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Energy efficiency upgrade potential of existing Victorian houses

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Abstract

The paper provides an overview of a number of projects undertaken to understand the energy efficiency upgrade potential of existing houses in Victoria, Australia. The *On-Ground Assessment* study used field surveys to obtain data from a reasonably representative sample of 60 houses, identify their efficiency status, assess their practical upgrade potential, and model the costs and savings of the upgrades. It found an average House Energy Rating (HER) of only 1.81 stars. The analysis identified the applicability of the different upgrade measures and their relative cost-effectiveness, as well as the greenhouse gas savings. In addition to the average impact across the 60 houses, and for those houses in which different upgrades were modelled, the study identified the diversity of outcomes achieved, and explored the underlying reasons for this.
A series of separate energy efficiency retrofit trials were also undertaken to assess the actual costs and qualitative and quantitative impacts of 9 key efficiency upgrades. The impact of the upgrades was determined from a 'differential analysis' that compared the pre- and post-retrofit monitoring periods. The studies also explored the extent to which the rebound effect reduced the level of savings achieved by the energy efficiency upgrades.

Keywords: residential energy efficiency; energy efficiency upgrade potential; energy efficiency retrofitting

1. Introduction

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 energy efficiency can be practically upgraded, and the cost and cost-effectiveness of doing this. In 2009 Sustainability Victoria (SV) commenced a research program to address these information gaps. Through the *On-Ground Assessment* study data was collected from 60 existing (pre-2005) houses in Victoria and used to: determine the energy efficiency status of the houses and key appliances; identify the energy efficiency upgrades which could be practically applied to the houses and appliances; and, to estimate the upgrade costs and the annual energy, energy bill and greenhouse savings which could be achieved.

The results of the *On-Ground Assessment* study [1] are estimates based on modelling, using data collected from real houses. The next phase of SV's work on the existing housing stock was to implement energy efficiency upgrades in houses and assess the actual impacts achieved. Through the Residential Energy Efficiency Retrofit Trials [2] key energy efficiency retrofits were implemented in houses recruited for the various studies, and the impacts monitored to assess the 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. The studies also sought to identify practical issues which need to be taken into consideration when these upgrades are implemented.

Nomenclature

ACH	Air changes per hour – a metric used for measuring the rate of air leakage from a house. In this report we use the "natural air change rate", the air change rate at a 50 Pascal pressure differential divided by 20
EES	Energy Efficient Strategies – consultancy that undertook some data analysis for the retrofit trials
HER	House Energy Rating – a rating from 1 to 10 stars based on the efficiency of a house's building shell, under the Australian Nationwide House Energy Rating (NatHERS) Scheme
OGA	*On-Ground Assessment* study
SV	Sustainability Victoria, a Victorian Government agency

2. On-Ground Assessment study

The *On-Ground Assessment* study [1] involved the collection and analysis of energy efficiency data from a reasonably representative sample of 60 existing (pre-2005) class 1 dwellings in Victoria. The data was analysed to estimate the energy efficiency upgrade potential of Victoria's existing housing stock. The energy efficiency status of the houses' existing building shells (as measured by their House Energy Ratings) was determined as well as the energy performance of the existing lighting and key appliances. Modelling was then undertaken to estimate the costs and annual savings (energy, $ and greenhouse gas emission) which could be achieved through application of the building shell, lighting and key appliance upgrades which were both possible and practical for the houses, to identify those energy efficiency upgrades which can provide the "biggest bang for buck". In addition to providing information on the impact of the various upgrades studied when they are applied, this work has also given an insight into the impacts which could be achieved across the existing Victorian housing stock.

The average House Energy Rating (HER) of the 60 *OGA* study houses was 1.81 Stars, making these houses considerably less efficient than new 6 Star houses constructed today. The average HER of the houses studied increased steadily over the last century, with a significant increase from the 1990s, corresponding to the introduction of mandatory insulation requirements for new houses in Victoria in 1991. The average HER of houses constructed prior to 1990 was 1.57 Stars and the average of the houses constructed between 1990 and 2005 was 3.14 Stars. In addition to the 1991 mandatory insulation requirements, certain trends in the construction of houses are likely to have contributed to the observed increase in efficiency, including the shift to concrete slab-on-ground construction for floors and the elimination of wall vents from most houses constructed since the 1990s.

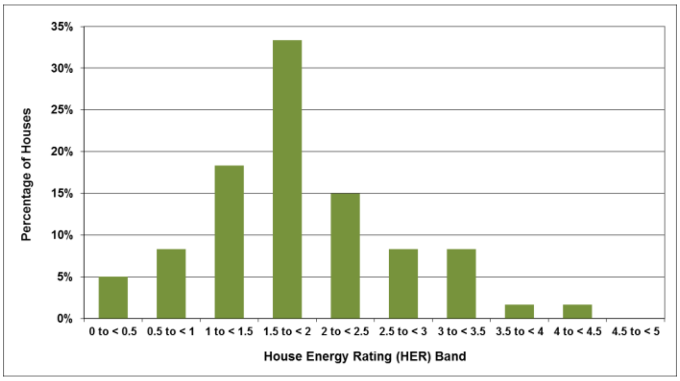
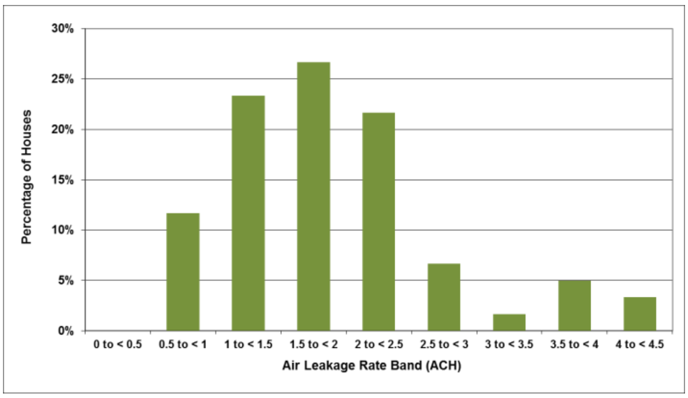


Fig. 1. Distribution of House Energy Ratings for the 60 OGA study houses

One reason for the low efficiency level of the existing houses studied was a high level of air leakage, measured using a "blower door" test. The average natural air leakage rate for the *OGA* study houses was 1.90 air changes per hour (ACH), with houses constructed prior to 1990 having a higher average natural air leakage rate (2.02 ACH) than houses constructed between 1990 and 2005 (1.20 ACH). Much of this difference is likely to be related to the changing house construction trends noted above, as well as the impact of "wear and tear" on older houses.



A blower door test was used to measure the air leakage rate (m^3/hr) at a 50 Pascal pressure differential. This was divided by the house volume (m^3) and then by 20 to estimate the natural air leakage rate in air changes per hour.

Fig. 2. Distribution of natural air leakage raates for the 60 OGA study houses

As well as the existing houses having quite inefficient building shells, the lighting and appliances found in the *OGA* study houses were considerably less efficient than the new lighting and appliances available today. This was particularly the case for the lighting, heating and cooling, water heating, refrigerators and televisions.

The impact on the House Energy Rating of applying 11 different building shell upgrades to the *OGA* study houses was modelled [1]. The measures were assumed to be applied progressively in the order shown in Figure 3, although it was assumed that double glazing (9) and drapes and pelmets (9a), which have a similar impact, were applied separately. The application of all measures was estimated to increase the average HER of the houses from 1.81 Stars to 5.05 Stars, an increase of 3.24 Stars. The average HER of the pre-1990 houses was increased from 1.57 Stars to 5.00 Stars (an increase of 3.42 Stars) while the average HER of the post-1990 houses was increased from 3.14 Stars to 5.37 Stars (an increase of 2.23 Stars). The wall insulation upgrade was the main energy efficiency measure which was responsible for bringing the HERs of the pre- and post-1990 houses much closer together.

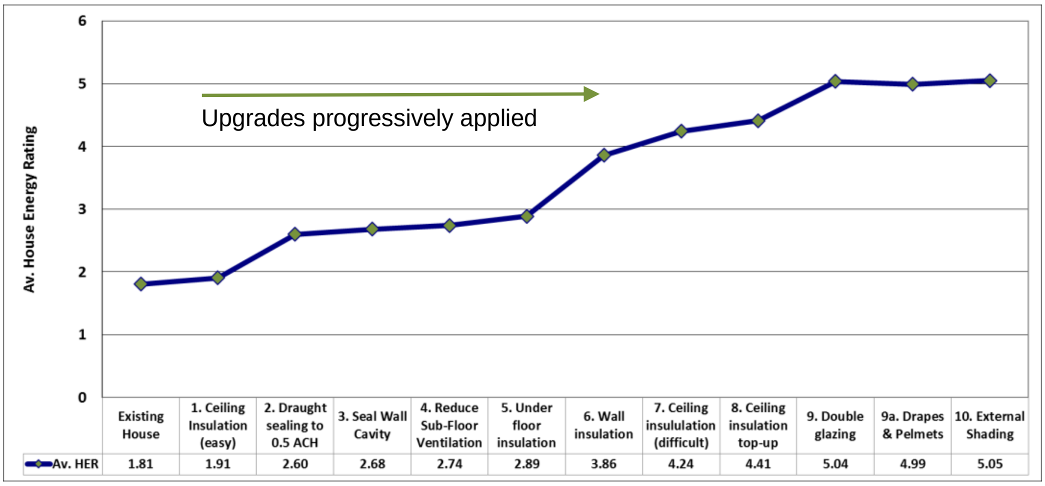


Fig. 3. Impact of the building shell upgrades on average HER of the 60 house, as applied progressively

Wall insulation (average 0.97 Star increase), draught sealing (0.69 Stars), double glazing (0.63 Stars) and drapes and pelmets (0.58 Stars) were the building shell upgrades which had the biggest impact on increasing the average HER of the houses. These measures had quite a large impact when implemented and also a high level of applicability across the stock of *OGA* study houses. Ceiling insulation measures had a large impact when implemented, but as they had a much lower level of applicability – most houses in Victoria already have a certain level of ceiling insulation – they had a lower impact on the average HER of the houses.

The average cost of increasing the HER of the existing houses to just above 5 Stars was $11,405 if it was assumed that only drapes and pelmets were used (and not double glazing) and $24,742 if it was assumed that double glazing was used (and not drapes and pelmets). The cost of upgrading the pre- and post-1990 houses was quite similar.

In addition to modelling the impact of building shell upgrades on the HER of the houses, the costs and benefits of a range of building shell, lighting and appliance upgrades were modelled (see Table 1). Across the stock of *OGA* study houses it was estimated that the application of all relevant building shell upgrade measures could achieve average energy savings of around 22,600 MJ/yr (dominated by gas), average energy bill savings of $430 per year, and annual greenhouse gas savings of around 1.4 tonnes/yr. The average cost of these upgrades was $9,392 if drapes and pelmets were used and $19,501 if double glazing was used. The costs are slightly different to the building shell–HER analysis discussed above as only those upgrades that would produce an actual energy saving were modelled. Draught sealing, wall insulation, double glazing and drapes and pelmets provided the largest overall savings across the stock of houses. Draught sealing (6.6 year payback), and insulating an uninsulated ceiling (4.1 year and 8.2 year payback for the easy and difficult cases respectively) were the most cost-effective upgrades.

The application of all relevant lighting and appliance upgrade measures was estimated to achieve average energy savings of around 13,200 MJ/yr (more evenly split between electricity and gas), average energy (and water) bill savings of $588 per year, and annual greenhouse gas saving of around 2.0 tonnes/yr. The average cost of these upgrades was $5,882, making them more cost effective overall than the building shell upgrades. The largest average savings were provided by the heating, low flow shower rose, water heating, lighting and refrigerator upgrades. Low flow shower rose (0.8 year payback), lighting (5.7 years), clothes washer (7.7 years), water heating (8.2 years) and heating (8.8 years) upgrades were the most cost effective upgrade.

Applying all energy efficiency upgrade measures modelled in the *OGA* study houses was estimated to achieve average energy savings of around 35,800 MJ/yr (split approximately 84% - 16% between electricity and gas) for an average bill saving of around $990 per year, and average greenhouse gas savings of around 3.4 tonnes/yr. The average cost of all the upgrades was $15,274 if drapes and pelmets were used and $25,383 if double glazing was used. The results for all energy efficiency upgrade measures modelled are shown in Table 1 below, based on the average impact across the 60 houses studied.

Table 1. Average impact of all modelled upgrade measures across the stock of 60 existing (pre-2005) houses

Upgrade	% Houses Applied to	Energy saving (MJ/yr)	GHG saving (kg/yr)	Bill saving ($/yr)	Cost ($)	Payback (yrs)
Low flow shower rose	56.7%	1,402	95	$57.9	$48.8	0.8
Ceiling insulation (easy)	11.7%	990	64	$19.3	$78.6	4.1
Lighting	93.3%	1,202	365	$93.5	$535.8	5.7
Draught sealing	98.3%	8,030	496	$153.9	$1,019.8	6.6
Clothes washer	55.0%	152	12	$24.9	$190.9	7.7
Water heater – High Efficiency Gas	58.3%	1,463	330	$58.2	$477.3	8.2
Ceiling insulation (difficult)	33.3%	1,698	111	$33.8	$278.2	8.2
Heating	80.0%	6,454	411	$125.9	$1,110.6	8.8
Refrigerator	86.7%	1,202	365	$93.5	$1,103.7	11.8
Reduce sub-floor ventilation	21.7%	601	36	$11.2	$116.7	14.9
Seal wall cavity	50.0%	927	57	$17.6	$270.4	15.3
Television	95.0%	696	273	$54.1	$964.3	17.8
Ceiling insulation top-up	43.3%	875	54	$16.6	$335.3	20.2
Underfloor insulation	40.0%	1,813	102	$32.4	$784.7	24.3
Dishwasher	43.3%	112	34	$10.4	$258.1	24.9
Clothes dryer – heat pump	45.0%	353	107	$27.5	$727.7	26.5
Cooling	40.0%	160	49	$12.5	$464.8	37.3
Wall insulation	95.0%	5,412	331	$102.5	$3,958.7	38.6
Drapes & pelmets	100.0%	2,263	139	$42.9	$2,035.9	47.5
Double glazing (full replacement)	100.0%	2,344	146	$45.0	$12,145.0	270
External shading	31.7%	9	3	$0.7	$346.6	694
Total (excluding Double glazing)		**35,813**	**3,434**	**$989**	**$15,274**	**15.4**
Total (excluding Drapes & pelmets)		**35,894**	**3,441**	**$991**	**$25,383**	**25.6**

Bill savings are based on a gas tariff of 1.75c/MJ, and electricity tariffs of 28c/kWh (peak) and 18c/kWh (off peak). Bill savings for low flow shower rose, clothes washer and dishwasher include water savings. The upgrades have been costed at commercial rates and do not include any government incentives. Building shell upgrades, low flow shower rose and lighting costs are the full upgrade cost. Appliance upgrade costs are 'adjusted' to take into account the age of the appliance – full cost is used if the existing appliance is new, the cost difference between the high efficiency and average new appliance is used if the existing appliance is at or past its average lifetime, with a linear interpolation used between.

If all the energy efficiency upgrade potential identified in Table 1 was applied to the existing (pre-2005) houses in Victoria still standing today, the estimated total annual energy bill savings would be at least $1,500 Million per year and total annual greenhouse gas abatement at least 5,200 kt per year. Even if only all measures with a payback up to 10 years were applied, the estimated total annual energy bill savings would be at least $900 Million per year and annual greenhouse gas abatement at least 3,100 kt per year.

The *OGA* study analysis found that there was a very wide diversity in the energy savings (and consequently paybacks) which could be achieved for any given energy efficiency upgrade measure. Much of this diversity is due to the level of energy service which was being provided at a particular house (related to the number of occupants, occupancy profile, size of the house, appliance type and appliance settings) and to how different appliances are used. This high level of diversity means that while the average results presented in this paper provide a guide for the most cost-effective energy efficiency upgrade options, careful assessment is required for an individual household to identify the most appropriate and most cost effective upgrade options.

The total energy saving potential from all the main measures modelled is estimated to be equivalent to 45.2% of the total electricity and gas use of the average existing house in Victoria, 50.5% of average gas use and 28.8% of average electricity use (See Figure 4). Both the overall energy saving potential and the gas saving potential are dominated by heating and cooling measures. In contrast, the electricity saving potential is dominated by the appliance upgrade measures, with the savings potential for lighting and water heating also being significant.

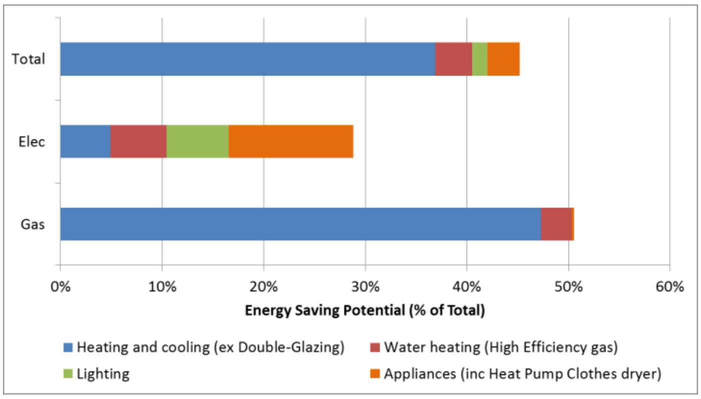


Fig. 4. Estimated energy efficiency upgrade potential of existing (pre-2005) Victorian houses

While the results of the *OGA* study are based on modelling for the 60 selected houses, we believe they give a reasonable indication of the energy saving potential and the economics of energy efficiency upgrades across the wider stock of existing (pre-2005) houses in Victoria. If anything, the characteristics of the houses included in the study suggest that slightly higher savings may be possible. Further, the upgrades assessed do not cover all possible measures, which suggests that larger overall energy savings could be achieved.

The *OGA* study focused exclusively on "hardware" measures, and significant additional savings – in the order of 10% to 20% - could be possible through better energy use practices, requiring behaviour change. In addition, there are a range of "hardware" measures which were not considered that could yield additional savings:

- Installation of rooftop photovoltaic (PV) panels to generate electricity would reduce (off-set) mains electricity consumption as well as feed electricity into the grid;
- Replacement of old existing gas heating ductwork with high efficiency new ductwork could give additional heating energy savings of around 10% to 20% in the houses in which this measure is applicable;
- Installation of Standby Power Controllers (SPCs) attached to nests of home entertainment equipment and computer equipment can automatically reduce standby power use;
- Remediation of ceiling insulation to cover gaps, especially where downlights have been used as the main form of lighting, could give further savings on heating and cooling energy use;
- Installation of solar air heating devices to provide supplementary heating;
- Installation of "grey water" heat recovery systems to recover heat from the shower drain; and,
- The use of voltage optimisation devices connected to a house's electrical switchboard.

It is important to keep in mind that the *OGA* study analysis is based on a snapshot in time. The housing stock is dynamic and changes from year-to-year. While the houses' building shells change quite slowly, the stock of lighting and appliances changes more rapidly. Given this, it is likely that some of the upgrade potential identified in the *OGA* study has already been taken up, and that more will be progressively taken up over time due to a combination of: a general improvement in the energy efficiency of lighting and appliances; government regulations relating to minimum energy performance standards (MEPS) for appliances and energy efficiency regulations which apply to home renovations; the Victorian Energy Efficiency Target (VEET) scheme; and, increasing consumer preference for higher efficiency lighting and appliances in response to increasing energy prices.

The costs used in this study are based on the commercial cost of the upgrades, and do not include any of the government financial incentives available. In some cases the upgrades could be undertaken as a DIY project, also reducing the costs. Also, the cost of some upgrades are decreasing and their cost effectiveness is likely to improve. This is the case for LED lighting, televisions and heat pump clothes dryers. There may also be some areas where further market development and increased competition could result in lower costs, e.g. pump-in wall insulation.

The energy (and water) bill savings are based on the energy (and water) tariffs which applied at the time the analysis was undertaken. As energy prices seem likely to continue to rise in real terms, the cost-effectiveness of many of the energy efficiency upgrades studied are likely to improve over time.

The savings documented in this paper are based only on the energy (and in some cases water) bill savings which result directly from the upgrades studied. Any value associated with the greenhouse gas savings, or comfort or health improvements which could result from the building shell upgrades have not been included. Studies evaluating the costs and benefits of large-scale insulation programs undertaken in New Zealand [3] suggest that the associated health benefits could be significant. Currently, there is not widespread agreement on how to include the value of greenhouse abatement in such analysis, and as yet there is no evidence base which would allow the comfort and health benefits for households in Victoria to be included in the analysis. While some of these benefits might accrue directly to the households, they will be shared with governments and society more broadly.

There are additional co-benefits which are likely to result from residential energy efficiency upgrades, especially if there was widespread uptake across the existing housing stock in Victoria:

- Upgrades which result in electricity savings put downward pressure on the price of electricity by reducing future investment in electricity generation and supply infrastructure, and helping to suppress the wholesale price of electricity at times of system demand peaks; and,
- There are potentially significant flow-on economic benefits from the more widespread uptake of energy efficiency, including employment generation, and the flow on benefits when energy bill savings are spent.

Taken together, the costs and savings assumptions which have been used as the basis of the analysis presented in this paper mean that we present a reasonably conservative picture of the economics of upgrading the energy efficiency of existing houses in Victoria.

3. Residential Energy Efficiency Retrofit Trials

3.1. Overview

The Residential Energy Efficiency Retrofit Trials were a logical follow-on from the *OGA* study [1], moving beyond modelling to actual implementation. Key energy efficiency retrofits were implemented in existing houses in Victoria and monitoring and surveys undertaken to assess the actual costs and savings, the impact on the level of energy service provided, and householder perceptions and acceptance of the upgrade measures. Practical issues that need to be considered to achieve successful upgrades were identified. The Trials also provided the opportunity to develop and test methodologies to estimate annual energy savings using data collected during, typically, a three to four month monitoring period. In total 12 different energy efficiency retrofit measures were trialled in 96 houses, plus comprehensive whole-of-house retrofits in 14 houses. This paper provides an overview of the results from the nine individual retrofit trials for which the data analysis has been completed [2].

For the Trials Sustainability Victoria contracted organisations to recruit the partipating households, undertake on-site and householder surveys and install metering equipment, manage the retrofit sub-contractors, and liaise with the householders during the life of the project. The Trials were generally undertaken over the May to September period, as the focus was mainly on end-uses (heating, lighting, water heating, clothes drying) for which energy use is highest in winter. The majority of the data analysis and report preparation was undertaken by Sustainability Victoria, although Energy Efficient Strategies (EES) was contracted to undertake detailed analysis for the gas water heating, clothes dryer and refrigerator retrofit trials.

The Trials involved the installation of metering equipment to monitor energy use, temperatures, lighting use, water use, etc., as necessary, both before and after the retrofits. Generally there was a monitoring period of 4 to 6 weeks prior to the retrofits being undertaken and 6 to 8 weeks afterwards, with most retrofits undertaken around the end of June. For trials that involved upgrades that reduced heating energy consumption, most houses had gas ducted heating, and the electricity use of the gas ducted heater was monitored as a proxy for the gas consumption as this was cheaper and easier, and there is a linear relationship between the electricity and gas consumption. Householder surveys were conducted before and after the retrofits to assess householder satisfaction with the upgrades, their perceived impacts, and to identify any issues or unintended impacts caused by the retrofits.

The impact of the upgrades was determined from a ‘differential analysis’ that compared the pre- and post-retrofit monitoring periods, and sought to remove any behavioural and weather related variability. Due to the relatively short monitoring periods involved, these factors can reduce the accuracy of the energy saving estimate. A full description of the methodology used in each trial can be found in the various trial reports [2].

3.2. Estimation of heating energy savings

Where the upgrades were expected to result in heating energy savings, the metered energy use of the heaters before and after the retrofits was used to give a ‘raw’ estimate of the energy savings, based on average daily energy consumption on the days the heating was used. However, as outside temperatures, household occupancy and heater usage can change from day-to-day, and between the pre- and post-retrofit periods, a different approach was used to obtain an estimate of the likely annual energy saving resulting from the upgrades [2]. The metered power consumption data from the heater (1 or 2 minute logging interval), and internal and external temperature data (10 minute logging interval), was used to identify those times when the heating was operating in a steady state condition, and the relevant packets of data extracted for analysis. The average heater power consumption and average difference between internal and external temperatures derived from these data packets was plotted on a scatter diagram, and lines of best fit applied to identify the relationship between heater power consumption and temperature difference. The slope of these lines for the pre- and post-retrofit data was then compared. If an energy saving had been achieved, the post-retrofit line had a smaller slope compared to the pre-retrofit line, as for a given temperature difference the heater power consumption was lower. This approach was used to estimate the percentage saving achieved, and this was applied to an estimate of the annual gas consumption of the heater derived from energy billing data to estimate the annual energy saving (refer to specific reports [2] for full details).

3.3. Overview of the Retrofit Trial results

The detailed descriptions and results of the various Retrofit Trials are available in the reports [2] on each trial which can be downloaded from Sustainability Victoria's website, and key findings from the trials are provided below:

- **Draught sealing** – Blower door testing was used to measure the air leakage rate in 16 houses as they were progressively draught sealed using a range of common measures. The average initial natural air leakage rate was found to be 1.8 air changes per hour, and this was reduced by 54% when a comprehensive package of measures with an average commercial cost of $1,001 was applied. An estimated average heating energy saving of 10.5% was achieved for an average payback of 7.5 years. The key draught sealing measures were found to be general caulking, evaporative cooler outlet covers, exhaust fan covers, sealing external doors and sealing wall vents.
- **Cavity wall insulation** – Hydrophobic granulated rockwool was pumped into the external wall cavity of 15 houses, at an average cost of $4,440. This achieved estimated average heating energy savings of 15.5% for an average payback of 29 years. At four of the houses, savings in the range of 19% to 27% were achieved. The upgrades improved thermal comfort and increased internal temperatures when the heating was not operating. This is currently a low volume industry with only a few companies operating, and there is potential for lower costs if the volume of insulation work undertaken increased.
- **Gas heating ductwork replacement** - Old gas heating ductwork was replaced with new high efficiency (R1.65) ductwork at 8 houses, for an average cost of $2,849. Infrared imaging showed that duct surface temperatures decreased by around 7^{o}C after the retrofits, and holes, rips and tears in the old ductwork that allowed hot air to escape were eliminated. Estimated average energy savings of 14.1% were achieved, for an average payback of 16.1 years. The cost effectiveness of this upgrade may be better if undertaken at the same time as when an old gas heating furnace is replaced.
- **Window film secondary glazing** – 'Heat shrink' window film was used to produce a double-glazing effect on windows in the main living areas of 8 older houses, for an average commercial cost of $504 ($84 if undertaken as a DIY project). Infrared imaging of the windows showed that the film reduced winter heat losses. Condensation and draughts were also reduced in some houses. The heating energy savings were harder to determine in this trial, but estimated to be around 4%, giving an average payback of 11.6 years at commercial rates, and 1.9 years as a DIY project. The condition of the window frames and preparation before applying the film were found to be critical issues for successful installation.
- **Halogen downlight replacement** – 12 volt halogen downlight lamps located in the main living areas of 16 houses were replaced with low energy lamps. Light levels were found to be 49% lower in the four houses where CFLs were used as the replacement, and increased – by 28% in general circulation areas and 16% in benchtop areas – in the 12 houses where LEDs were used. There were also significant differences between CFLs and LEDs for customer satisfaction, lighting usage and energy savings. Daily hours of lighting use increased by 37.7% where CFLs were used and remained the same where LEDs were used. The average energy saving was 57% for CFLs and 80% for LEDs, and the average payback was 3.4 years for CFLs and 7.9 for LEDs. The cost of the LED lamps has come down significantly since the Trial, and they can now often be installed for free under the Victorian *Energy Saver Incentive* Scheme.
- **Gas water heater replacement** - Old gas storage water heaters were replaced with high efficiency gas water heaters at 6 houses, five with 5-Star storage systems and one with a 6-Star instantaneous system. Gas and hot water consumption, hot and cold water temperatures, and ambient air temperature were measured, and used to derive data on daily hot water use and daily hot water task, as well as the daily profile of hot water use across the day. The results show that hot water use for the average 2.5 person Victorian household (around 101 L/day) is much less than that used as the basis of Gas Energy labelling for water heaters (200 L/day). The estimated average gas saving was 18.8% for an average payback of 10.3 years if the replacement is undertaken at end of life of existing unit. The new gas instantaneous water heater performed much better than the new storage units, achieving an energy saving of 68%.
- **Clothes dryer replacement** – Conventional electric clothes dryers were replaced with high efficiency heat pump clothes dryers at 4 houses, most of which were heavy dryer users. The electricity use of the clothes dryers was monitored to assess the energy savings, and EES developed a novel technique to estimate the size of the washing load dried based on measured energy use. It was found that the average load size dried was only 1.5 kg, much less than the rated capacity of the dryers. The average energy per load cycle dried decreased from 1.55 kWh to 0.48 kWh (68%). Overall there was an increase in total load dried per day after the retrofits, reducing the energy saving to 59%. The estimated average

annual energy saving was 623 kWh per year ($171), giving a payback of 9 years on the differential cost of a new heat pump dryer.
- **Refrigerator replacement** – Older refrigerators were replaced with new high efficiency models at 7 houses. The electricity consumption of the refrigerators and ambient air temperature were monitored. The average energy saving was estimated to be 616 kWh/yr ($169 per year), or 67%. The average additional cost of the new high efficiency fridges compared to the market average fridge was $637, giving an average payback of around 4 years if undertaken at the end of life of the existing refrigerator.
- **Swimming pool pumps** - Older single-speed pool pumps were replaced with 8-Star 3-speed pool pumps at 8 houses, and the electricity consumption of the pool pumps was monitored. Householder satisfaction with their pool pump increased significantly after the replacement, mainly due to the lower noise, lower energy use and better quality pool water. Very large energy savings (75%) are possible if the 3-speed pumps can run pump for most of the time on the lowest speed setting, but this is not always possible. An estimated average energy saving of 1,040 kWh per year was achieved, or 50% saving, giving payback of 2 years on the differential cost of the high efficiency pump compared to a standard pump.

3.4. Evidence for a Rebound Effect

Economists often assume that there will be a direct rebound, or take-back effect, from efficiency upgrades due to the cost of the energy service being cheaper afterwards, and that this will reduce the level of energy savings achieved [4]. The Retrofit Trial data was analysed to see if there was evidence of a rebound effect. For example, in the gas heating ductwork trial a rebound would mean that either the heating was operated for longer hours or the thermostat setting was increased after the retrofits. In this case, the evidence (Figure 5) suggested the heating was used in the same way after the retrofit as before, and there was no rebound. In most Trials there did not seem to be a rebound, although there were some exceptions. There was a distinct rebound when CFLs were used to replace halogen downlights, but none where LEDs were used – this seemed to be more of a 'technology effect' than an economic rebound. Hot water use increased at two of the gas water heater trial houses, but at one house this was due to the original unit being faulty. In clothes dryer trial the average load of clothes dried each day increased by 22%, reducing the expected saving by around 15%.

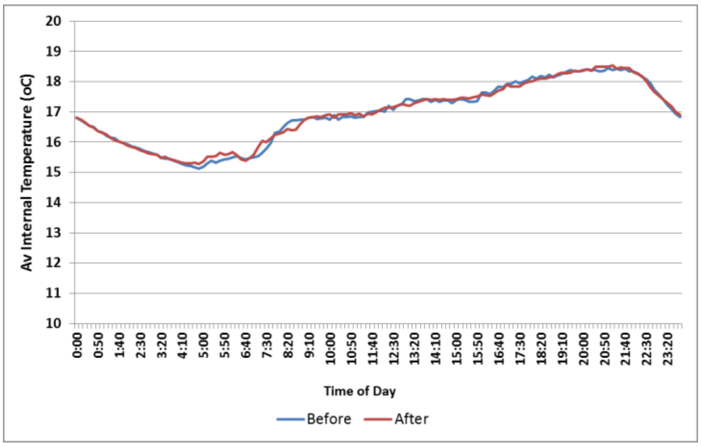


Fig. 5. Average daily temperature profiles in houses that had gas heating ductwork upgraded, before and after retrofit

Acknowledgements

In addition to the households that participated in our various studies SV acknowledges the contribution of the organisations that were contracted to implement them, including Moreland Energy Foundation Ltd, EnviroGroup Pty Ltd, RMIT Centre for Design, Air Barrier Technologies and Energy Efficient Strategies.

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