)) \times 100\%}{1} = 15.1\% \).
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 9 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 internal 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 9, a given temperature difference does not always correspond to the same average heater power consumption (or rate of heat output) – this is likely to be due mainly to different wind conditions on different days and also changes in user behaviour (e.g. having some windows or doors open, closing off some heating vents, changing heater settings) on different days.

Replacing the old existing ductwork with new high efficiency ductwork should increase the overall energy efficiency of the gas ducted heating system. This will mean that a given rate of heat output from the heater can be achieved at a lower rate of gas consumption, as less heat is lost in the ductwork. For given climatic conditions and a given temperature difference this should reduce the rate of gas consumption (and corresponding electricity consumption) to achieve 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 ductwork retrofits. The slope of the lines of best fit before and after the retrofit can be used to estimate the technical energy saving achieved by the retrofits.

The result of applying this methodology to all houses is provided in Table 5. This shows the estimated 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 saving, retrofit cost and payback period.

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28 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 both the house and possibly also the ductwork. We did not collect any data on wind speed or pressure differential as part of the Gas Heating Ductwork Retrofit Trial. Factors such as humidity levels, rain and amount of daily sunshine will also impact on the rate of heat loss from the house.

29 The bill saving is based on a natural gas tariff of 1.75 c/MJ and an electricity tariff of 28 c/kWh.
Based on the data in Table 5, we estimate that across all houses the ductwork retrofits saved an average of 5,137 MJ per year of gas and 47.1 kWh per year of electricity, for a total annual energy bill saving of around $103.1 per year. This corresponds to an average heating energy saving across the eight houses of 8.6%. The average upgrade cost was $2,773.6, giving an average payback of 26.9 years. However, there seem to be a number of issues with at least two of the houses which give anomalous results:

- The analysis for house DR2 suggests that energy consumption actually increased by 17.5% after the retrofit. The original gas ducted heater in this house was damaged when the ductwork was replaced and this resulted in the heater running flat out. This issue was not fixed until near the end of the monitoring period, making this data unreliable, and we believe that this is likely to be responsible for the unusual result.

- The analysis for house DR5 suggests that the energy consumption increased by 7.1%. It is not clear why this would be the case as the thermal imaging suggested that the ductwork installation was more efficient – the temperature of the outer surface of the ductwork decreased from 20.6°C after the retrofit to 15.9°C after the retrofit, and air leakage from holes was eliminated as well as heat losses from the ductwork joins. The householder surveys suggested that there was a better distribution of heat to a comfortable temperature. This may be one explanation for an increase in energy use. A detailed inspection of the power consumption of the gas ducted heater shows that the power consumption of during an “on” cycle is fairly irregular (rather than closely matching a square wave), and the energy saving analysis technique used may not be best suited to this type of heater.

- The saving of only 4% for house DR8 is also unusual. The original ductwork in this house was quite hot (26.8°C) when the heater was running, and this temperature was reduced substantially (to 19.1°C) after the retrofit, suggesting that heat losses from the ductwork were reduced. This heater had a very short cycle, generally less than 5 minutes of on time, and this also may not be best suited to the analysis technique used.

If houses DR2 and DR5 are eliminated from the analysis the average annual energy saving across the remaining six houses rises to 8,940 MJ per year for gas and 72.7 kWh per year for electricity, or an annual electricity bill saving of around $176.8 per year. The average annual greenhouse saving was 574 kg per year. The average upgrade cost for these houses was $2,849.1, giving an average payback of 16.1 years. The average heating energy saving across the houses was 14.1%, with savings ranging from 4% up to 23%.

Half of the houses had an estimated heating energy saving in the range of 15 to 20%. It is clear that in some cases the ductwork upgrades can yield very significant energy savings and represent a good investment for houses which have high annual heating costs. House DR1 had a very high annual gas heating use (117,541 MJ/year) and in this case the upgrade is estimated to have resulted in a heating energy saving of 18.5%, giving energy bill savings of $417.8 per year and a payback of only 7.0 years.

The replacement of old existing gas heating ductwork with new high efficiency (minimum R-value of R1.5) ductwork is an eligible measure in the Victorian Energy Efficiency Incentive scheme. Currently this could provide a subsidy in the range of around $240 to $460 in areas with a mild climate and $380 to $740 in areas with a cold climate. Where households can access this subsidy the costs will be considerably reduced. In particular this would make this upgrade much more cost effective in the colder regions where heating usage, and therefore the saving, is likely to be higher and the subsidy larger.

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**TABLE 5: ESTIMATED TECHNICAL SAVINGS FOR THE GAS HEATING DUCTWORK 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>DR1</td>
<td>117,541</td>
<td>18.5%</td>
<td>21,758</td>
<td>132.4</td>
<td>$417.8</td>
<td>$2,938.3</td>
<td>7.0</td>
</tr>
<tr>
<td>DR2</td>
<td>53,812</td>
<td>-17.5%</td>
<td>-9,417</td>
<td>-36.7</td>
<td>-$175.1</td>
<td>$2,545.0</td>
<td>-14.5</td>
</tr>
<tr>
<td>DR3</td>
<td>35,011</td>
<td>5.3%</td>
<td>1,864</td>
<td>17.5</td>
<td>$37.5</td>
<td>$2,810.0</td>
<td>74.9</td>
</tr>
<tr>
<td>DR4</td>
<td>32,475</td>
<td>15.7%</td>
<td>5,084</td>
<td>40.6</td>
<td>$100.3</td>
<td>$2,471.5</td>
<td>24.6</td>
</tr>
<tr>
<td>DR5</td>
<td>44,025</td>
<td>-7.1%</td>
<td>-3,125</td>
<td>-22.4</td>
<td>-$60.9</td>
<td>$2,549.4</td>
<td>-41.8</td>
</tr>
<tr>
<td>DR6</td>
<td>74,690</td>
<td>15.1%</td>
<td>11,301</td>
<td>128.9</td>
<td>$233.9</td>
<td>$3,213.7</td>
<td>13.7</td>
</tr>
<tr>
<td>DR7</td>
<td>45,650</td>
<td>23.3%</td>
<td>10,625</td>
<td>88.4</td>
<td>$210.7</td>
<td>$2,958.6</td>
<td>14.0</td>
</tr>
<tr>
<td>DR8</td>
<td>75,741</td>
<td>4.0%</td>
<td>3,007</td>
<td>28.1</td>
<td>$60.5</td>
<td>$2,702.7</td>
<td>44.7</td>
</tr>
<tr>
<td>All houses</td>
<td>59,868</td>
<td>8.6%</td>
<td>5,137</td>
<td>47.1</td>
<td>$103.1</td>
<td>$2,773.6</td>
<td>26.9</td>
</tr>
<tr>
<td>Av. Ex DR2 &amp; DR5</td>
<td>63,518</td>
<td>14.1%</td>
<td>8,940</td>
<td>72.7</td>
<td>$176.8</td>
<td>$2,849.1</td>
<td>16.1</td>
</tr>
</tbody>
</table>

30 This shows the averages for all houses except DR2 and DR5.

31 Over the next few years we will obtain gas billing data from these houses and see if this gives a better indication of the level of energy savings being achieved.

32 This measure can generate 12.13 certificates for small systems and 15.4 certificates for medium systems in areas with a mild climate. This would yield a subsidy in the range of around $240 to $460 for a certificate price in the range of $20 to $30. There is a multiplier of 1.61 for cold regions.
Impact on usage of heating

As part of the study we investigated whether the ductwork retrofits had an impact on the way in which the households used their heating. In particular, we were interested to investigate whether or not there was a rebound effect associated with the 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 Commissions 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 ductwork 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 8 houses which participated in the Trial is provided in Figure 10. The temperature profile after the retrofits is a very close match to the temperature profile before the retrofits, suggesting that on average there has been little change in household behaviour across the stock of 8 houses studied. The average internal temperature across the day increased slightly after the retrofit, but only by only 0.01ºC. If all this increase was all interpreted as being the impact of the rebound effect, this would correspond to a reduction in the expected saving of only 0.2% (based on an average temperature difference when heating of 8.60ºC before the retrofit).

Practical issues

The better insulated, high efficiency, ductwork is considerably larger than standard ductwork as it uses a thicker insulation blanket – the outside diameter of the ductwork used in this Trial was around 180 mm larger than the standard ductwork which was being replaced. For example, where standard 300 mm ductwork was replaced, the new ductwork had a diameter of around 480 mm. EnviroGroup advised that in practice this meant that clearance of at least 500 mm was required under the floor or in the roof space for the ductwork replacement to be feasible.

Detailed data on the temperature profiles in the individual houses is provided in Appendix A3. A sustained increase in thermostat settings after the retrofits is evident in three of the houses (DR4, DR5 and DR8), although the increase in only slight. A sustained decrease in thermostat settings after the retrofits is evident in two houses (DR2 and DR3 (evening only)). In the other houses the temperature profiles before and after retrofit were either almost identical or displayed both increases and decreases across the day. So, while some change in behaviour seems to have taken place after the ductwork retrofits in some houses, this change might have led to higher or lower energy use. The net effect is that little if any rebound effect is evident. This result is not entirely unexpected – all houses which participated in the Trials had gas ducted heating controlled by thermostat, and in the majority houses this heating was considered to be providing adequate comfort levels prior to the retrofits. In most houses the daily operating routine for the heating was determined by the occupancy pattern of the household, and in some cases the daily operation of the heating was controlled by timer. This meant that there was often limited scope for heating behaviour to change.
3. Summary and Conclusions

Summary

Through the Gas Heating Ductwork Retrofit Trials Sustainability Victoria investigated the replacement of old gas heating ductwork with new high efficiency ductwork. One key reason to investigate ductwork retrofits is that gas ducted heating is now the main form of heating used in Victorian houses (41.9% of houses) and, where present, is responsible for very significant gas use – we estimate the average annual gas use of gas ducted heating systems in existing (pre-2005) houses is around 60,000 MJ per year at a cost of around $1,000 per year at current gas prices. A considerable proportion of the current Victorian stock of around 915,000 gas ducted heaters is quite old, with around 550,000 systems having been installed prior to the year 2000, and older systems are likely to be less efficient and have higher than average energy use.

The other key reason is that gas ducted heating is a heating system, and the overall efficiency of the system is determined by both the efficiency of the gas furnace and the efficiency of the ductwork. Studies undertaken in both the US and in Australia have shown that heat losses from old gas heating ductwork can lead to low overall system efficiencies for gas ducted heating, and that ductwork upgrades have the potential to achieve large energy savings. A previous study undertaken in Victoria [Palmer 2008] in ten houses measured average heat losses from the old existing ductwork of 35% and found that these losses could be reduced to an average of 17% when the ductwork was replaced with a good quality new installation. The results of the Palmer study combined with data collected during Sustainability Victoria’s OGA study, suggest that retrofitting old gas heating ductwork in pre-2000 houses could achieve average annual energy bill savings of around $235 per year and annual greenhouse savings of 745 kg/year. Victoria-wide this represents a potential annual energy bill saving of around $129 Million/year and greenhouse savings of around 409 kT per year.

While the ductwork retrofits involved the installation of new, well insulated ductwork as well as insulated ductwork joins and branches, the existing boots which channel the heated air into the house were retained. The thermal imaging showed that these were significant sites of heat losses, and that heat losses could have been reduced even further by using insulated boots or covering the existing boots with a foil-backed insulation blanket.

The majority households which participated in the Trial experienced the ductwork retrofit as an increase in the thermal comfort of their homes and half of the houses reported a reduction in the difficulty of heating their homes. The improvements were linked to a reduction in the time taken to heat up the home, better retention of the heat in rooms and, in some cases, better distribution of the heat throughout the house. A number of houses also reported that they were now able to reduce thermostat settings or close outlet registers in some rooms, and both of these actions should reduce energy consumption further.

The average cost of retrofitting the ductwork in the 8 houses was $2,773.6. Analysis of the thermal imaging data obtained from each house suggested that the retrofit had significantly reduced the heat losses from the ductwork:

- The average surface temperature of the ductwork was reduced from around 22.2°C prior to the retrofits to around 14.9°C after the retrofits, suggesting that the extra insulation in the new ductwork was reducing the conducted heat losses through the walls of the ductwork by slightly over a half;
- The external temperature of ductwork joins and branches were also significantly reduced, suggesting that the heat losses through these ductwork elements had also been reduced; and,
- The ductwork retrofit eliminated the heat losses which were evident from rips and tears on the outer surface of the old existing ductwork.

A total of 8 houses were recruited to participate in Sustainability Victoria’s initial Gas Heating Ductwork Retrofit Trial33. Infrared thermal imaging was used to assess the heat losses from the old existing ductwork prior to retrofit, and compare this with the heat losses from the new high efficiency ductwork following the retrofit. 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 ductwork upgrades.

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33 A second trial was conducted in 2014. This involved replacing both the existing ductwork and the gas ducted heater in 5 houses. In addition to thermal imaging, air pressurisation testing was undertaken on the ductwork to assess the extent to which the ductwork retrofit reduces air leakage from the ductwork.
By reducing the heat losses from the existing gas heating ductwork, the ductwork retrofits were also expected to lead to heating energy savings, and therefore reduced heating costs. Metering data collected during the pre- and post-retrofit period for all 8 houses was analysed to obtain plots of the average heater electrical power consumption against the average temperature difference between inside and outside the house on days on which the heater was operating and the heater was displaying steady state operation. The heater’s electrical power consumption was assumed to be a reasonable proxy for the heater’s gas consumption. The slopes of the lines of best fit on these graphs allowed an estimate of the technical energy savings to be made. This suggested an average heating energy saving of 8.6% across all eight houses. However, there were issues with the data collected for two of the houses (DR2 & DR5). If these two houses are eliminated from the analysis, the average heating energy saving was 14.1%, giving an average energy bill reduction of $176.8 per year for an average investment of $2,849, or an average payback of 16.1 years. Average greenhouse savings were 574 kg per year.

The costs of the ductwork replacement would be lower where households are able to access the subsidy available through the Victorian Energy Saver Incentive, especially in the colder areas of Victoria where the subsidy is larger, reducing the payback period.

As part of the study, we collected internal temperature data to help assess the impact of the ductwork retrofits on household behaviour. Some economists argue that a rebound effect exists, which in the context of ductwork 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. The average daily internal temperature profiles of the houses on days on which the heating was operating were compared before and after the retrofit. We found that the post-retrofit temperature profile was a very close match for the pre-retrofit temperature profile, suggesting that little if any rebound effect was occurring. While there was some increase in the internal temperatures after the retrofit, this increase was very small - a net difference of 0.01ºC compared to an average temperature difference when heating of 8.6ºC - and may not have all been due to user behaviour. The observed increase in temperature was all attributed to a rebound effect it would correspond to a rebound of only 0.2%.

The main practical issue identified during the Trial was that it was important to have adequate clearance under the house or in the roof space to make ductwork retrofits a feasible option. New high efficiency ductwork has a substantially larger diameter than the standard older ductwork and a clearance of at least 500 mm is likely to be necessary for successful installation.

### Conclusions

The Gas Heating Ductwork Retrofit Trial has shown that the replacement of old existing ductwork with new high efficiency ductwork can be an effective strategy to reduce heating energy consumption in existing Victorian houses. It reduced heat losses through the walls of the ductwork by around a half and eliminated heat losses through holes and tears in the ductwork. Estimated heating energy savings of around 14% (or an energy bill saving of $177 per year) were achieved for an average cost of $2,849, giving an average payback of around 16.1 years.

Both the costs and paybacks would be lower where households can access the incentives available under the Victorian Energy Saver Incentive scheme.

Four of the 8 houses studied had an estimated heating energy saving in the range of 15% to 23%. In houses with high annual gas heating energy use this level of savings can result in paybacks of less than 10 years. It is clear that in some houses the ductwork retrofit can result in very substantial energy savings, although detailed investigative work is likely to be required to identify those houses which will give such large savings. This might require a combination of visual inspection and thermal imaging to identify the extent to which the external cover of the ductwork has been degraded (e.g. holes and tears), and possibly air pressurisation testing to measure the air leakage rate from the ductwork.

Residential energy prices have risen significantly in Victoria since 2006/07 and seem likely to continue to increase in future, especially for natural gas. Continued price rises for natural gas will improve the payback on gas heating ductwork retrofits.

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34 The original gas furnace in DR2 was damaged at the time of the ductwork retrofit and did not operate correctly for most of the post-retrofit monitoring period. While the thermal imaging data for DR5 suggested that heat losses from the ductwork had been substantially reduced, analysis of the monitoring data suggests a slight increase in energy use after the retrofit. This may have been because the retrofit improved the distribution of heat throughout the house, effectively heating more of the house, or it may have been because the irregular nature of the power consumption of the heater during an “on” cycle was not suited to the analysis methodology used.

35 Some of the observed increase in temperature during the middle of the day may well have been due to the warmer weather which occurred during the post-retrofit period.

36 The retail price index for electricity in Melbourne increased by 88% in real terms from 2006/07 to 2013/14, and the corresponding retail price index for gas increased by 45% over this same period. [State of the Energy Market 2014, Australian Energy Regulator 2014]. While the growth in electricity prices is expected to moderate over the next few years recent studies suggest that the price of natural gas will continue to rise in response to the development of an export market for LNG, although there is some uncertainty regarding the likely magnitude of the price rises. See for example Eastern Australian Domestic Gas Market Study, Department of Industry & Bureau of Resource & Energy Economics, 2014.
References


Palmer 2008  Field study on gas ducted heating systems in Victoria: A minor thesis submitted to RMIT University, Graham Palmer, September 2008. (Funding support provided by Sustainability Victoria)


APPENDICES

A1: Photographs and thermal images

Photographs and infrared thermal images of the ductwork were taken by EnviroGroup, both before and after the retrofits were undertaken. The images taken for the different houses are provided below, with images shown side-by-side. The thermal images have a colour coded scale which gives an indication of the surface temperature of the objects being imaged. A number of measurement points are included on each image, and we have indicated the temperature of these points.
House DR1

Pre-retrofit

M1 (39.4°C), M2 (20.4°C), M3 (33.7°C)

M1 (19°C), M2 (31.9°C), M3 (30.1°C)

M1 (31.0°C), M2 (30.0°C), M3 (27.2°C), M4 (19.6°C)
REPORT Gas Heating Ductwork Retrofit Trial

Post-retrofit

M1 (42.4°C), M2 (38.3°C), M3 (39.4°C)

M1 (16.9°C), M2 (29.1°C), M3 (14.4°C)

M1 (15.5°C), M2 (13.8°C)

M1 (13.1°C)
House DR2

Pre-retrofit

No thermal images are available for the post-retrofit situation.
House DR3

Pre-retrofit

There is no photograph of this section of ductwork.
REPORT  Gas Heating Ductwork Retrofit Trial

Post-retrofit

M1 (12.7°C), M2 (20.3°C), M3 (10.6°C)

M1 (27.3°C), M2 (13.1°C), M3 (18.2°C)
House DR4

Pre-retrofit

M1 (50.2°C)

M1 (60.1°C), M2 (45.9°C), M3 (50.6°C), M4 (35.5°C)

M1 (62.4°C), M2 (20.4°C)

M1 (43.0°C), M2 (22.6°C), M3 (48.4°C)

M1 (43.0°C), M2 (22.6°C), M3 (48.4°C)

M1 (62.4°C), M2 (20.4°C)
REPORT  Gas Heating Ductwork Retrofit Trial

Post-retrofit

M1 (14.4°C), M2 (22.8°C), M3 (14.9°C)

M1 (53.6°C), M2 (23.1°C), M3 (18.3°C)
House DR5

Pre-retrofit

There is no photograph of this section of ductwork.
Post-retrofit

M1 (15.7°C)

M1 (15.8°C), M2 (16.1°C)
House DR6

Pre-retrofit

M1 (35.4°C), M2 (32.7°C)

M1 (41.3°C), M2 (19.9°C)

M1 (36.3°C), M2 (33.2°C), M3 (20.3°C)
Post-retrofit

M1 (13.9°C), M2 (19.4°C)

M1 (14.0°C), M2 (22.8°C)
House DR7

Pre-retrofit

M1 (29.5°C), M2 (17.9°C)

M1 (46.3°C), M2 (24.5°C)
Post-retrofit

There is no photograph of this section of ductwork.
House DR8

Pre-retrofit

M1 (45.8°C), M2 (27.1°C), M3 (35.3°C)

M1 (28.5°C)

M1 (43.6°C), M2 (24.7°C)

M1 (4.3°C), M2 (24.7°C)
Post-retrofit

M1 (38.7°C), M2 (19.2°C), M3 (24.8°C)

M1 (18.9°C), M2 (26.7°C), M3 (19.4°C)

M1 (21.8°C), M2 (18.9°C), M3 (22.2°C)
A2: Detailed householder survey results

Surveys were conducted before and after the ductwork 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.

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.

<table>
<thead>
<tr>
<th>House No.</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>After – Generally quite warm throughout the house. Seems warmer since the retrofit.</td>
</tr>
<tr>
<td>DR2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>Before – Uncomfortable throughout the whole house. After – Lot more airflow since new ducting installed.</td>
</tr>
<tr>
<td>DR3</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Before – Very much colder without heater. After – Very comfortable. Definite improvements since the ducting retrofit. [Bathroom] is almost overheated as it is a very small room.</td>
</tr>
<tr>
<td>DR4</td>
<td>2.5</td>
<td>4</td>
<td>1.5</td>
<td>After – Rooms get heated a lot quicker. Back room &amp; kitchen lose heat due to large windows. [Lounge] heats quicker and retains the heat.</td>
</tr>
<tr>
<td>DR5</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>After – Comfortable, but has some cold spots because no heating in certain spaces.</td>
</tr>
<tr>
<td>DR6</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>After – One bedroom is slightly colder than other rooms, but we have organised for this to be adjusted soon. Lounge and rest of house are comfortable.</td>
</tr>
<tr>
<td>DR7</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Before – Least comfortable is the lounge room. After – Quite comfortable.</td>
</tr>
<tr>
<td>DR8</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>After – Previously had rooms that were too hot or too cold. But now rooms are balanced. Very happy. Lounge room is very comfortable.</td>
</tr>
</tbody>
</table>

Average 2.4 4.0 1.6

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 FOLLOWING RETROFIT

<table>
<thead>
<tr>
<th>House No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>House warms up quicker and maintains heat, an improvement since the ductwork retrofit.</td>
</tr>
<tr>
<td>DR2</td>
<td>Good change, now that the ducting system is working properly.</td>
</tr>
<tr>
<td>DR3</td>
<td>Yes. Improved heating and more comfort. House heats up very quickly.</td>
</tr>
<tr>
<td>DR4</td>
<td>More comfortable and house heats up quicker.</td>
</tr>
<tr>
<td>DR5</td>
<td>Yes, more comfortable. Better balance and distribution of heat throughout the house.</td>
</tr>
<tr>
<td>DR6</td>
<td>No real change. House heats up quicker.</td>
</tr>
<tr>
<td>DR7</td>
<td>Cannot notice a significant change.</td>
</tr>
<tr>
<td>DR8</td>
<td>Yes, much more comfortable throughout the whole house now.</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. 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>House No.</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>After – Still some draughts in the house, but house heats up quickly now. [Lounge] holds its heat very well. [Bedrooms] hold heat well.</td>
</tr>
<tr>
<td>DR2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Before – Very easy to heat. After – The house heats up quicker than before the ducting retrofit.</td>
</tr>
<tr>
<td>DR3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>Before – Heats up fairly quickly. After – Very easy to heat most of the house.</td>
</tr>
<tr>
<td>DR4</td>
<td>4</td>
<td>1</td>
<td>-3</td>
<td>Before – With the ducted heating it takes a while because it is in the roof space. After – Not now with new ducting.</td>
</tr>
<tr>
<td>DR5</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>After – Not difficult, but heater can use a lot of energy.</td>
</tr>
<tr>
<td>DR6</td>
<td>3</td>
<td>1</td>
<td>-2</td>
<td>Before – Some portion of the house gets more heating. After – Very easy to heat now. [Lounge] heats up very quickly.</td>
</tr>
<tr>
<td>DR7</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Before – Easy to heat the home.</td>
</tr>
<tr>
<td>DR8</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>Before – No difficulty, except for the bedroom and hallway. Front bedroom and hallway heat slowly but always feel colder than the other rooms. After – Very easy to heat. Front bedroom is now easy to heat.</td>
</tr>
<tr>
<td>Average</td>
<td>2.3</td>
<td>1.4</td>
<td>-0.9</td>
<td></td>
</tr>
</tbody>
</table>
Time taken to heat house

Following the retrofits the householders were asked whether or not they were finding it takes less time to heat rooms up since the ductwork retrofit. The responses are provided in Table A4.

<table>
<thead>
<tr>
<th>House No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>Yes, very noticeable. House warms up quicker.</td>
</tr>
<tr>
<td>DR2</td>
<td>Yes, less time to heat.</td>
</tr>
<tr>
<td>DR3</td>
<td>Yes, definitely takes less time.</td>
</tr>
<tr>
<td>DR4</td>
<td>Yes, absolutely.</td>
</tr>
<tr>
<td>DR5</td>
<td>Yes, definitely.</td>
</tr>
<tr>
<td>DR6</td>
<td>Yes, the house heats up quicker.</td>
</tr>
<tr>
<td>DR7</td>
<td>Yes, takes less time. But also might be the new heater installation.</td>
</tr>
<tr>
<td>DR8</td>
<td>Yes, takes less time to heat.</td>
</tr>
</tbody>
</table>

This house had a new gas ducted heater installed about halfway through the pre-retrofit monitoring period. The analysis of the energy savings for this house is based only on the period when the new heater was installed.

Changes in the use of gas heater

Following the retrofits the householders were asked whether or not there had been any changes to the way in which they used the gas ducted heater following the retrofit. The responses are provided in Table A5.

<table>
<thead>
<tr>
<th>House No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>Don’t alter settings but have closed off some of the outlet [registers] in bedroom now.</td>
</tr>
<tr>
<td>DR2</td>
<td>Heater was running at full capacity when it was turned on, due to damage to the heater. (Issue was ultimately rectified.)</td>
</tr>
<tr>
<td>DR3</td>
<td>Adjusted the ducting outlets to increase pressure to the back rooms. Haven’t adjusted the thermostat.</td>
</tr>
<tr>
<td>DR4</td>
<td>Have had to start turning thermostat down because of overheating. Have never done that before.</td>
</tr>
<tr>
<td>DR5</td>
<td>No, have just left the thermostat the same.</td>
</tr>
<tr>
<td>DR6</td>
<td>No real change.</td>
</tr>
<tr>
<td>DR7</td>
<td>Now set thermostat to 18 to 19°C, used to be 19 to 20°C.</td>
</tr>
<tr>
<td>DR8</td>
<td>Now have [the thermostat] at 19°C when it used to be 20°C.</td>
</tr>
</tbody>
</table>
Problems or issues

Following the retrofits the householders were asked whether or not any issues or problems had been created by the ductwork retrofit. The responses are provided in Table A6.

<table>
<thead>
<tr>
<th>House No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1</td>
<td>No</td>
</tr>
<tr>
<td>DR2</td>
<td>Some damage occurred to the heater when the ducting was changed over. This meant that the heater was running at full capacity in order to heat the house. This was an old heater and has now been replaced.</td>
</tr>
<tr>
<td>DR3</td>
<td>No</td>
</tr>
<tr>
<td>DR4</td>
<td>No</td>
</tr>
<tr>
<td>DR5</td>
<td>No</td>
</tr>
<tr>
<td>DR6</td>
<td>No</td>
</tr>
<tr>
<td>DR7</td>
<td>Had some issues with sizing of the system. Issue has been rectified now.</td>
</tr>
<tr>
<td>DR8</td>
<td>No</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 Gas Heating Ductwork Retrofit Trial.

In addition to some basic information about each of the houses – location, monitoring dates and retrofit dates, and the initial and final natural air leakage rates – we provide the following information:

- 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 prior to the ductwork 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 ductwork retrofits;
- A graph which compares the average daily internal temperature profiles of the houses before and after the retrofits were undertaken. This gives an idea 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. 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 heating is displaying steady state operation 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 DR1

Monitoring started: 4/6/13
Retrofit undertaken: 25/6/13
Monitoring ended: 5/8/13

Av. daily electricity consumption of heater fan –
Before (4.00 kWh/day), After (3.12 kWh/day)

Av. daily operating time of heater –
Before (20.89 hrs/day), After (21.07 hrs/day)

Av. temperature difference when heater operating –
Before (7.77°C), After (7.37°C)
House DR2

Monitoring started: 5/6/13
Retrofit undertaken: 26/6/13
Monitoring ended: 7/8/13

Av. daily electricity consumption of heater fan –
Before (1.62 kWh/day), After (1.34 kWh/day)

Av. daily operating time of heater –
Before (11.68 hrs/day), After (9.90 hrs/day)

Av. temperature difference when heater operating –
Before (12.06ºC), After (9.57ºC)
House DR3

Monitoring started: 4/6/13
Retrofit completed: 28/6/13
Monitoring ended: 2/8/13

Av. daily electricity consumption of heater fan –
Before (1.84 kWh/day), After (1.38 kWh/day)

Av. daily operating time of heater –
Before (8.33 hrs/day), After (7.32 hrs/day)

Av. temperature difference when heater operating –
Before (9.06ºC), After (7.59ºC)
House DR4

Monitoring started: 5/6/13
Retrofit undertaken: 27/6/13
Monitoring ended: 1/8/13

Av. daily electricity consumption of heater fan –
Before (1.51 kWh/day), After (1.07 kWh/day)

Av. daily operating time of heater –
Before (4.72 hrs/day), After (4.47 hrs/day)

Av. temperature difference when heater operating –
Before (8.33ºC), After (7.14ºC)
House DR5

Monitoring started: 6/6/13
Retrofit completed: 26/6/13
Monitoring ended: 7/8/13

Av. daily electricity consumption of heater fan –
Before (1.75 kWh/day), After (1.45 kWh/day)

Av. daily operating time of heater –
Before (14.4 hrs/day), After (11.54 hrs/day)

Av. temperature difference when heater operating –
Before (6.91°C), After (6.79°C)
House DR6

Monitoring started: 4/6/13
Retrofit completed: 25/6/13
Monitoring ended: 11/8/13

Av. daily electricity consumption of heater fan –
Before (4.72 kWh/day), After (3.64 kWh/day)

Av. daily operating time of heater –
Before (17.53 hrs/day), After (19.53 hrs/day)

Av. temperature difference when heater operating –
Before (8.51ºC), After (8.52ºC)
House DR7

Monitoring started: 27/6/13 (New heater installed on this date)
Retrofit completed: 19/7/13
Monitoring ended: 19/8/13

Av. daily electricity consumption of heater fan –
Before (2.02 kWh/day), After (1.96 kWh/day)

Av. daily operating time of heater –
Before (8.13 hrs/day), After (9.25 hrs/day)

Av. temperature difference when heater operating –
Before (7.48ºC), After (7.75ºC)
House DR8

Monitoring started: 6/6/13
Retrofit completed: 27/6/13
Monitoring ended: 5/8/13

Av. daily electricity consumption of heater fan –
Before (4.01 kWh/day), After (3.62 kWh/day)

Av. daily operating time of heater –
Before (19.42 hrs/day), After (20.68 hrs/day)

Av. temperature difference when heater operating –
Before (8.64ºC), After (7.30ºC)