REPORT

Window Film Secondary Glazing Retrofit Trial

Sustainability Victoria

VICTORIA State Government

Window Film Secondary Glazing Retrofit Trial

January 2017

Authorised and published by
Sustainability Victoria,
Level 28, Urban Workshop
50 Lonsdale Street Melbourne
Victoria 3000 Australia

Accessibility
This document is available in PDF
and Word format on the internet at
www.sustainability.vic.gov.au

ISBN 978-1-920825-21-8

Foreword

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

In 2009 Sustainability Victoria commenced a program of work to address these information gaps. Through the *On-Ground Assessment* study data was collected from a reasonably representative sample of 60 existing (pre-2005) 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 has been to *implement* energy efficiency upgrades in houses and assess the actual impacts achieved. Through the *Residential Energy Efficiency Retrofit Trials* we have implemented key energy efficiency retrofits[1] in existing houses and monitored 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 have also sought to identify practical issues which need to be taken into consideration when these upgrades are implemented.

The *On-Ground Assessment* study found that the installation of new double-glazing to replace existing single-glazed windows was the third most effective measure for improving the energy efficiency of the building shell of existing Victorian houses, but that due to the high cost of this measure it was also one of the least cost-effective energy efficiency retrofit measures. The installation of window film secondary glazing on existing windows can have an insulating effect similar to double-glazing, but is substantially cheaper and, if undertaken as a DIY project, is one of the most cost effective ways of improving the thermal performance of windows.

In this report we present the results of our *Window Film Secondary Glazing Retrofit Trial,* which was undertaken in 8 houses in 2013. Special heat shrink window films were applied to the frames of windows in the main living areas of the houses to create a double-glazing effect. Infrared thermal imaging was used to assess the winter heat losses from the existing windows prior to retrofit, and compare this with the heat losses from the windows after the film had been applied. 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 window film retrofits.

The thermal imaging undertaken as part of the *Retrofit Trial* suggests that installing window film on the frames of existing single-glazed windows resulted in reduced winter heat losses through these windows[2]. The majority of households experienced this as an increase in the thermal comfort of their houses and as a reduction in the difficulty of heating them. The improvements were linked to the rooms in which the film was installed being warmer, heating more quickly and retaining the heat better and, in

---

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

[2] The installation of the film should have also resulted in reduced heat gains through the windows during summer, but this issue was not investigated as part of this study.

some cases, a reduction in draughts. The film was found to reduce or eliminate problems with condensation on the windows in many of the houses. A number of households also reported that they were now able to reduce the heater thermostat settings slightly at times and still feel comfortable. By reducing winter heat losses from windows in the living areas, the window film retrofits were also expected to lead to heating energy savings, and therefore reduced heating costs.

Analysis of the data collected during the *Window Film Secondary Glazing Retrofit Trial* suggests that applying the film to existing windows in the living areas of the houses resulted in a modest reduction of winter heating energy use, in the range of 3% to 4% on average (although at one house estimated savings of 12.1% were achieved). This is broadly consistent with the results of the *OGA* study, which found that replacing single-glazed windows with double-glazed windows in the heated area of houses would result in an average heating energy saving of 5.7%. The savings achieved using the window film were expected to be lower than this, as only windows in the living areas of the houses had the film applied and it was not always possible to achieve the optimal spacing between the outer pane of glass and the window film in the *Retrofit Trial* houses.

While the energy savings achieved in the *Retrofit Trial* were fairly modest, the window film is relatively cheap, and if installed as a DIY project was found to result in a payback on the energy bill savings of around 2 years, making this one of the more cost-effective energy efficiency upgrades.

The *Retrofit Trial* has also found that the condition of the window frames, and the preparation of the frame and inside of the window, are critical issues for the successful installation of the window film.

Acknowledgements

This study is based on the analysis of data and information collected from window film secondary glazing 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, installation of the window film on existing windows in heated living areas, 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 window film retrofits, and to prepare a brief project implementation 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 *Window Film Secondary Glazing Retrofit Trial* below.

Project conception, design & funding, and project oversight	Sustainability Victoria
Lead contractor / project manager	EnviroGroup Australia Pty Ltd
Household recruitment and liaison	EnviroGroup Australia Pty Ltd
Data collection, householder surveys, and meter installation	EnviroGroup Australia Pty Ltd
Window film installation	EnviroGroup Australia Pty Ltd
Project implementation report	EnviroGroup Australia Pty Ltd
Analysis of data from 8 houses and final report	Sustainability Victoria

Contents

Abbreviations and Acronyms

Approx.	Approximately
Av.	Average
c	cents
$CO_{2\text{-}e}$	Carbon dioxide equivalent
°C	Degrees Celsius
Diff.	Difference
Elec.	Electricity
Ex.	Excluding
GHG	Greenhouse gas
HER	House Energy Rating
K	Degrees Kelvin. By convention this is used when referring to a temperature difference. A difference of 1°C is 1 K.
kt	Kiloton (1 kt = 1,000 Tonnes)
kW	Kilowatt, used to measure electrical power consumption (1 kW = 1,000 Watts)
kWh	Kilowatt-hour, used to measure electrical energy consumption. (1 kWh = 1,000 Wh = 3.6 MJ)
GWh	Giga-watt hours (1 GWh = 1,000,000 kWh)
m	metres
MJ	Megajoule, used to measure energy consumption
No.	Number
OGA	On-Ground Assessment
PJ	Petajoule, used to measure energy consumption (1 PJ = 1,000,000,000 MJ
SV	Sustainability Victoria
Temp.	Temperature
W	Watts, used to measure electrical power consumption
Wh	Watt-hour, used to measure electrical energy consumption

Glossary

Building shell	The key (external) elements of a house, including walls, roof/ceiling, floor and windows. The thermal properties of these building shell elements play an important role in determining the overall energy efficiency of a house.
Conversion efficiency	The ratio of the useful energy output divided by the energy input. In this report it is used in reference to the heating equipment.
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.
U-Value	This is a measure of how readily a window conducts heat. It is expressed in Watts/m^2K, or the rate of energy transfer per square meter in Watts for a temperature difference of one degree Kelvin.

1. Introduction

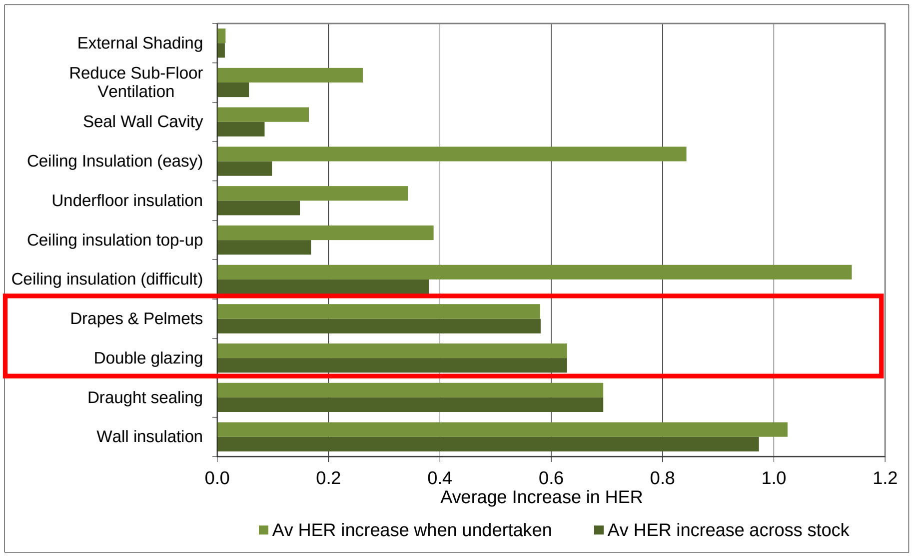
Background to the trial

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) 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 relative impact of 11 different building shell upgrades on the energy efficiency of existing houses, as measured by the House Energy Rating (HER). The HER is a number from 0 to 10 which rates the energy efficiency of a house's building shell. Houses which have higher HERs are more naturally comfortable, have lower heating and cooling requirements, and therefore are more energy efficient. The average HER of the 60 existing houses which participated in the *OGA* study was only 1.81, much lower than the minimum HER of 6.0 which is required for new houses built today. The impact of the different building shell upgrade measures on the average HER of the houses is shown in Figure 1, both the average increase across all houses and the average increase in those houses in which the measures were implemented. [SV 2015] Two measures which reduce heat transfer through single-glazed windows – double glazing and drapes and pelmets – were ranked within the top four measures in terms of their effectiveness for increasing the average HER, with both leading to an average increase in HER of around 0.6 across the stock of houses studied.

FIGURE 1: IMPACT OF BUILDING SHELL UPGRADES ON THE AVERAGE HER OF THE 60 *OGA* STUDY HOUSES



Through the *OGA* study we also assessed the cost-effectiveness of a total of 21 different building shell, lighting and appliance energy efficiency upgrades which could be applied to the houses which participated in the study. The results of this analysis are summarised in Table 1 ranked in the order of increasing payback [SV 2015] – the results have been normalised to show the estimated average savings and costs for the 60 houses studied.

TABLE 1: AVERAGE IMPACT OF ALL UPRADE MEASURES, ACROSS THE STOCK OF 60 *OGA* STUDY HOUSES

		Av. Energy Saving (MJ/Yr)						
Across stock	**% Houses Applied To**	**Gas**	**Elec**	**Total**	**Av. GHG Saving (Kg/Yr)**	**Av. Saving ($/Yr)**	**Av. Cost ($)**	**Av. Payback (Yrs)**
LF Shower Rose	56.7%	1,333	69	**1,402**	95	$57.9	$48.8	0.8
Ceiling Insulation (easy)	11.7%	958	32	**990**	64	$19.3	$78.6	4.1
Lighting	93.3%	-	1,202	**1,202**	365	$93.5	$535.8	5.7
Draught Sealing	98.3%	7,809	221	**8,030**	496	$153.9	$1,019.8	6.6
Clothes Washer	55.0%	135	16	**152**	12	$24.9	$190.9	7.7
Water Heater – High Eff. Gas	58.3%	460	1,004	**1,463**	330	$58.2	$477.3	8.2
Ceiling Insulation (difficult)	33.3%	1,630	68	**1,698**	111	$33.8	$278.2	8.2
Heating	80.0%	6,239	215	**6,454**	411	$125.9	$1,110.6	8.8
Refrigerator	86.7%	-	1,202	**1,202**	365	$93.5	$1,103.7	11.8
Reduce Sub-Floor Ventilation	21.7%	589	12	**601**	36	$11.2	$166.7	14.9
Seal Wall Cavity	50.0%	903	24	**927**	57	$17.6	$270.4	15.3
TV	95.0%	-	696	**696**	273	$54.1	$964.3	17.8
Ceiling Insulation (Top Up)	43.3%	853	22	**875**	54	$16.6	$335.3	20.2
Underfloor Insulation	40.0%	1,803	10	**1,813**	102	$32.4	$784.7	24.3
Dishwasher	43.3%	-	112	**112**	34	$10.4	$258.1	24.9
Clothes Dryer – Heat Pump	45.0%	-	353	**353**	107	$27.5	$727.7	26.5
Cooling	40.0%	-	160	**160**	49	$12.5	$464.8	37.3
Wall Insulation	95.0%	5,283	130	**5,412**	331	$102.5	$3,958.7	38.6
Drapes & Pelmets	100.0%	2,209	54	**2,263**	139	$42.9	$2,035.9	47.5
Double-Glazing	100.0%	2,278	66	**2,344**	146	$45.0	$12,145	270
External Shading	31.7%	-	9	**9**	3	$0.7	$463.6	694
Total (ex Double-Glazing)		**30,203**	**5,610**	**35,813**	**3,434**	**$989**	**$15,274**	**15.4**
Total (ex Drapes & Pelmets)		**30,273**	**5,621**	**35,894**	**3,441**	**$991**	**$25,383**	**25.6**

Note that energy bill savings in Table 1 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. 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 model is used if the existing appliance is at or past its average lifetime, with a linear interpolation used between.

While the installation of drapes and pelmets and the installation of double-glazing were found to have wide applicability across the stock of *OGA* study houses, and were capable of moderate energy bill savings (around $45 per annum on average), they were amongst the least cost effective measures studied, due to their fairly high implementation cost. This was particularly the case for double-glazing, which had an estimated average installation cost of just over $12,000 per house and a payback on the energy savings of around 270 years. It is important to note however that in this case the cost of double-glazing was based on removing the existing single-glazed windows in heated areas of the houses and replacing them with new double-glazed windows. In addition to the full cost of the new double-glazed window units, there are considerable labour costs involved with removing the existing windows and installing new double-glazed windows[3].

Replacing existing single-glazed windows with new double-glazed windows is the most expensive option for improving the overall thermal performance of the windows in an existing house, and cheaper options are available. Secondary glazing systems allow either an extra pane of glass or acrylic material to be installed in the existing window frame in conjunction with the existing pane of glass to create a double-glazing effect, at around 50% to 60% of the cost of new double-glazing. The installation of a close-fitting, thick curtain housed in a box pelmet can also achieve an effect similar to double-glazing (when the curtain is drawn) at around 15% to 20% of the cost of new double-glazing. The lowest cost option is to install special heat shrink films on the existing window frame to create a still air gap between the existing pane of glass and the film. This can be installed commercially or as a DIY project at significantly lower cost – in this case the basic material cost is around $10 per m^2 and there is an additional cost of around $50 per m^2 if the film is installed commercially[4].

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 have *implemented* key energy efficiency retrofits[5] in existing houses and monitored 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 have also sought to identify practical issues which need to be taken into consideration when these upgrades are implemented.

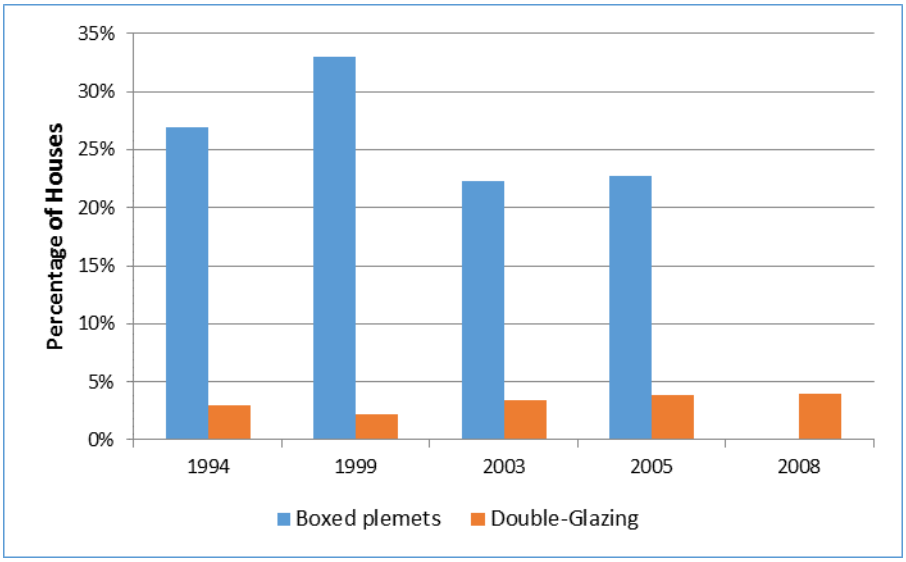
As part of the *Retrofit Trials* we investigated the installation of window film secondary glazing on existing single-glazed windows. Data from the Australian Bureau of Statistics [ABS 2008] suggests that despite the cold climate in Victoria only a relatively small percentage of the windows in existing houses have treatments which significantly reduce heat losses through the windows in winter. Statistics on the incidence of window treatments are presented in Figure 2. While the incidence of double-glazing has increased slightly since 1994, the incidence of boxed pelmets seems to have actually decreased, possibly due to changing fashions in interior design. By 2005 only around one-fifth (22.7%) of houses had curtains housed in a boxed pelmet, and only 4% of houses had double-glazed windows. Based on the results of SV's *On-Ground Assessment* study, we estimate that if the approximately 70% of pre-2005 Victorian houses which seem to have little protection from heat loss through windows in winter had double-glazing or drapes and pelmets installed, this would generate total Victoria-wide energy bill savings of around $84.2 Million per annum and total greenhouse savings of around 273 kt per annum across the Victorian residential sector.

[3] Double-glazing is a much more cost-effective option in new homes, extensions and in homes where existing windows need to be replaced. In this case the additional cost is simply the difference in the cost between the double- and single-glazed window units. The cost is much lower and therefore the paybacks are also much lower.

[4] These figures are based on the installation costs for the *Window Film Secondary Glazing Retrofit Trial*.

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

FIGURE 2: INCIDENCE OF WINDOW TREATMENTS IN VICTORIAN HOUSES[6]



As a low cost option for improving the thermal performance of existing single-glazed windows, window film secondary glazing has the potential to both increase the energy efficiency of the building shells of existing houses and achieve savings on both heating and cooling energy bills. However, we are not aware of any systematic studies which have looked at the energy savings which can be achieved from this retrofit in practice, the suitability of these films to different existing window types, and the likely householder acceptance of these products.

How the trial was undertaken

The *Window Film Secondary Glazing 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 *Trial* involved a number of key steps:

- Houses were recruited by EnviroGroup to participate in the trial. The key target was existing houses which had reasonably large single-glazed windows in heated living areas of the home with little winter heat loss protection, a gas heater which used a fan to circulate heated air, 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 3;
- The installation of the window film was undertaken around the end of June, to coincide with the middle of the monitoring period. The window film was installed by EnviroGroup using 3M Window Insulation Kits;
- EnviroGroup took photographs of the windows before and after the retrofits were undertaken, to help show the visual impact of installing the film. They also took thermal images of the windows during the installation process to provide an indication of the impact that the films can have on heat losses through the windows. Examples of these photographs and thermal images are provided in Chapter 3, and the photographs and thermal images from all houses are provided in Appendix A1;
- Metering equipment was installed at the houses to assist us to monitor the impact of the window film secondary glazing retrofits. Small stand-alone battery operated temperature

[6] Note that data specifically on boxed pelmets was not available for 2008 – in this year 59% of houses were shown as having window treatments designed to stop hot or cold, which includes drapes in boxed pelmets.

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 heater. This was set to record the average power consumption of the gas heater at one-minute intervals during the day. This allowed us to identify the times when the 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 consumption[7]. The metering equipment was installed around one month prior to the window film 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 trial 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 heating[8]. Where possible, estimates were undertaken for a number of recent years for each house, temperature corrected[9] 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, their perceptions of any changes in the effectiveness of their gas heating system, and their acceptance of the window film;
- All surveys, data and images collected during the *Window Film Secondary Glazing Retrofit Trial* were provided to Sustainability Victoria and analysed to determine the impacts of the window film retrofits. The results of this analysis are presented in this report.

Overview of the report

In Chapter 2 we give a general overview of approaches to reducing winter heat losses through single-glazed windows, including secondary glazing. This is intended to put the work undertaken during window film secondary glazing trial in context.

In Chapter 3 we provide an overview of the houses which were recruited for the *Window Film Secondary Glazing Retrofit Trial*, and present the results of our analysis. In particular we look at the impact of the window film retrofits on the winter heat losses from the windows, householder perceptions of any changes in thermal comfort and the effectiveness of their heating systems as well as their general

[7] All 8 houses had gas ducted heating. 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 electrical power 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.

[8] 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.

[9] 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.

acceptance of the window film retrofits, 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 window film retrofits, and the ways in which these can be overcome.

In Chapter 4 we present our summary and conclusions.

More detailed data and analysis is presented in the Appendices. In Appendix A1 we provide copies of the photographs and thermal images of the windows which were taken during the retrofit process. These give an indication of the extent to which the window films reduce winter heat losses through the windows. In Appendix A2 we present the detailed results of the householder surveys which were used to assess the qualitative impacts of the window film 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 retrofits.

2. Reducing winter heat losses through single-glazed windows

Introduction

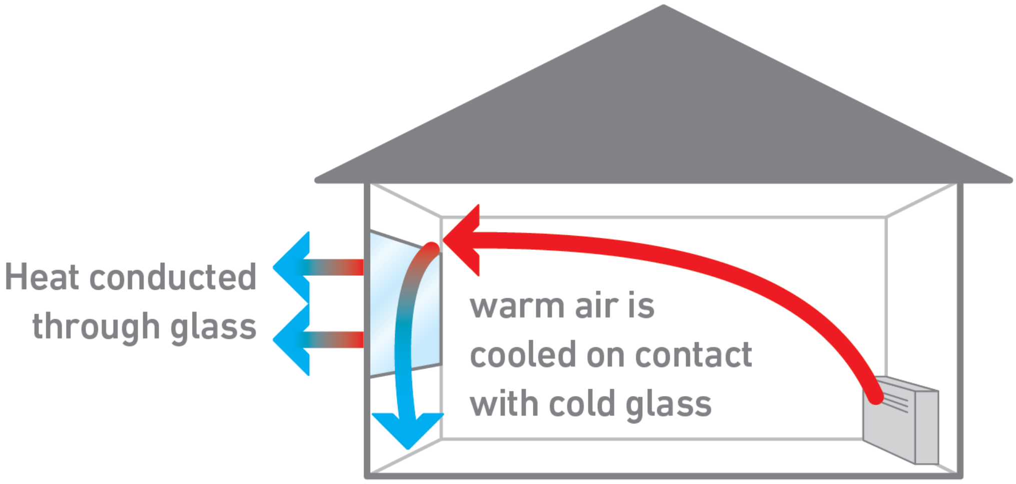
Windows are an important component of the building shell of a house. They let in light during the day, allow outside views, provide security and assist with ventilation. They also have an important impact on the comfort and energy efficiency of a house in both summer and winter. In summer, east, west and north windows are exposed to the sun's radiant heat (sunshine) and this can lead to overheating if they are not adequately shaded. Windows also allow heat from the outside air to enter the house via conduction through the glass. In winter, north facing windows allow access by the low-angled sun – providing fee heating – but bare single-glazed windows can be a significant source of conducted heat loss in winter and also reduce occupant comfort through radiation losses and the creation of draughts.

The two key mechanisms for winter heat loss through windows are illustrated in Figure 3. Glass is a very good conductor of heat, so the inside surface of a single-glazed window will be quite close to the outside air temperature. Warm room air which comes into contact with the cold internal surface of the glass loses heat to the glass, and the cooled, denser, air sinks to the ground where it can create a draught. In addition to this, body heat is radiated to the cold glass surface, further reducing the comfort of occupants. [SEAV 2001a].

The area between the cold glass of the window and the heated internal air is sometimes referred to as the "zone of discomfort" [SGG 2014], and represents a transition between the cold temperature of the glass and the internal room temperature. The poorer the thermal performance of the window, the larger this zone of discomfort will be.

It is estimated that 10% to 20% of winter heat losses *from an uninsulated home* occur through the windows [SEAV 2001b]. Where houses have some insulation and/or are reasonably well draught-sealed, the proportion of winter heat losses which occur through windows will be higher. In houses that have well insulated ceilings, walls and floors and good draught sealing, the windows can be the major source of heat losses in winter.

FIGURE 3: WINTER HEAT LOSSES THROUGH WINDOWS



Winter heat losses from windows occur through a number of mechanisms [EH 2009, SGG 2014]:

1. By *convection*[10] from the warm room air to the colder surfaces of the window glass and frame. The larger the temperature difference between the room air and the window, and the greater the circulation speed of the room air, the higher the rate of heat loss will be;
2. By *radiation* from warmer surfaces in the room to the cold surface and frames of the window. The rate of heat transfer depends on the temperature difference between the surfaces, and also the emissivity of the surfaces. The lower the emissivity, the lower the rate of heat transfer;
3. By *conduction* through the window glass and window frame – the heat losses occur from the warmer inner surface of the window to the colder outer surface. Glass is generally the most conductive part of the window, although metal window frames can also be a significant source of heat loss (see below);
4. By *air leakage* through the window, either by letting in cold outside air or allowing warm inside air to escape. This is called *air infiltration losses* and can occur even when the windows are closed. The extent of air leakage will depend on the type of windows[11], the tightness of fit between the openable and fixed parts of the window, and on the condition of the frames. In older windows which are comprised of a number of individual window panes which are held in the frame using putty, the deterioration of the putty can lead to greater air infiltration losses[12]; and,
5. Finally, by a combination of convection and radiation from the outer surface of the window to the cold outside air and colder outside surfaces. Heat losses will be greatest when outside temperatures are very low and in higher wind speeds.

The key heat loss mechanism through window glass in winter is conduction. The U-value (or U_w when it refers to the entire window) is a measure of how readily a window conducts heat. It is expressed in Watts/m^{2}K, or the rate of energy transfer per square meter in Watts for a temperature difference of one degree Kelvin[13] across the window. When it refers to the entire window it covers the glass, window frame and any seals and spacers. [DoI, 2014] The higher the U-value of a window the greater the winter heat losses through the window will be.

The U-value of typical single glazed windows is around 6 Watts/m^{2}K, although the exact value will depend on the type and thickness of the glass and the type and design of the window frame. The total rate of heat loss through a window with an area of A square meters for a temperature difference between inside and outside the house of T ^{o}C (or K) is expressed by the formula [DoI, 2014]:

Heat loss rate (Watts) = U_w x T x A

For example, for a window with the dimensions of 2.4 m x 2.1 m (5.04 m^2), a U_w value of 6 Watts/m^{2}K, an inside temperature of 20^{o}C and an outside temperature of 5^{o}C (or a temperature difference of 15 K), the rate of heat loss through the window would be 454 Watts. Houses with large areas of bare single-

[10] This is the transfer of heat between a solid surface and a liquid or a gas.

[11] Air infiltration losses from double-hung timber sash windows can be quite high. Laboratory testing undertaken for English Heritage on one timber sash window found that air infiltration losses accounted for 60% of the overall winter heat losses from the window. They found that this could be cut to 20% if the frame was repaired and the window draught-sealed. [EH 2009]

[12] For further discussion of how the thermal performance of older style windows can be improved by renovating the frames fixing putty see [EH 2009] and [HS 2010].

[13] This is essentially the same as a 1^{o}C temperature difference, although by convention temperature differences are expressed in Kelvin rather and Celsius.

glazed windows will experience significant heat losses through the windows in winter, making them hard and expensive to heat.

As noted above, both the glass and the window frame have an impact on the overall level of conducted heat transfer through a window. The impact of different types of window frames is as follows [DoI 2014]:

- ***Aluminium*** is a good conductor of heat and standard aluminium frames can reduce the overall thermal performance of windows. A single-glazed window with a standard aluminium frame will generally have the highest U-value and therefore the greatest heat losses in winter. In summer, aluminium frames are good at conducting heat from the outside air into the house. The frames also absorb a lot of radiant heat from the sun, especially dark coloured frames, and conduct it inside. A thermal break is used in *thermally improved* aluminium frames to reduce the heat conducted through the frame. It separates the exterior and interior sections of the window frame using a layer of material which has low thermal conductivity;
- ***Timber*** is a much better insulator than aluminium, so a single-glazed window with a timber frame has a lower overall U-value, and therefore lower winter heat losses, than the same window with a standard aluminium frame. The timber frames require larger tolerances between the openable parts of the window and the fixed frame, and this can result in gaps that allow greater air infiltration losses than aluminium windows, unless good draught seals are installed;
- ***Un-plasticised polyvinyl chloride (uPVC)*** has similar insulation properties to timber, and windows with uPVC frames will have similar overall U-values to timber windows. The frames can be moulded into complex profiles that provide excellent air seals, meaning that their air infiltration losses can be lower than for timber framed windows;
- ***Composite frames*** have an outer aluminium section combined with either a timber or uPVC inner section. These combine the low maintenance and durability of aluminium frames with the improved thermal performance of the timber and uPVC frames.

In addition to heat loss, condensation can also be a problem for single-glazed windows in winter [SEAV 2001a]. Condensation can occur when warm moist air inside the house comes into contact with the cold inner surface of the glass or window frame. Sustained condensation throughout the winter months can cause mould and fungus growth, which can lead to health issues and can also degrade the window frame. [DoI, 2014]

Improving the thermal performance of a window will also generally reduce any condensation problems. Reducing internal sources of moisture and good ventilation can also reduce condensation problems related to windows. Extended heating will also reduce condensation problems, but at the expense of high winter heating energy use and high energy bills.

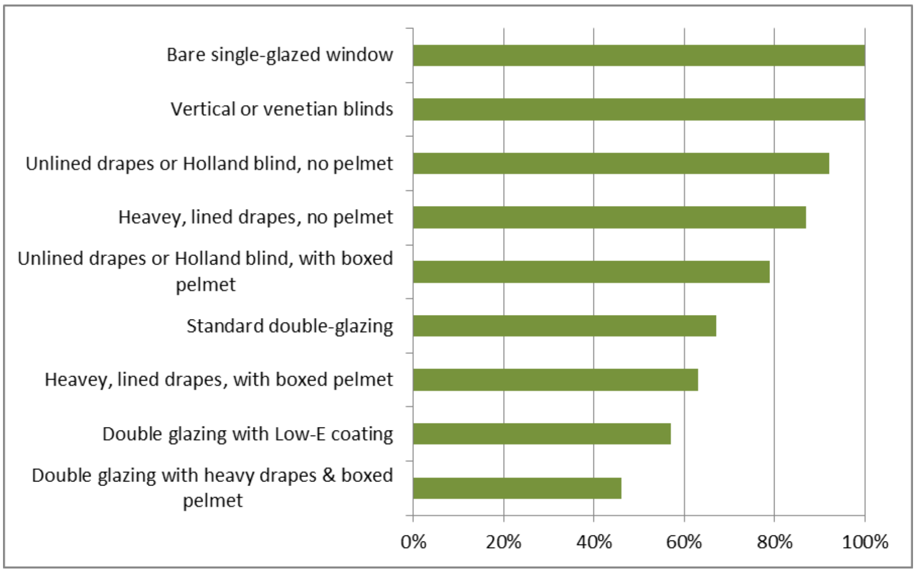
Approaches to reducing heat transfer

There are a range of options for reducing winter heat losses through single-glazed windows, including [SEAV 2001a]:

- Double-glazing
- Secondary glazing
- Curtains and blinds
- Shutters
- Low emissivity films

Some options involve replacing existing single-glazed windows with better performing windows (e.g. double-glazing), while others involve applying different treatments to the existing single-glazed windows (e.g. single-glazed window with a heavy curtain and boxed pelmet). A general comparison of the effectiveness of some of the key options at reducing winter heat losses is provided in Figure 4 [SEAV 2001a], with heat losses compared to a bare single-glazed window. This figure shows the typical performance of the various options, although in practice a range of performance outcomes could be achieved. In particular, better performing double-glazed units are available (see Figure 6 below).

FIGURE 4: COMPARISON OF WINTER HEAT LOSSES THROUGH WINDOWS – IMPACT OF THE TYPE OF WINDOW PROTECTION



The following window treatments have little or no effect in reducing winter heat loss [SEAV 2001a]:

- Venetian (including timber) and vertical blinds. These allow heated air to pass through the gaps between the slats and offer little resistance to heat loss. They may improve occupant comfort slightly by creating a barrier between the cold glass and occupants;
- Laminated and thickened glass; and
- Reflective coatings and tinted glass. These reduce radiant heat and light entry throughout the year, and are mainly employed to reduce heat gains through east and west facing windows during winter.

Double glazing

Double-glazed windows consist of two panes of glass separated by a sealed air space, typically between 6 to 20 mm wide – an air space of around 13 to 16 mm gives optimum thermal performance[14]. The sealed air space between the panes of glass acts as an insulator, and reduces the rate of heat transfer through the window while still allowing natural light and radiant heat from the sun to pass through. A desiccant material is incorporated into the sealed air space to absorb moisture and prevent condensation inside the double-glazed unit.

Double-glazing also reduces noise transmission through windows as well as the potential for condensation on the inside of the window [SEAV 2001a].

[14] http://windows.lbl.gov/adv_Sys/hi_R_insert/GapWidths.html

FIGURE 5: DOUBLE-GLAZED WINDOW UNIT

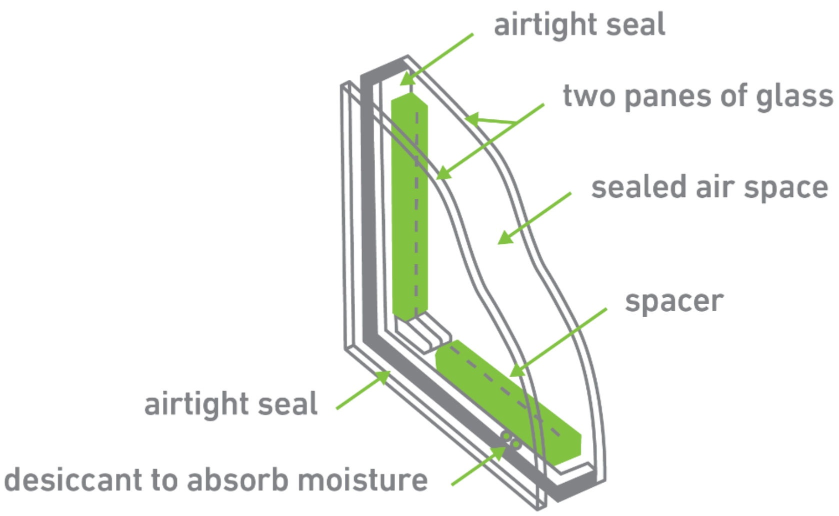
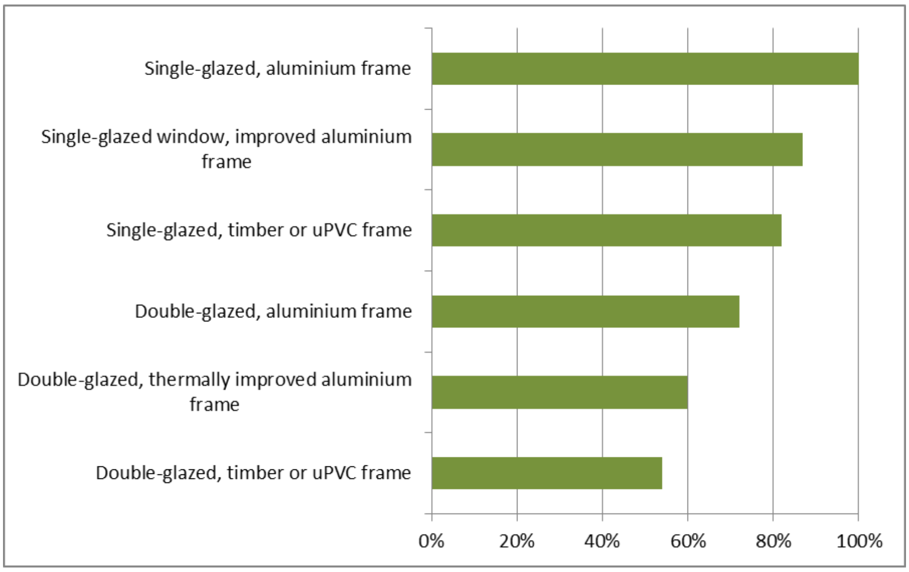


FIGURE 6: COMPARISON OF WINTER HEAT LOSSES THROUGH WINDOWS – IMPACT OF THE WINDOW FRAME



A range of treatments can be applied to double-glazed windows to improve their thermal performance:

- Frames with better performance than standard aluminium frames can be used. This includes thermally improved aluminium frames (with thermal breaks), and timber, uPVC and composite frames. The impact that different framing materials can have on the performance of standard single- and double-glazed windows is indicated in Figure 6;
- The use of blinds and curtains – ideally closely-woven, tight fitting and housed in a boxed pelmet. The impact of this is indicated in Figure 4;
- The use of low-emissivity coatings on the internal pane of glass (see below and Figure 4);
- Rather than being filled with air, some double-glazed window units are filled with gases such as argon or krypton, which have better thermal properties.

Secondary glazing

Rather than installing a double-glazed window, an additional pane of glass or clear acrylic can be fitted to an existing single-glazed window to form a double-glazed window within the existing window frame. It is essential that the air space between the panes of glass is well sealed and has a desiccant added to absorb any moisture present in the space between the panes of glass. [SEAV 2001a] Windows which have secondary glazing applied have thermal properties similar to double-glazed windows, although the overall performance of the window will depend on the size of the air gap which can be achieved and the type of window frame. Deviation from the optimal air gap of 13 to 16 mm and a standard metal window frame will reduce the performance of the window. The application of the secondary glazing might also reduce the infiltration losses from air leakage through the existing window, giving a further improvement in performance. This especially the case with windows comprised of segments where the glass is held in place with putty.

A special transparent film can also be fitted to the frame of an existing window, creating an air space between the film and the glass. A heat shrink film is attached to the window frame using transparent double-sided tape and then shrunk tight using a hair dryer. [SEAV 2001a] This is the lowest cost option for creating a double-glazing effect and is the one which was used in the *Window Film Secondary Glazing Retrofit Trial*. As with secondary glazing in general, the thermal properties of the window with this treatment applied will depend on the type of window frame and the size of the air gap which can be achieved.

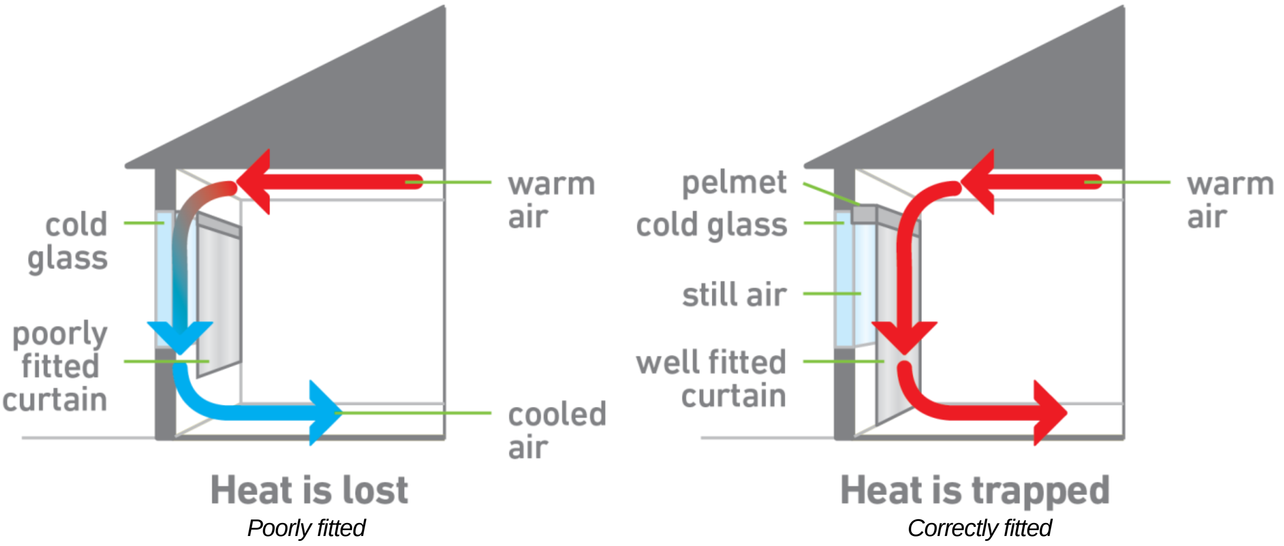
FIGURE 7: WINDOW FILM APPLIED TO WOODEN FRAME OF WINDOW

Curtains and blinds

Closely-woven, close-fitted curtains are an effective way to protect windows from winter heat loss. A snug fit is required on both sides of the window to stop warm room air contacting the cold inside surface of the glass, and also at the top of the curtain to stop warm air from moving down behind the curtain and cooling. This can be achieved with boxed pelmets or solid barriers above the curtain rail, or the curtain positioned within the window reveal. Curtain tracks which provide a return of curtain to the wall to give a better seal achieve even better results. The difference between a poorly fitted curtain and a properly fitted curtain is illustrated in Figure 8. The aim is to create a still air gap between the curtain and the existing pane of glass, as this provides an insulating effect in the same way as the still air gap between the two panes of glass in a double-glazed window. [SEAV 2001a]

Tightly fitted Holland, Roman, Austrian or multi-cell blinds using closely woven fabrics are can also reduce winter heat losses through windows. As with curtains, for optimum performance the blinds must be tightly fitted against the window surrounds or within the window reveal. [SEAV 2001a]

FIGURE 8: IMPACT OF CURTAIN INSTALLATION ON HEAT LOSSES THROUGH A WINDOW



A properly installed curtain or blind can have a thermal performance similar to a double-glazed window *when the curtain is closed*. The overall performance of the curtain will depend on how it is used by the householder. To have the maximum effect on reducing winter heat losses the curtain needs to be closed when the heating is operating. However, when the winter sun is shining on east, north and west facing windows, the curtains should be opened to allow the free heat from the sun to enter the house.

Shutters

Shutters can be installed on the inside or outside of the window. For maximum impact on reducing heat losses they should fit tightly against the window frame with no gaps between louvres so that there is a still air gap between the shutter and the existing pane of glass. [SEAV 2001a]

Low emissivity films

Low emissivity (low-E) glass has a special coating or film applied that reflects radiant heat back into the room. It is generally used in double-glazed windows and can improve their thermal performance by up to 20% compared with standard double-glazing. [SEAV 2001a] Low-E films can also be applied to existing single-glazed windows to improve their thermal performance.

3. Results of the window film secondary glazing retrofit trials

Housing Sample

Details of the 8 houses which participated in the *Window Film Secondary Glazing Retrofit Trial* are shown in Table 2. Pictures showing the types of windows to which the film was applied at each house are provided in Appendix A1. All houses had gas ducted heating as the main form of heating. The estimated annual gas use for heating of the houses which participated in the *Trial* was 52,499 MJ per year. This is lower than the average gas use for gas ducted heating found in the *OGA* study houses (62,689 MJ per year).

TABLE 2: DETAILS OF THE HOUSES WHICH PARTICIPATED IN THE RETROFIT TIRAL

House No.	No. of People	Approx. Age of House (Yrs)	Construction Details*	Floor Area (m^2)	Type of Windows & Coverings	Location & Area of Retrofitted Windows	Heating Gas Use (MJ/Yr)
WF1	2	90	Wall - WB; Floor - ST; Some of ceiling insulated	130	Wooden frame, many with leadlight. Venetian blinds and some drapes.	Kitchen / Living (8.5m^2)	41,813
WF2	4	55	Wall - BV; Floor - ST; Ceiling & walls insulated	70	Steel frame. Drapes on curtain rail.	Kitchen / Living (10.4m^2)	82,141
WF3	4	50	Wall - BV; Floor - ST; Ceiling insulated	120	Steel frame. Some bare, some with Roman blinds.	Kitchen / Living (10.5m^2)	59,357
WF4	4	75	Wall - BV; Floor - ST; Ceiling insulated	200	Steel frame. Inner & outer drapes, capped at top.	Lounge (12.6m^2)	69,269
WF5	4	8	Walls - WB; Floor - ST; Ceiling & walls insulated	205	Wooden frame. Holland blinds.	Upstairs living & downstairs hallway (10.1m^2)	43,964
WF6	1	85	Wall – WB; Floor - ST; Ceiling & some of wall and floor insulated	120	Aluminium & some wooden frame. Most have drapes.	Kitchen / Living & front entrance (7.5m^2)	40,149
WF7	6	50	Wall - CB; Floor - ST; Ceiling & some of floor insulated	220	Wooden frame. Vertical blinds.	Kitchen / Living & Lounge (14.5m^2)	59,935
WF8	3	80	Wall - WB; Floor - ST; Ceiling insulated	140	Wooden frame, double sash. Some bare, some with venetian blinds. Some with leadlight.	Kitchen / Lounge (7.6m^2)	23,366
Av	**3.5**	**63**		**163**		**10.2 m^2**	**52,499**

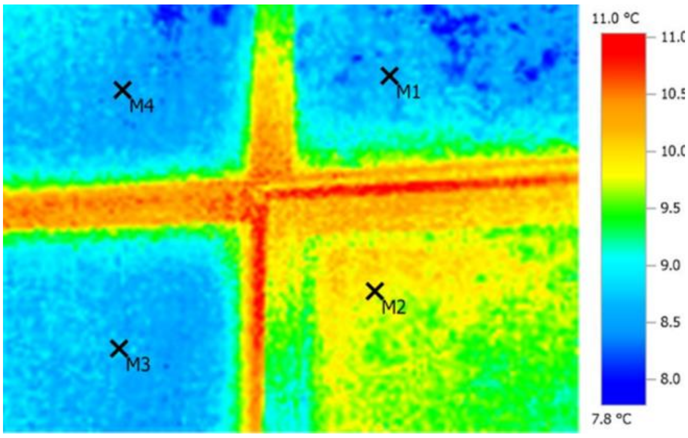
* **Walls:** WB = weatherboard; CB = cavity brick; **Floors:** ST = suspended timber.

Reduction of heat losses from the windows

Thermal images were taken of some windows during the retrofit process to help illustrate the impact that the installation of the window film had on the reduction in winter heat losses through the windows. The thermal images are colour coded and show the temperature on the surface of the windows and other objects in the images. All images taken for the different houses are provided in Appendix A1, and an example is provided in Figure 9. This shows the impact of the window film on the external temperature of one window in house WF2. Windows with film applied would be expected to be warmer than windows without film applied when viewed from the inside, and colder than windows with film applied when viewed from the outside. In Figure 9, the sections of window with the film applied (see M1, M3 and M4) are around 1ºC colder than the section of window without the film applied (M2), when viewed from outside the house.

FIGURE 9: IMPACT OF WINDOW FILM ON EXTERNAL WINDOW TEMPERATURE, HOUSE WF2

Window viewed from outside living room



M1 (film) – 8.7ºC; M2 (no film) – 9.8ºC; M3 (film) – 8.6ºC; M4 (film) – 8.5ºC

TABLE 3: AVERAGE TEMPERATURE OF GLASS SURFACE BEFORE AND AFTER APPLICATION OF WINDOW FILM

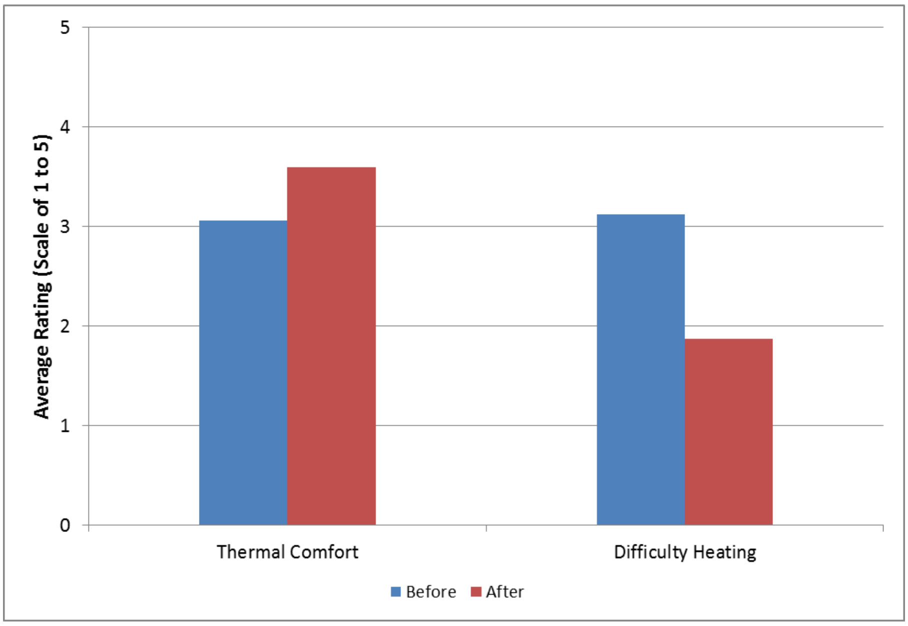
House No.	*Av. Internal Window Temperature viewed from Inside (ºC)*			*Av. External Window Temperature viewed from Outside (ºC)*		
	Without Film	With Film	Difference	Without Film	With Film	Difference
WF1	18.6	19.1	0.5	-	-	-
WF2	-	-	-	9.8	8.6	-1.2
WF3	-	-	-	13.6	12.4	-1.2
WF4	-	-	-	13.3	12.4	-0.9
WF5	11.2	11.7	0.5	10.9	10.3	-0.6
WF6	12.9	13.7	0.8	13.0	12.3	-0.7
WF7	13.1	14.3	1.2	-	-	-
WF8	11.2	11.9	0.7	-	-	-
Average	**13.4**	**14.1**	**0.7**	**12.1**	**11.2**	**-0.9**

We have analysed the thermal imaging data provided in Appendix A1 to estimate the average surface temperature of the windows with and without the film applied. 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, all windows with the film applied behaved as expected. The internal surface temperatures of the windows with the film applied were higher that the internal surface temperature of the windows without the film applied, with an average temperature difference of 0.7ºC between windows with and without film (range of 0.5 to 1.2ºC). Conversely, the external surface temperatures of the windows with the film applied were lower than the external surface temperatures of the windows without the film applied, with an average temperature difference of -0.9ºC between windows with and without film (range -0.6 to -1.2ºC). This suggests that the window film is indeed reducing the winter heat losses through the windows.

Householder perceptions

Surveys were conducted before and after the window film secondary glazing was installed 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 10, and the detailed householder responses are reported in Appendix A2. Overall the householders reported that the level of thermal comfort of their houses increased after the window film retrofits had been undertaken (from an average score of 3.1 to 3.6)[15]. This corresponded with a reduction in the perceived difficulty of heating their homes (from an average score of 3.1 to 1.9)[16].

FIGURE 10: SUMMARY OF HOUSEHOLDER SURVEY RESULTS



Thermal comfort

Comments on level of thermal comfort following the retrofit
The back living area is a bit warmer and easier to heat. (WF1)
Definitely less breezy, air flow is reduced. Improved comfort in the living room. Living space retains heat a lot better. The heater doesn't go on for as long. The house heats up quicker, a lot quicker. (WF2)
Less draughts in the back corner. Makes the room more comfortable. The house heats up quicker. (WF3)
The lounge is more comfortable. Retains the heat more. (WF4)
The house is heating up a bit quicker. Seems to be retaining heat better in the lounge room. Sitting in front of the TV in the sitting area is more pleasant, not as cold. (WF7)
Less draughty and fewer cold patches in the house. The heater doesn't seem to be turning itself on as often. When sitting on the couch there is no draught on neck. The living space is definitely more comfortable. (WF8)

[15] The level of winter comfort was ranked on a scale from 1 (extremely uncomfortable) to 5 (extremely comfortable).
[16] The difficulty of heating was ranked on a scale from 1 (small difficulty) to 5 (extremely difficult).

The pre-retrofit rating of thermal comfort (3.1) suggests that most householders felt that their houses were reasonably comfortable before the window film was installed. This may have been because all houses had gas ducted heating as the main form of heating - as long as this is adequately sized it should be able to maintain comfortable temperatures throughout a house. A selection of comments from the householders on changes to the comfort of their houses following the retrofits is provided above. In general, the rooms in which the window film retrofits were undertaken were perceived as being warmer, heated up more quickly and were better at retaining the heat, and a number of householders also noted a reduction in draughts[17]. Large single-glazed windows cool the room air when it is cold outside and this cold air sinks to floor level where it can create a draught, and the application of the film should reduce this effect to some extent. The film should also reduce the size of the "zone of discomfort" around the window, making it more comfortable for people seated close to the window.

When asked specifically about heat retention in rooms following the retrofits, six out of the eight houses reported that the rooms in which the retrofits had been undertaken now retained the heat longer.

Difficulty heating

Half of the households which participated in the study had little difficulty heating their house prior to the window film retrofits, and the other half had some difficulty (giving a difficulty rating of 4 out of 5). Overall the houses reported that their houses were easier to heat after the retrofits (average difficulty rating decreased from 3.1 to 1.9), although three of the houses did not perceive any change in the difficulty of heating their house. A selection of comments from householders concerning the impact of the window film retrofits on the difficulty of heating their homes is provided below. A key reason for the perceived reduction in difficulty of heating their houses was that the rooms heated up more quickly following the retrofits.

Comments on the difficulty of heating the home

After – Very easy to heat the house. Doesn't take long to heat. (WF1)

Before – Takes a long time to heat in the morning. Can feel a breeze in the house. *After* – Back rooms heat up a lot quicker. (WF2)

Before – Time to heat up is an issue. *After* – Very easy to heat. (WF3)

Before – Not too difficult to heat but need heater on constantly. *After* – Relatively easy to heat the house. (WF4)

Before – If the house is not heated during the day I find it takes a while to get comfortable heating in the lounge, kitchen, TV and dining rooms. *After* – Heats up quickly – ducting system is good for living and bedrooms. (WF5)

Changes in the use of the heater

Householders were asked if there had been any changes in the way they used their heating following the retrofits, and also if there had been any other behavioural changes. The majority of houses (6 out of 8) reported that there had been no changes in the way in which their heater was used. Two of the houses (WF6 and WF8) reported some changes (see comments box below). Both of these houses reported that they were now able to reduce the thermostat setting slightly at certain times, and this in itself could result in an energy saving – every 1^{o}C lower that the thermostat is set to in winter can result in around a 10% reduction in the energy used for heating. Two houses also reported some other changes after the retrofit: WF8 reported that they now made more use of the living room as it was now

[17] This may have been because the installation of the window film reduced air leakage through the existing windows or because the film reduced the draught of cooled air coming off the window.

more comfortable; and, WF2 reported that they no longer had to always close the curtains at night to keep the heat in and were now not going to install pelmets on their windows. Both curtains with pelmets and windows with secondary glazing film applied reduce the heat losses through windows on a cold night.

Comments on changes in the use of the heating & other behavioural changes

Use of heating

Have tried setting the temperature at 19.5ºC rather than 20ºC as a trial to reduce gas use. On very cold nights set it back to 20ºC. (WF6)

Still leave it on. Turned the heater lower overnight – used to leave it on. Now turn the heater low when out of the house. Before it would be working all the time. (WF8)

Other behavioural changes

Sometimes leave the curtains open at night. Before would have closed up the house because of the cold. We were going to install pelmets, but not anymore. (WF2)

I used to take the baby into the other room to play, but now spend more time in the living room. (WF8)

Appearance of the window film

Following the retrofits householders were asked to comment on the appearance of the window film. The majority of the households (7 out of 8) did not have any problems with the film, although two of these (WF2 and WF3) reported that there were some visual impacts from the film, including increased glare and reflection, some distortion and some minor flaws and streaks across the film. The household which did have an issue with the installation of the film (WF4) reported noticeable textures in the film. Some of the issues with the visual impact of the film may have been reduced if greater care was undertaken during the installation process.

Comments on appearance of the window film

Sometimes it can be a bit distorting. There is more glare / reflection since [it was] installed. It doesn't really impact on us though. (WF2)

No. People comment that they don't notice the film. At night you can notice it more. There are some minor flaws in the film, streaks across the film. (WF3)

Yes. Expected the film to be clearer. Can notice it, textures in the film. (WF4)

Chalk textas were used on the film and was cleaned off easily with no mess. (WF7)

Issues and unexpected benefits

Householders were asked to comment on any issues or problems which arose as a result of the window films retrofits, and also on any unexpected benefits. The main issue, reported in half of the houses, was that the film had peeled off on some of the windows. This issue was rectified in all houses – it is related to the type and state of the window frames, and the strength of the tape used (see below for further information). If properly installed the window film seems to be quite robust – one house reported that even determined efforts by their young son had not resulted in the film peeling.

> **Comments on issues and unexpected benefits**
>
> ***Issues***
>
> Some windows have peeled. They have since been replaced. Condensation has formed on several windows. Water may be trapped in the window. (WF2)
>
> The film has peeled off in some places. Stronger tape has now been used in these spots. (WF3)
>
> No [issues]. Our young boy likes to poke at the film and try to peel it off, but it hasn't peeled off yet. (WF4)
>
> The window film has peeled on two windows, which have since been rectified. (WF6)
>
> A couple of windows have peeled and been fixed. We have to be careful not to puncture the door film when opening the doors. (WF7)
>
> ***Unexpected benefits***
>
> Condensation has been reduced on a number of windows. All widows used to get condensation, but not anymore. (WF2)
>
> The condensation at the bottom of the windows is gone. This is a big positive for window film. We will install it on other windows in the bedrooms because of this. (WF3)
>
> Yes definitely. No condensation on the windows with window film compared to other windows. (WF6)

One house also reported that condensation was forming inside the gap between the window and the film. This may have been because the inside of the windows and frames were not adequately dried before the film was installed. The use of a desiccant in conjunction with the film is one potential way to reduce the likelihood of this issue.

The main unexpected benefit, reported in three of the houses, was that the film had reduced or eliminated condensation on the windows.

Economics of retrofitting

The thermal imaging undertaken as part of the trial suggests that installing window film on the frames of existing single-glazed windows in the living areas of the 8 houses which participated in the *Window Film Secondary Glazing Retrofit Trial* has resulted in reduced winter heat losses through these windows[18]. The majority of households experienced this as an increase in the thermal comfort of their houses and as a reduction in the difficulty of heating them. The improvements were linked to the rooms in which the film was installed being warmer, heating more quickly and retaining the heat better and, in some cases, a reduction in draughts. A number of households also reported that they were now able to reduce the heater thermostat settings slightly at times. By reducing winter heat losses from windows in the living areas, the window film retrofits were also expected to lead to heating energy savings, and therefore reduced heating costs.

The level of energy savings achieved by the window film retrofits would be expected to be fairly modest. Analysis undertaken for the *OGA* study suggested that replacing existing single-glazed windows with double glazing could achieve average heating energy savings of around 5.7% and average cooling energy savings of around 6.7%. For the houses which had gas ducted heating this translated into an estimated annual gas saving of 3,394 MJ per year, average electricity savings of 87 kWh per year, and an overall average energy bill saving of around $66 per year. [SV 2015] The energy savings achieved by the window film secondary glazing retrofits would be expected to be lower than this as it is generally not possible to achieve the optimal air gap of around 13 to 16 mm when the window film is installed, and

[18] The installation of the film should have also resulted in reduced heat gains through the windows during summer, but this issue was not investigated as part of this study.

only the windows in the main living areas had the window film applied, rather than all windows in the heated areas of the houses.

All houses which participated in the *Trial* 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 day[19].

As part of the *Window Film Secondary Glazing Retrofit Trial* we sought to estimate the heating energy savings which were achieved from the window film retrofits, by monitoring the energy use of the heating, and the 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 to be made[20] – if there was a 5% reduction in electricity use, it was assumed that this would correspond to a 5% reduction in gas use.

The meters installed on the electricity supply to the gas ducted heaters were set to measure the average electrical power consumption over each 1 minute interval throughout the day. As well as allowing the daily electricity consumption of the heaters to be calculated[21] this enabled us to identify those times of the day when the heater was operating to heat the house. Gas ducted heaters are operated by a thermostat. When switched on both the gas burner and air circulation fan operate to heat air and circulate the heated air through the house via the ductwork. Once the internal air temperature has reached the thermostat setting, the gas burner and air circulation fan switch off, and will remain off until the internal air temperature falls below the thermostat setting by a certain amount[22]. 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.

[19] 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*.

[20] In a number of the *Comprehensive Retrofit Trials* Sustainability Victoria has monitored both the gas and electricity consumption of the gas ducted heaters. This has confirmed that there is essentially a linear relationship between the gas and electricity consumption.

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

[22] 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.

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.

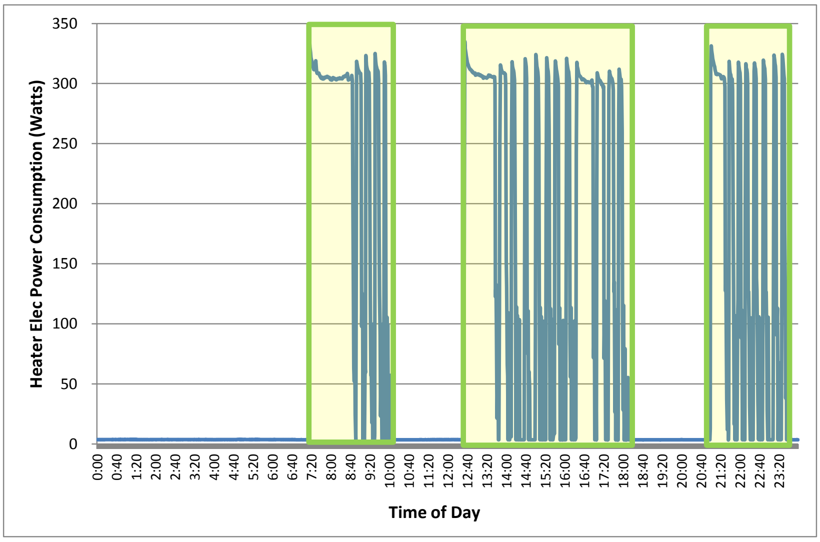
In addition to reducing winter heat losses, the installation of the window film would be expected to also reduce summer heat gains – heat conducted through the windows – and in houses which use air conditioning for summer cooling this should lead to additional energy savings. These savings were not estimated and were not included in the payback analysis, as they would be expected to be quite small.

An example of the data collected from the metering equipment is provided in Figure 11. The graphs show the data collected by the meters throughout the day for House WF6 on 17 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 three separate periods, in the morning from around 7:20 to 10:00 am, in the afternoon from around 12:40 to 18:20 pm and in the evening from around 20:50 to 23:30 pm.

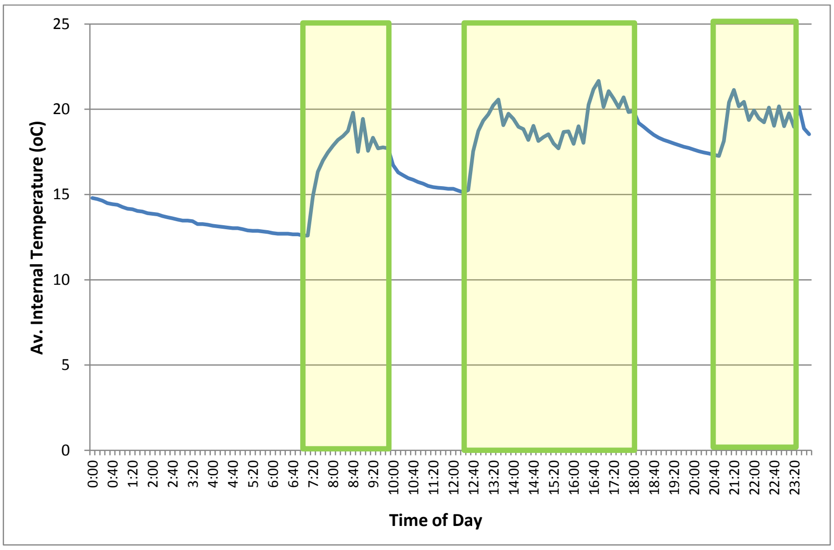
The first graph shows the electricity consumption of the gas ducted heater. In this case the heater has an electricity consumption of around 310 Watts when it is operating and an electricity consumption of around 3.6 Watts when it is in standby mode. The heater operated (cycled on and off) for a total of 11.1 hours on this day, with the heater fan operating for a total of 8.9 hours during this period. The daily electricity consumption of the heater was 2.20 kWh, with 2.14 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 initially to around 18^{o}C when first switched on in the morning and then increased to around 20^{o}C late in the afternoon. Later in the evening the thermostat seems to have been set to around 19^{o}C. The final graph shows the average temperature between the inside of the house and outside. The average temperature difference during the time that the heater was operating was 8.8^{o}C.

The monitoring results for all houses which participated in the *Window Film Secondary Glazing 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.

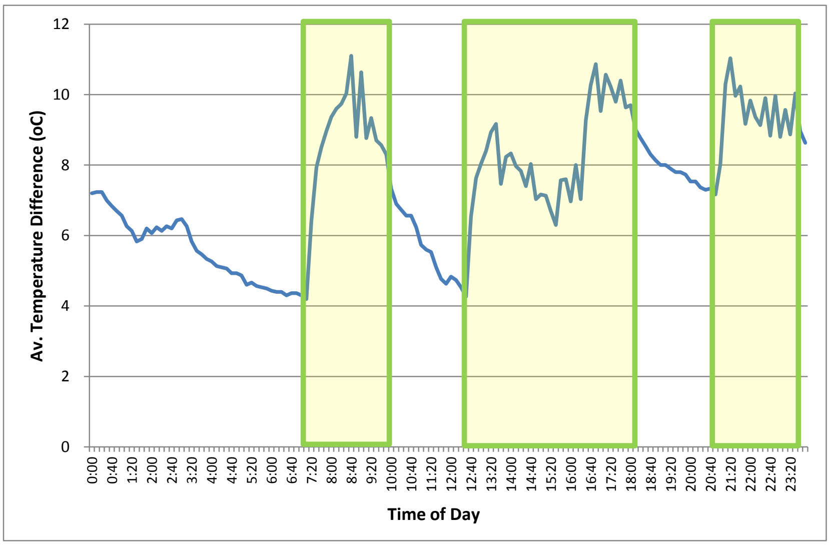
FIGURE 11: METER DATA FOR HOUSE WF6, 17 JUNE 2013



Electricity consumption of gas ducted heater



Average internal temperature in heated area



Average temperature difference – heated area to outside

The 'raw' results for the *Window Film Secondary Glazing Retrofit Trial* are provided in Table 4. Taken on face value, these suggest that an average heating energy saving of 11.3% was achieved across the 7 houses for which adequate metering data was available, somewhat higher than the upper limit of a 5.7% average saving found in the *OGA* study. In 5 of the 7 houses the electricity use and, by implication, the gas use of the gas ducted heaters was lower after the retrofits, with the savings ranging from 1.6% (WF5) to 29.8% (WF3). However, some caution needs to be used when interpreting these raw 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 THE RETROFITS

House	Weighted Av. Temperature Difference when Heating (ºC)			Av. Heater Operating Time (hrs/day)			Av. Elec. Use of Heater when Operating (kWh/day)		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
WF1	8.05	7.08	-12.0%	7.29	8.30	13.9%	1.82	1.87	3.1%
WF2	8.47	7.57	-10.6%	12.11	11.15	-7.9%	2.51	2.27	-9.7%
WF3	10.30	9.75	-5.4%	15.60	12.03	-22.9%	2.69	1.89	-29.8%
WF4	8.57	7.46	-12.9%	19.50	18.02	-7.6%	2.92	2.34	-19.7%
WF5	8.99	7.84	-12.8%	4.03	3.96	-1.7%	1.50	1.48	-1.6%
WF6	11.20	8.90	-20.5%	5.91	5.77	-2.4%	1.27	1.01	-20.4%
WF7	*Data was not available for this house*[23]								
WF8	8.45	7.97	-5.6%	15.31	15.04	-1.7%	3.13	3.19	1.9%
Av.	**9.15**	**8.08**	**-11.7%**	**11.39**	**10.61**	**-6.9%**	**2.26**	**2.01**	**-11.3%**

An inspection of the data in Table 4 shows that energy use increased slightly in two of the houses after the retrofits. In WF1 the electricity use of the heater increased by 3.1% after the retrofit. In this case this is likely to be because the operating time of the heater increased by 13.9% after the retrofit. In WF8 the electricity use of the heater increased by 1.9% after the retrofit. It is not evident why this is the case, as both the average temperature difference and average operating time decreased slightly after the retrofit.

[23] It was found that it was not possible to install an electric power meter on the electricity supply to the gas ducted heater at this house, so no electricity consumption data is available. While a temperature sensor was installed on one of the gas ducted heater's outlet registers to give an indication of when the heater was operating (see Appendix A3), it was not possible to accurately estimate the operating time and therefore average internal temperature and temperature difference using this data.

The raw data collected during the *Window Film Secondary Glazing Retrofit Trial* was further analysed in an attempt to obtain a more accurate estimate of the energy savings achieved. Two approaches were used:

1. Data on the average temperature difference and average operating time of the heater, combined with data on the thermal properties of the windows before and after retrofit and the efficiency of the gas ducted heaters, was used to estimate the heating energy saving from the *reduction in conducted heat losses* through the windows expected from the retrofits;
2. Data on the electricity consumption of the heater, average temperature difference and operating time of the heater was used to estimate the *"technical" energy saving* achieved. This is the saving which is independent of the temperature difference between the inside and outside of the house 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.

Reduction in conducted heat losses

The installation of the window film should reduce the U-value of the windows to which it is applied[24], reducing the heat losses through the window when the heater is operating and thereby reducing heater energy consumption. As was noted in Chapter 2, the heat loss rate (Watts or MJ/hr) through the windows is a function of the total window area, the U-value of the windows and the temperature difference across the windows. The total annual energy losses through the windows (kWh or MJ) are then the product of the heat loss rate and the total annual operating time (hours) of the heater. Dividing these annual energy losses by the conversion efficiency[25] of the heater allows an estimate to be made of the annual heater energy use which is required to account for the window energy losses.

For the purpose of our analysis we assumed that the existing windows had a U-value of 6.9 Watts/m^{2}K (single-glazed aluminium frame) and that the retrofitted windows had a U-value of 4.2 Watts/m^{2}K (double-glazed, aluminium frame with a 6 mm air gap), which means the application of the window film should reduce winter heat losses through the window by around 39%[26]. We used the following methodology to estimate the energy savings expected from the window retrofits for each house:

- Data on the annual gas heating consumption for each house was combined with data on the total heating degree days (HDD) in 2013 and the HDD during the monitoring period for each house to estimate the gas heating use during the monitoring period;
- The total operating time of the heater and average temperature difference between inside and outside the house when the heating was operating during the monitoring period was estimated from the data collected during the pre- and post-retrofit monitoring periods;
- The average window heat loss rate over the monitoring period was estimated for the existing windows and the retrofitted windows by multiplying the total window area by the assumed U-value and average temperature difference, and this was converted into a total energy loss by multiplying by the total operating time of the heater over the monitoring period;

[24] The thermal imaging suggests that the application of the film has reduced the heat losses through the windows, as when the heating is operating the temperatures are lower on the outside of the window and higher on the inside of the window where the film has been applied.

[25] This is the ratio of the heat energy output of the heater divided by the energy input to the heater.

[26] The actual percentage reduction in heating energy use will be somewhat less than this, and will depend on the windows' contribution to total heat losses from the houses. Key factors here will be the window area compared to the total area of the houses' external surfaces (ceiling, walls, floor), the level of insulation, and the amount of air leakage from the houses.

- Data on the make, model and age of the gas ducted heater was used to estimate the conversion efficiency of the gas ducted heating system (gas heater and ductwork combined)[27]. This was then used to estimate the gas energy consumption during the monitoring period required to account for the window energy losses, with and without the window film in place. The difference between these figures gave an estimate of the gas energy saving from the retrofit, and this was divided by the estimated gas consumption during the monitoring period to convert it into a percentage;
- This percentage saving was applied to the estimated annual gas and electricity consumption of the heater to estimate the annual energy savings. Current gas and electricity tariffs[28] were applied to the energy savings to estimate the annual energy bill savings, and combined with data on the cost of the retrofits to estimate the payback period.

Table 5 shows the estimated *maximum impact* of the window film retrofits for the seven houses for which adequate data was available, using the method described above. The analysis suggests that the window film retrofits could achieve energy savings comparable to those estimated for double-glazing for the houses which participated in the *OGA* study. The average energy saving across the 7 houses analysed was 6.1% - 3,147 MJ per year for gas and 27 kWh per year for electricity – giving an average energy bill saving of around $63 per year. Based on the average full (commercial) installation cost of $504 this gave a payback of 8.0 years, and based on the lower average DIY cost of $84 this gave a payback of 1.3 years.

TABLE 5: ESTIMATED MAXIMUM IMPACT OF THE WINDOW FILM RETROFITS, BASED ON WINDOW HEAT LOSSES

House No.	Gas Heating Energy Use (MJ/Yr)	Est. Heating Energy Saving	Est. Gas Saving (MJ/Yr)	Est. Elec Saving (kWh/Yr)	Est. Bill Saving ($/Yr)	Full Retrofit Cost	Full Payback (Yrs)	DIY Retrofit Cost ($)	DIY Payback (Yrs)
WF1^{M}	41,813	4.5%	1,867	14.8	$36.8	$510.0	13.8	$85	2.3
WF2^{H}	82,141	4.2%	3,411	18.5	$64.9	$624.0	9.6	$104	1.6
WF3^{M}	59,357	8.3%	4,954	39.9	$97.9	$630.0	6.4	$105	1.1
WF4^{H}	69,269	10.6%	7,345	55.5	$144.1	$756.0	5.2	$126	0.9
WF5^{M}	43,964	2.2%	947	5.6	$18.1	$606.0	33.4	$101	5.6
WF6^{M}	40,149	3.6%	1,437	6.9	$27.1	$450.0	16.6	$75	2.8
WF8^{L}	23,366	8.8%	2,065	48.0	$49.6	$456.0	9.2	$76	1.5
Av	**51,437**	**6.1%**	**3,147**	**27.0**	**$62.6**	**$504.0**	**8.0**	**$84.0**	**1.3**

However, it should be noted that the estimates presented in Table 5 represent the *maximum level* of savings which might be achieved, and in practice lower energy savings would be expected. Many of the windows which had the window film applied already had some window protection in the form of curtains

[27] Lists of certified gas appliances maintained by the Australian Gas Association allow the Energy Rating of the most heaters to be identified. Where a model could not be identified the Energy Rating was based on the typical Energy Rating of a heater of that age. The Energy Rating can be used to estimate the conversion efficiency of the heater. It was assumed that ductwork that was less than 5 years old had an efficiency of 85%. For each year greater than 5 years the efficiency of the ductwork was reduced by 0.5%. The estimated efficiency of the heating system for each house is provided in the tables in Appendix A3.

[28] A gas tariff of 1.75 c/MJ and an electricity tariff of 28c/kWh was used in the analysis.

or blinds[29], and this would tend to reduce the energy savings achieved as the curtains or blinds would help to reduce the heat losses through the window compared to a bare single-glazed window. The effect of this would depend on the level of effective insulation provided by the curtains and blinds (see Chapter 2), and the extent to which the curtains and blinds were used by householders both before and after the retrofits. No data was collected on how householders used their curtains before and after the retrofits, although in Table 5 we give an indication of the level of protection likely to be provided by the existing curtains and blinds. Where a high level of protection is provided *and* where the curtains are used by the households before and after the retrofits this would be expected to reduce the energy savings by up to 40%.

To obtain a more realistic estimate of the level of energy savings which might be achieved, we re-calculated the savings shown in Table 5 on the basis that the energy savings were reduced by 10% where existing window protection was poor, 25% where existing window protection was medium and 40% where existing window protection was high. The results of this analysis are presented in Table 6. This suggests average winter heating energy savings of around 4.2% across the 7 houses analysed - 2,174 MJ per year of gas and 19.7 kWh per year of electricity – for an energy bill saving of around $43.6 per year. This would give a payback of 11.6 years on a commercial installation and 1.9 years on a DIY installation. This would still make a DIY installation a very cost effective energy saving option for those houses in which the window film could be installed.

TABLE 6: ESTIMATED IMPACT OF THE WINDOW FILM RETROFITS TAKING WINDOW COVERINGS INTO ACCOUNT

House No.	Gas Heating Energy Use (MJ/Yr)	Est. Heating Energy Saving	Est. Gas Saving (MJ/Yr)	Est. Elec Saving (kWh/Yr)	Est. Bill Saving ($/Yr)	Full Retrofit Cost	Full Payback (Yrs)	DIY Retrofit Cost ($)	DIY Payback (Yrs)
WF1^{M}	41,813	3.3%	1,400	11.1	$27.6	$510.0	18.5	$85	3.1
WF2^{H}	82,141	2.5%	2,046	11.1	$38.9	$624.0	16.0	$104	2.7
WF3^{M}	59,357	6.3%	3,716	29.9	$73.4	$630.0	8.6	$105	1.4
WF4^{H}	69,269	6.4%	4,407	33.3	$86.4	$756.0	8.7	$126	1.5
WF5^{M}	43,964	1.6%	710	4.2	$13.6	$606.0	44.5	$101	7.4
WF6^{M}	40,149	2.7%	1,078	5.2	$20.3	$450.0	22.2	$75	3.7
WF8^{L}	23,366	8.0%	1,858	43.2	$44.6	$456.0	10.2	$76	1.7
Av	**51,437**	**4.2%**	**2,174**	**19.7**	**$43.56**	**$504.0**	**11.6**	**$84.0**	**1.9**

Technical energy saving

The raw data collected during the *Retrofit Trial* was further analysed to see if a more accurate estimate of the energy savings could be obtained. The methodology used seeks to estimate the "technical" energy saving, or the saving which is relatively independent of the climatic conditions in the pre- and post-retrofit periods, and also independent of user behaviour. The analysis methodology employed was based on advice provided by Energy Efficient Strategies (EES)[30] and sought to estimate the average

[29] In the "House No." column we have indicated those windows which had some protection from curtains and blinds as well as the level of insulation provided: L = low (e.g. vertical blinds), M = Medium (e.g. Holland blinds or curtain without pelmet), and H = High (e.g. curtain in pelmet).

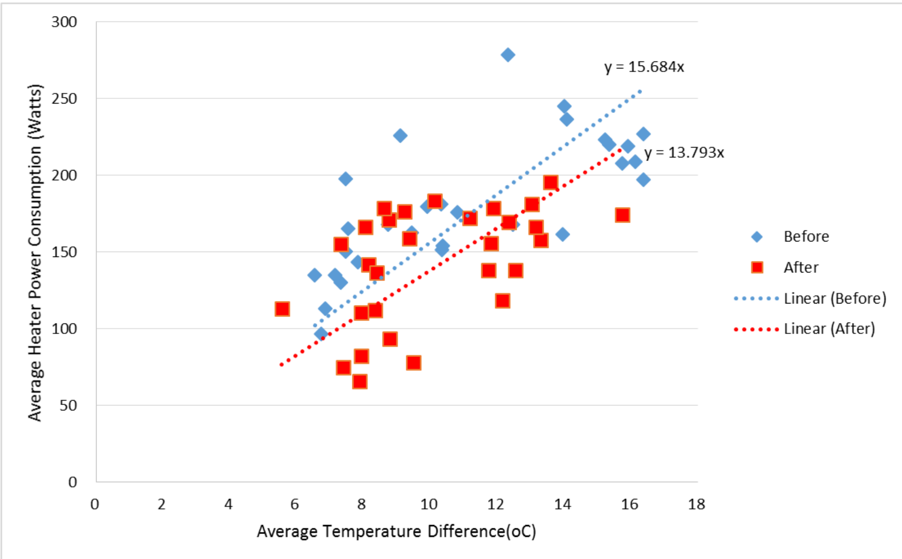
[30] EES were provided with data files for a number of houses which participated in draught sealing, wall insulation and ductwork upgrade retrofit trials and asked to provide advice on the best metric to use to identify the technical savings

power consumption of heater during times of steady state operation. The approach was to manually isolate sections of data when the heater was cycling on and off in a relatively uniform manner, and the internal and external temperature profiles indicated that the heater was displaying steady state operation[31]. In this case the temperature difference profile was fairly flat and tended to oscillate around a certain value. These packets of data were analysed to calculate the average electrical power consumption of the heater (in Watts) and the average temperature difference (in ^{o}C or K) during this time, the data points from before and after the retrofits plotted on a scatter diagram, and a linear regression analysis (with intercept set to zero) used to calculate the slope of the line of best fit for the data sets before and after the retrofit was undertaken. A comparison of the slope of the two lines was then used to estimate the technical energy savings achieved. A lower slope after the retrofits indicates that an energy saving has been achieved, as the heater power consumption is lower for the same temperature difference.

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

An example of the type of graph obtained is shown in Figure 12, and the graphs for all houses are provided in Appendix A3. In this example the estimated technical energy saving resulting from the window film retrofit was 12.06%[32], the highest of all of the houses.

FIGURE 12: SCATTER DIAGRAMS FOR HOUSE WF3



As noted previously, we are using the electricity consumption of the gas ducted heater as a proxy for the gas consumption of the heater, so in Figure 12 the average heater electrical power consumption over

and the methodology to use to derive this metric. The results presented in this report were calculated by Sustainability Victoria.

[31] For example, with reference to Figure 11, this would correspond to the periods between 14:00 to 16:30 pm and 21:30 to 23:30 pm.

[32] The estimated saving is = [1 – (13.793/15.684)] x 100% = 12.06%.

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 for a certain temperature difference should equal the average rate of heat loss from the house. As the temperature difference between inside and outside the house increases, the rate of heat loss from the house increases and the heater needs to provide more heat energy to achieve the same temperature setting, increasing the rate of energy consumption 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 of the heater over the heating period. When the temperature difference is zero, the heat losses will be zero, and therefore no heat input is required from the heater. As is evident from Figure 12, a given temperature difference does not always correspond to the same average rate of heat output – this is likely to be due mainly to different wind or other climatic conditions[33] on different days and also changes in user behaviour (e.g. having some windows or doors open, having curtains open or closed, changing heater settings) on different days.

Installing the window film secondary glazing reduces the rate of heat loss through the windows, and therefore the entire heated area, reducing the heat output required from the heater. This will mean that a given temperature difference between inside and outside the house can be achieved at a lower rate of gas consumption. The slope of the lines of best fit on the scatter diagrams are therefore proportional to average rate of energy consumption for a 1^{o}C temperature difference, and should therefore be lower following the installation of the window film. Thus, the slope of the lines of best fit before and after the retrofits can be used to estimate the energy saving achieved.

The result of applying this methodology to six of the eight houses which participated in the *Retrofit Trial* is provided in Table 7[34]. This shows the estimated annual gas energy use for heating prior to the retrofits, the estimated "technical" heating energy saving as a percentage of the total pre-retrofit consumption, the estimated annual gas and electricity savings and resulting annual energy bill saving[35], retrofit cost and payback period.

The results obtained using the "technical" energy saving methodology (Table 7) are quite different to those obtained from the window heat loss estimate when window coverings are taken into account (Table 6). They suggest that energy savings were achieved for five of the six houses analysed, although for house WF6 the results suggest that energy consumption increased, even though the thermal images for this house and the raw monitoring data (see Appendix A3) suggest an energy saving should have been achieved. For most houses the estimated technical energy savings are somewhat less than the energy savings estimates based on window heat losses. The estimated savings for WF1 were about the same (3.1% vs 3.3%), and for WF3 the estimated savings were substantially higher (12.1% vs 6.3%).

Across the 6 houses analysed the estimated average winter heating energy saving was 2.6% - 1,360 MJ per year of gas and 12.7 kWh per year of electricity – for an energy bill saving of around $27.4 per year. This would give a payback of 20.9 years on a commercial installation and 3.5 years on a DIY

---

[33] 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, including windows. Also, higher wind speeds will increase the pressure differential across the building and increase the air leakage rate of both the house. We did not collect any data on wind speed or pressure differential as part of the *Window Film Secondary Glazing Retrofit Trial*. Humidity and solar access to the house will also impact on the heat loss rate from the house. Whether or not any window coverings such as curtains and blinds are closed will also have an impact on the heat losses.

[34] Data was not available for house WF7 as it was not possible to install a power meter on the gas ducted heater. The heater in WF5 displayed very little cycling behaviour, and so there were not enough data points to prepare a scatter diagram.

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

installation. It is clear that in some cases (WF3, 12.1%) that the application of window film can achieve quite large energy savings. If the seemingly anomalous result for house WF6 is ignored, the estimated average savings become 3.7% - 2,047 MJ per year for gas and 17.3 kWh per year for electricity, for an energy bill saving of $40.7 per year. This would give a payback of 14.6 years on the commercial installation cost and 2.4 years on the DIY installation cost.

TABLE 7: ESTIMATED TECHNICAL SAVINGS FOR THE WINDOW FILM RETROFITS

House No.	Gas Heating Energy Use (MJ/Yr)	Est. Heating Saving	Est. Gas Saving (MJ/Yr)	Est Elec Saving (kWh/Yr)	Est Bill Saving ($/Yr)	Full Retrofit Cost	Full Payback (Yrs)	DIY Retrofit Cost ($)	DIY Payback (Yrs)
WF1	41,813	3.1%	1,298	10.6	$25.7	$510.0	19.9	$85	3.3
WF2	82,141	0.4%	309	1.7	$5.9	$624.0	105.9	$104	17.7
WF3	59,357	12.1%	7,157	59.0	$141.8	$630.0	4.4	$105	0.7
WF4	69,269	1.8%	1,232	9.5	$24.2	$756.0	31.2	$126	5.2
WF6[36]	40,149	-5.2%	-2,079	-10.3	-$39.3	$450.0	-11.5	$75	-1.9
WF8	23,366	1.0%	241	-5.7	5.8	$456.0	78.1	$76	13.0
Av.	**52,683**	**2.6%**	**1,360**	**12.7**	**$27.4**	**$571.0**	**20.9**	**$95.2**	**3.5**
Av. ex WF6	**55,189**	**3.7%**	**2,047**	**17.3**	**$40.7**	**$595.2**	**14.6**	**$99.2**	**2.4**

There are a number of possible explanations for the difference in energy savings estimates derived from the two methodologies employed:

- The technical energy saving analysis methodology may not be accurate enough for the relatively low level of savings which are expected from the window film retrofits. A larger number of data points covering a range of possible climatic conditions may be required to give a more accurate estimate. Note that the data available for house WF6 was quite limited, especially for the pre-retrofit monitoring period. The best data set available was the one for house WF3, and this had the highest estimated saving;
- For house WF6 the heating was operated for a relatively short time each day (around 6 hours), generally over two to three separate periods. This meant that the heater was cycling on and off for only short periods, and this would reduce the accuracy of the results obtained as it reduces the amount of time that the heating is operating under steady state conditions;
- Changes in user behaviour relating to opening and closing curtains before and after the retrofits might account for some of the discrepancies. For example, the occupants of WF2 noted that after the retrofits they no longer needed to close curtains at night to keep the heat in. The curtains in this house provided a fairly high level of protection, so by not closing curtains at night and relying only on the window film they may have increased heat losses during this period;
- Where houses had a reasonably high level of window protection provided by the curtains this may have had a bigger impact on reducing heat loss through the windows than was assumed for the estimates presented in Table 6, further reducing the impact of the window film retrofit. House WF4 had the highest level of protection from curtains, and this may

[36] Note that this heater had a fairly short daily operating time (around 6 hours) broken up into 2 or 3 segments. This meant that the analysed segments of data were only quite short, and this would reduce the accuracy of the analysis.

explain why the estimated technical energy saving is substantially lower than the estimate based on window heat losses;

- The impact of the window film may have been lower than expected from the estimates presented in Table 6, due to the gap between the film and the window being outside the optimal range. No data was collected on the gap that was achieved when the window film was installed; and,
- Changes in climatic conditions during the pre- and post- retrofit monitoring periods may account for some of the discrepancies. For example, if it was winder and there was more rain during the post-retrofit monitoring period, this might account for the lower than expected technical energy saving in some houses and the apparent increase in energy use at house WF6. Data on wind speed, humidity and rain was not collected as part of the *Trial*, so it is not possible to shed more light on this.

The results obtained from this *Retrofit Trial* suggest that any future window film secondary glazing study could be improved by:

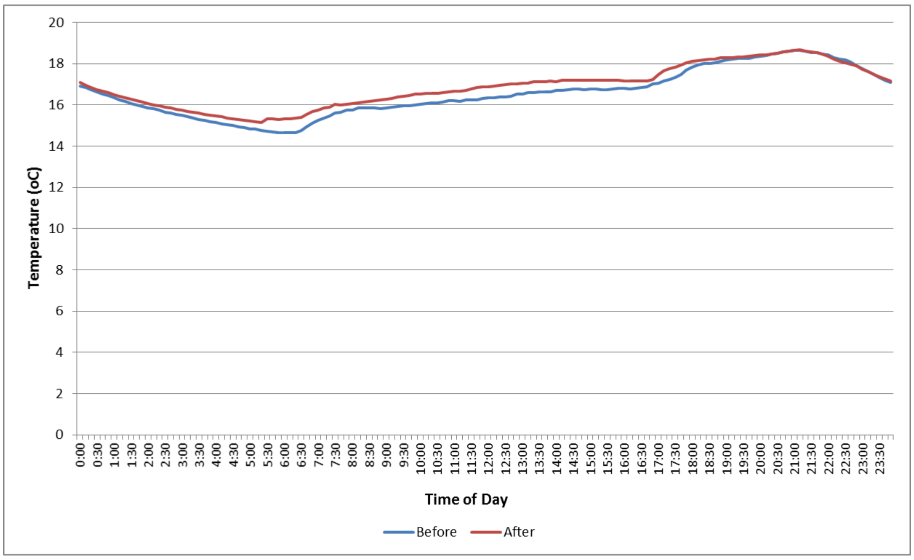
1. Having longer pre- and post-retrofit monitoring periods, so that larger data sets are available for the technical energy saving estimate;
2. Collecting better data on the windows retrofitted, including dimensions, frame type and the gap achieved between the window film and existing pane of glass. This would allow the thermal properties of the windows to be more accurately characterised;
3. Collecting better data on any existing window protection measures such as curtains and pelmets, including householder behaviour relating to opening and closing curtains before and after the retrofits, either through surveys or metering – it may be possible to use proximity meters to determine whether or not curtains are closed, although the cost of doing this could be prohibitive; and,
4. Undertaking air leakage measurements before and after the window films have been applied, to obtain a better understanding of the extent to which the window films can reduce infiltration losses.

Impact on usage of the heating

As part of the study we investigated whether the window film 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 Commission's report on its inquiry into energy efficiency [PC 2005] states that "energy efficiency makes energy appear cheaper relative to other items as less money is required to purchase the same energy services. Consequently, the household will tend to use more energy …". In the context of the window film 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 13. The temperature profile after the retrofits indicates that internal temperatures were slightly higher during the day, especially between 5:30 am and 6:30 pm. The average internal temperature across the day increased slightly after the retrofit by 0.31^{o}C. 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 3.4% (based on an average temperature difference when heating of 9.15^{o}C before the retrofit).

FIGURE 13: AVERAGE DAILY INTERNAL TEMPERATURE PROFILE OF ALL RETROFIT TRIAL HOUSES



The observed increase in temperature during the day may not all have been due to any rebound effect. Average outside temperatures were higher during the post-retrofit period and this will be reflected in higher internal temperatures during those times when the heating is not operating. In some houses the presence of the window film seems to have meant that the house retained heat better over night when the heating was not operating, which also results in higher internal temperatures during these times. (See for example graphs for houses WF1, WF2 and WF6 in Appendix A3.) Also, the presence of window film in some rooms may increase the temperature in these rooms, due to reduced heat losses, even though the thermostat setting of the heating has not changed.

Detailed data on the temperature profiles in the individual houses is provided in Appendix A3. A sustained increase in internal temperatures after the retrofits is evident in four of the houses (WF1, WF5, WF6 and WF7). In the other four houses the temperature profiles before and after retrofit were either almost identical (WF2 and WF4), or displayed both increases and decreases across the day (WF3 and WF8). So, while some change in behaviour seems to have taken place after the window film retrofits in some houses, this change might have led to higher or lower energy use. The net effect is that little 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.

Practical issues

The installation of window film is fairly straightforward and could be completed by householders as a DIY project. It was found that the window film is suitable for most window types as long as the surface of the frame is in good condition and offers enough space for the window tape to be attached. As part of the *Retrofit Trial* EnviroGroup noted a range of practical issues which need to be taken into consideration for successful installation of the window film [EG 2013].

Installation of the window film

The tools required for window film installation are:

- Measuring tape;
- Cleaning cloth, plastic scourer and cleaning solution, such as methylated spirits;
- Scissors;
- Blow dryer;
- Razor or other sharp cutting blade; and
- Window film and clear double-sided tape (provided in the kit).

The process for window film installation is as follows:

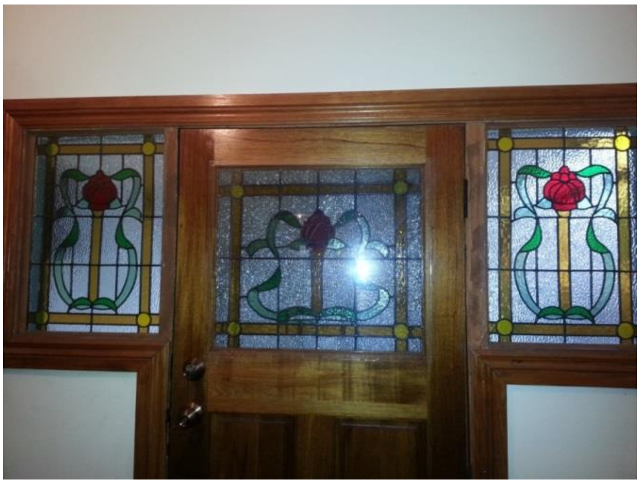
1. Measure the window area to determine the size of the window film sheet required;
2. Clean the window and window frame thoroughly, and ensure that the window and frame are completely dry. It is essential to give the window frame a very good clean before the tape and window film are installed, especially windows located in kitchen areas where the frames may have a film of oil and grime. Methylated spirits and a plastic scourer were found to be effective for this;
3. Unfold the film and cut to suit the width of the window, allowing 25 mm extra on all sides;
4. Remove the liner paper on one side and firmly apply the double-sided tape around the window frame. Remove the remaining liner paper on the double-sided tape. Note that any latches and other mechanisms installed on the windows can be temporarily removed while the window film is installed;
5. Apply the window film to tape around the window frame. Reposition the film and stretch to remove as many wrinkles as possible;
6. Remove remaining wrinkles by heat shrinking the window film using the blow dryer; and
7. Trim the remaining film from around the edges with sharp blade.

Suitability of different window types

The main issue which arose during the window film retrofit trial was peeling of the window film. This was related to the type of window frame and the condition of the frame. The best results were obtained for newly painted wooden, steel and aluminum window frames or newly varnished wooden window frames. The houses that had a relatively new coat of paint or varnish on the window frame did not experience any problems with the window film peeling off after installation. Examples of these types of windows are shown in Figure 14.

FIGURE 14: TYPES OF WINDOWS WHICH ARE WELL SUITED TO THE WINDOW FILM INSTALLATION

Painted wooden frame



Varnished wooden frame

Painted metal frame

There were several houses where the double-sided tape did not stick properly, meaning that the window film peeled back from the frame, and had to be reapplied. There were several reasons for this:

- Rough paintwork on the window frames. Two of the houses had old and fairly rough paintwork on the window frames, meaning that the tape could not form a strong adhesive bond. The solution was to sand back the window frames to make them smooth;
- Old flaking paint on window frames, which meant that the paint peeled off when the window film was applied. The solution was to sand back and re-paint the window frames; and
- Rough, unpainted, wooden surfaces on the window frames, which does not allow a good bond between the double sided tape and the frame. The window film peeled off many of these frames after a short time period. The solution was to sand back these surfaces to make them smooth and this provided a good surface for the tape to adhere to. Varnishing the smooth surface would also help.

Examples of the types of windows which resulted in the window film peeling are shown in Figure 15. Once the issues were rectified there were no further problems with the window film peeling.

FIGURE 15: TYPES OF WINDOWS WHERE PEELING IS LIKELY TO OCCUR

Rough paintwork on metal frame window

Rough unpainted timber

Rough paintwork on wooden frame window

There are also a number of types of windows where it is either not possible to install the window film or where it is not possible to install the film on the whole window:

- Some types of window frames do not provide enough space to attach the double-sided tape which is required to hold the window film in place. The tape supplied with the window film kit was 15 mm wide, and this required the window frames to have a flat surface at least 15 mm wide in order to provide sufficient area for adhesion of the window film when it was shrunk tight using the blow dryer. Examples of these types of windows are provided in Figure 16;
- Fop double-hung sash windows it is not possible to apply film to the fixed upper section of the window. Only the bottom, moveable, section of the window can have the film applied. An example of this type of window is provided in Figure 17; and
- As with double-hung sash windows it may not be possible to apply film to the fixed part of sliding windows or doors.

FIGURE 16: EXAMPLES OF WINDOWS WHERE THERE IS INSUFFICIENT SPACE TO INSTALL WINDOW FILM

FIGURE 17: DOUBLE HUNG SASH WINDOW

Only the lower sections of window can have film applied

At two of the houses where the windows were not suitable for installing the window film (WF6 and WF7), the householders identified an innovative way to get around this issue. A secondary frame was constructed to fit inside the existing window frame and when installed allowed the window film to be attached. Examples of these windows are provided in Figure 18.

FIGURE 18: USE OF SECONDARY FRAMES TO ENABLE INSTALLATION OF WINDOW FILM

New internal wooden frame was installed at this property.

A new piece of wooden framing was installed at this property allowing for the window film to be installed.

Moisture trapped by the window film

In half of the houses which participated in the *Trial* the residents noted that the installation of the window film had eliminated or reduced condensation on the inside of the windows. However in one house condensation was forming between the original pane of glass and the window film (see Figure 19). It is believed that water entered the window from outside, but that the moisture was then trapped between the original window and the window film, leading the window to become foggy. To solve this problem the window film was removed and a clear silicone filler used to seal all gaps around the window. This prevented any water from again leaking into the space between the window and the window film. The window film was then reinstalled.

FIGURE 19: CONDENSATION TRAPPED BETWEEN THE ORIGINAL PANE OF GLASS AND THE WINDOW FILM

4. Summary and Conclusions

Summary

Through the *Window Film Secondary Glazing Retrofit Trial* Sustainability Victoria investigated the installation of window film secondary glazing on existing single-glazed windows. A key reason to investigate this retrofit was that the *On-Ground Assessment* study showed that the replacement of single-glazed windows with double-glazed windows had the potential to significantly increase the energy efficiency of the building shell of existing (pre-2005) houses, but that this retrofit was not very cost-effective due to the high cost of the removing existing windows and installing new double-glazed windows. Window film secondary glazing can be undertaken as a DIY project and is one of the lowest cost methods of improving the thermal performance of existing windows.

A total of 8 houses were recruited to participate in Sustainability Victoria's *Window Film Secondary Glazing Retrofit Trial*. Infrared thermal imaging was used to assess the heat losses from the windows with and without the window film applied, to obtain an indication of whether or not the window film was reducing winter heat losses. 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 window film retrofits.

The average cost of installing the window film in the 8 houses was $504 when valued at commercial rates and $84 when valued at DIY rates (material cost only). Analysis of the thermal imaging data obtained from each house suggested that the installation of the film had indeed reduced winter heat losses through the windows on which it was installed: the average temperature of the surface of the windows increased by 0.7°C when viewed from inside the house and decreased by 0.9°C when viewed from outside the house, compared to windows without the film installed.

The majority of households which participated in the *Trial* (5 out of 8) experienced the window film retrofit as an increase in the thermal comfort of their homes and most (5 out of 8) reported a reduction in the difficulty of heating their homes. The improvements were linked to the rooms in which the window film was installed being warmer, heating more quickly and retaining heat better and, in some cases, a reduction in draughts. A number of houses also reported that they were able to reduce thermostat settings slightly at times after the retrofits and still feel comfortable. The majority of households (7 out of 8) did not have any problems with the appearance of the window film, although some of these noted that there were some visual impacts, including increased glare and reflection, some distortion and some minor flaws and streaks across the film. One house commented that there were noticeable textures in the film, which were a concern.

By reducing the winter heat losses through existing single-glazed windows located in the main living areas of the houses the window film retrofits were also expected to lead to heating energy savings, and therefore reduced heating costs[37]. Metering data collected during the pre- and post-retrofit period for 7 of the 8 houses was analysed to estimate the energy savings which were achieved by the retrofits. Two approaches were taken: the first approach sought to estimate the reduction in annual heater energy consumption due to the expected reduction in the U-values of the windows once the window film was applied, combined with data on temperature difference and heater operating time and efficiency; the second approach sought to estimate the "technical" energy saving, the energy saving which is independent of the temperature difference between inside and outside the house and user behaviour.

The first approach suggested that the upper limit of the heating energy savings would be an average saving of 6.1% across the houses analysed, giving an annual energy bill saving of $62.6 per year. Once adjusted to take into account the fact that the retrofitted windows in all houses already had some level of

[37] In houses with air conditioning or evaporative cooling the film should also reduce the energy consumption for summer cooling. This saving has not been estimated and included in our analysis as it is expected to be quite small.

protection from winter heat losses provided by curtains and blinds, the estimated average heating energy saving was reduced to 4.2% or an annual energy bill saving of $43.6 per year. Based on an average commercial installation cost of $504 this gives a payback of 11.6 years. If installed as a DIY project – average materials cost of $84 – this would give an average payback of 1.9 years, making the window film retrofit a very cost effective investment.

For the second approach we prepared plots of the average heater electrical power consumption against the average temperature difference between inside and outside the house at times when the heating was cycling on an off in an even manner. The heater's electrical power consumption provides a reasonable proxy for the heater's gas consumption. Data obtained from before and after the retrofits was plotted separately for each house, and the slopes of the lines of best fit for each data set were used to estimate of the technical energy savings achieved. The results of this approach differed markedly from the first approach, with energy savings estimated for 5 out of the 6 houses analysed, and an increase in energy consumption estimated for one house (WF6). In general the estimated energy savings were lower than for the first approach, although in one house (WF1) they were about the same and for one house (WF3) the savings estimate was substantially larger (12.1% vs 6.3%). The estimated average heating energy saving across the 6 houses analysed was 2.6% or an annual energy bill saving of $27.4, giving a payback of 20.9 years for a commercial installation and 3.5 years for a DIY installation. If the anomalous result from house WF6 is eliminated, the estimated average heating energy saving was 3.7% or an annual energy bill saving of $40.7 per year, giving a payback of 14.6 years on a commercial installation and 2.4 years on a DIY installation.

There are a number of possible explanations for this discrepancy between the first and second approach to estimating the energy savings: the analysis methodology for estimating the technical energy saving may not be accurate enough for the relatively modest saving expected, and a longer monitoring period that allowed more data to be collected may be required; changes in user behaviour (such as closing curtains) between the pre- and post-retrofit periods may reduce the accuracy of the window heat loss estimation methodology; uncertainties relating to the impact of any curtains on reducing heat losses, and on the effectiveness of the window film installation (e.g. whether or not an optimal gap had been achieved) may reduce the accuracy of the window heat loss estimation methodology; and, changes in climatic conditions such as wind speed, rain and humidity between the pre- and post- retrofit periods.

As part of the study we collected internal temperature data to help assess the impact of the window film retrofits on household behaviour. Some economists argue that a *rebound effect* exists, which in the context of the window film 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. The post-retrofit temperature profile indicated a slight increase in internal temperatures compared to the pre-retrofit temperature profile. Averaged across the day the average temperature increase was 0.31^{o}C which would correspond to a rebound of 3.4% if the increased temperature was all attributed to a rebound effect. However, some of this increase is likely to have been due to the warmer external temperatures experienced during the post retrofit period, and a reduction in heat losses during the night time in some houses when the heating was not operating, meaning that little, if any, rebound was evident.

The main practical issue identified during the *Retrofit Trial* was that that in half of the houses the window film peeled off in some places after it had been installed. This was found to be due to the poor condition of some window frames (see Chapter 3) and was rectified in all houses by sanding, and in some cases painting, the window frames before the film was re-applied. Good preparation of the window frames was found to be a critical factor for successful installation.

The window frames in some houses were not suitable for the installation of the window film, as there was not adequate space to install the double-sided tape required to hold the window film in placed. In two of the houses this issue was addressed by installing secondary window frames inside the existing frame which allowed the film to be attached. In houses with double hung sash windows it was only possible to install the window film on the bottom moveable section of the window.

In some houses there were also minor wrinkles, smears and textures visible on the window film after installation. This may have been rectified if greater care was taken during the installation process. One house also observed condensation forming between the existing window and the window film. This was linked to moisture entering the window from outside, and was rectified by removing the film, filling gaps in the existing window with clear silicone filler and re-installing the window film.

Conclusions

The *Window Film Secondary Glazing Retrofit Trial* has shown that the installation of heat shrink window film on existing single-glazed windows can be an effective strategy to reduce heat losses through existing single-glazed windows and to improve occupant comfort, although in most cases only modest energy savings are likely to be achieved. It was also found to reduce or eliminate issues related to condensation forming on the internal surface of windows on cold winter nights in some houses.

While the window film clearly reduced heat losses through the windows to which it was applied, the level of energy savings achieved has been more difficult to determine. Average heating energy savings of around 4.2% were estimated by employing an approach which used monitoring data from the houses to estimate the reduction in gas heater energy consumption based on the expected reduction in window heat losses. This gave estimated average annual energy bill savings of $43.5 per year, or an average payback of 11.6 years if the film was installed commercially and 1.9 years if it was installed as a DIY project. An alternative approach to estimating the (technical) energy savings suggested average savings of around 3.7% at best, giving annual energy bill savings of $40.7 per year, and paybacks of 14.6 to 2.4 years, based on commercial and DIY installation respectively. In both cases, the installation of the window film was a very cost effective energy efficiency upgrade if undertaken as a DIY project by the householder, with a payback of around 2 years or less.

Residential energy prices have risen significantly in Victoria since 2007 and seem likely to continue to increase in future, especially for natural gas[38]. Continued price rises for natural gas will improve the payback on window film secondary glazing retrofits.

In some houses the installation of the window film resulted in quite large heating energy savings, with a saving of around 12% being achieved at one house (WF3). The absolute energy savings (and comfort improvement) from the installation of the window film is likely to be largest in houses which have a large window area in the heated parts of the home compared to the overall area of the external walls, floors and ceiling, and where the windows currently have either little protection (e.g. venetian blinds, vertical blinds, light curtains with no pelmet) or no protection from winter heat losses. The percentage savings will also be larger where the existing ceilings, walls and floors are well insulated and the windows account for a larger proportion of total winter heat losses from a house.

---

[38] Residential electricity prices in Melbourne increased by 88% in real terms over the period 2006/07 to 2013/14 and residential gas prices increased by 45% in real terms over the same period. Electricity prices are expected to remain relatively flat in the short term while gas prices are expected to continue to increase. *State of the Energy Markets 2014,* Australian Energy Regulator 2014. (The original source of this data is ABS Consumer price index, cat. No 6401.0. 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

ABS 2008 *ABS 4602.0.55.001 Environmental Issues: Energy Use and Conservation*, Australian Bureau of Statistics, March 2008

DOI 2014 "Glazing", *Your Home* website, www.yourhome.gov.au/passive-design/glazing Dr Peter Lyons & Bernard Hockings for the Department of Industry. (Accessed July 2014)

E3 2008 *Interpretive Testing of Residential Gas Ducted Heaters (unpublished),* Enertech Australia Pty Ltd for Sustainability Victoria, on behalf of the Equipment Energy Efficiency Committee, 21 November, 2008.

EG 2013 *Final Report – Energy Efficiency Retrofit Trials in Victorian Houses (unpublished)*, internal project report for Sustainability Victoria, EnviroGroup, October 2013.

EH 2009 *Research into the Thermal Performance of Traditional Windows: Timber Sash Windows,* English Heritage Research Report, prepared by Dr Paul Baker, Glasgow Caledonian University, June 2009.

HS 2010 *Thermal performance of traditional windows,* Historic Scotland Technical Conservation Group, Technical Paper 1, prepared by Dr Paul Baker, Glasgow Caledonian University, October 2008. Updated with clarifications and corrections September 2010.

PC 2005 *The Private Cost Effectiveness of Improving Energy Efficiency,* Productivity Commission Inquiry, No. 36, 31 August, 2005.

SEAV 2001a *Energy Saving for Windows,* Sustainable Energy Authority Victoria, August 2001

SEAV 2001b *Home Heating Tips,* Sustainable Energy Authority Victoria, October 2001

SGG 2014 *Glass and Thermal Insulation,* Saint Gobain Glass, http://nordic.saint-gobain-glass.com/upload/files/glass_and_thermal_insulation.pdf (accessed July 2014)

SV 2014 *The Energy Efficiency Upgrade Potential of Existing Victorian Houses*, Sustainability Victoria, February 2014.

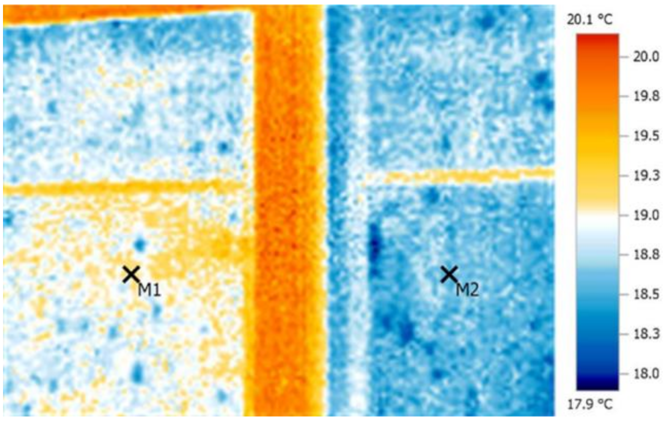
APPENDICES

A1: Thermal images of retrofitted windows

Photographs and thermal images were taken of some windows during the retrofit process to help illustrate the impact of the installation of the window film on the reduction in winter heat losses through the windows. The thermal images are colour coded and show the temperature on the surface of the ductwork and other objects in the images. Windows with film would be expected to be warmer than windows without film when viewed from the inside, and cooler than windows with film when viewed from the outside.

House WF1

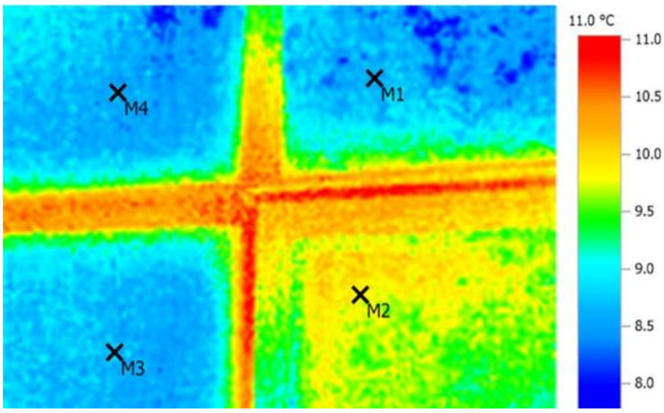
Images taken from inside living room



M1 (film) – 19.1ºC; M2 (no film) – 18.6ºC

House WF2

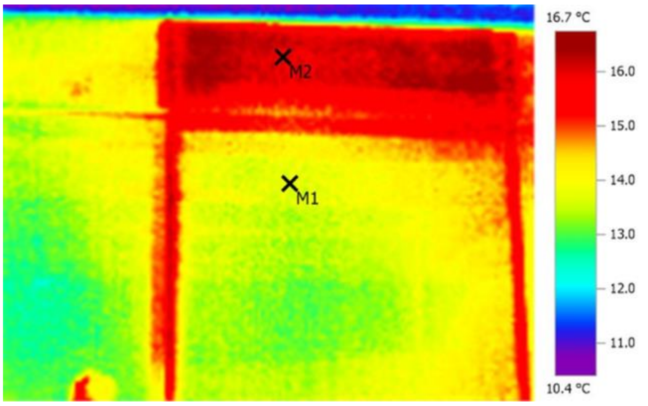
Images taken from outside living room



M1 (film) – 8.7ºC; M2 (no film) – 9.8ºC; M3 (film) – 8.6ºC; M4 (film) – 8.5ºC

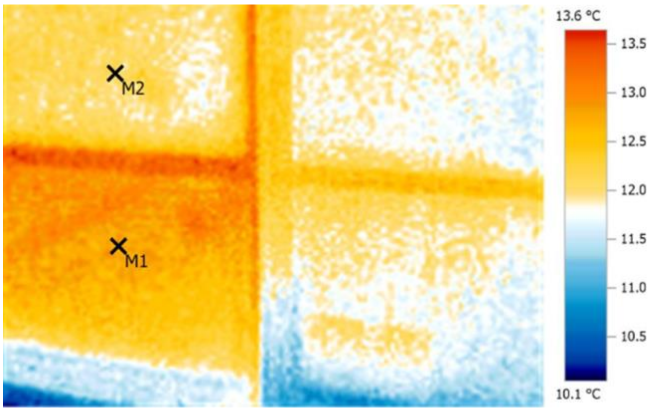
House WF3

Images taken from outside



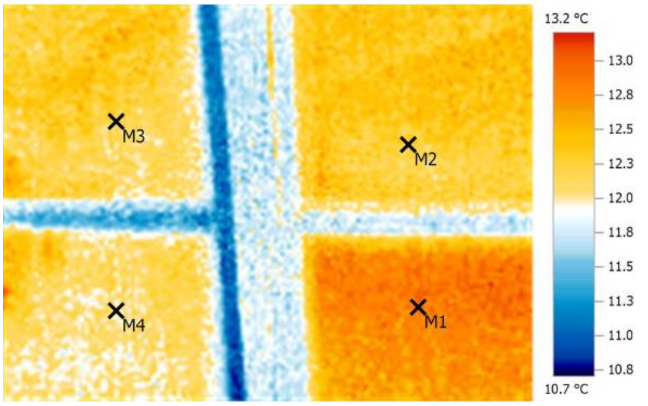
M1 (film) – 13.8ºC; M2 (no film) – 15.9ºC

Images taken from outside living room



M1 (no film) – 13.0ºC; M2 (film) – 12.1ºC

No photograph is available for this window.
Thermal image taken from outside.



M1 (no film) – 13.0ºC; M2 (film) - 12.1ºC; M3 (film) – 12.0ºC; M4 (film) 12.1ºC

House WF4

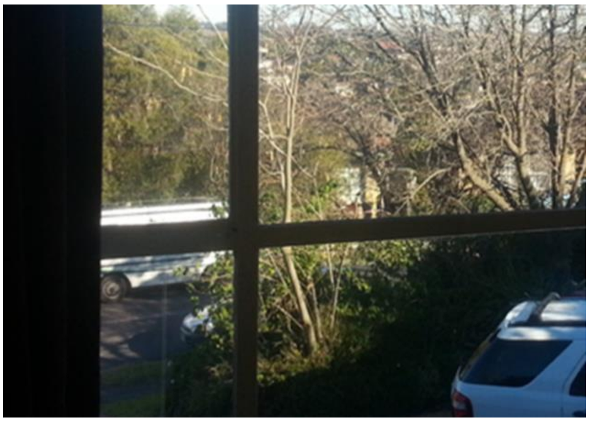
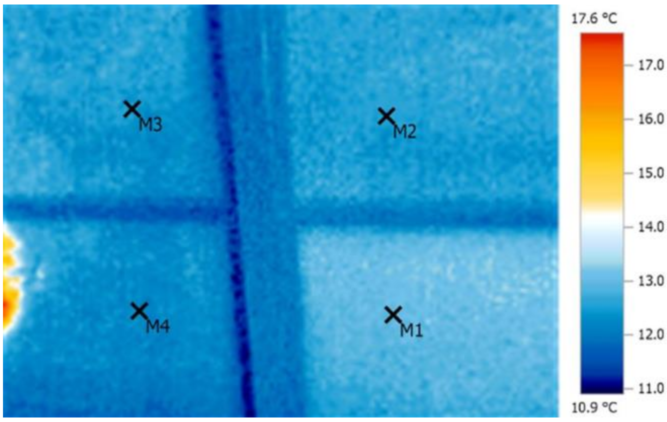
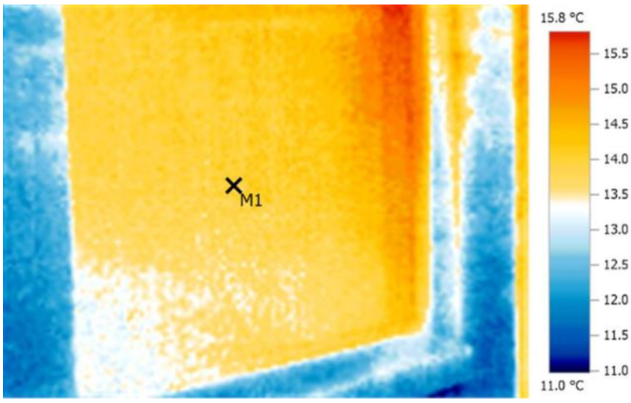


Photo taken from inside; thermal image taken from outside

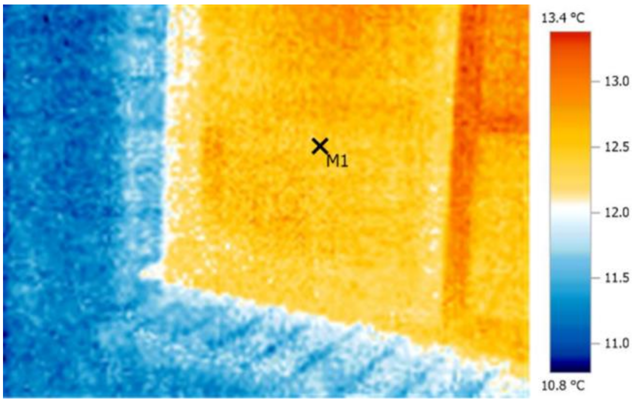


M1 (no film) 13.1ºC; M2 (film) – 12.5ºC; M3 (film) – 12.4ºC; M4 (film) – 12.2ºC



M1(no film) – 13.9ºC

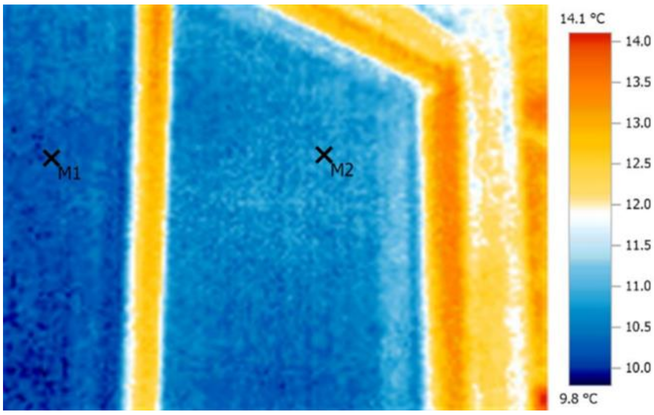
Images taken from outside (1) kitchen window & (2) lounge window. No photos are available of these windows.



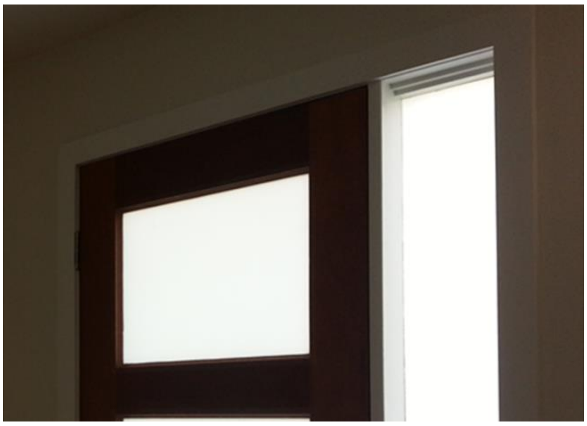
M1 (film) – 12.4ºC

House WF5

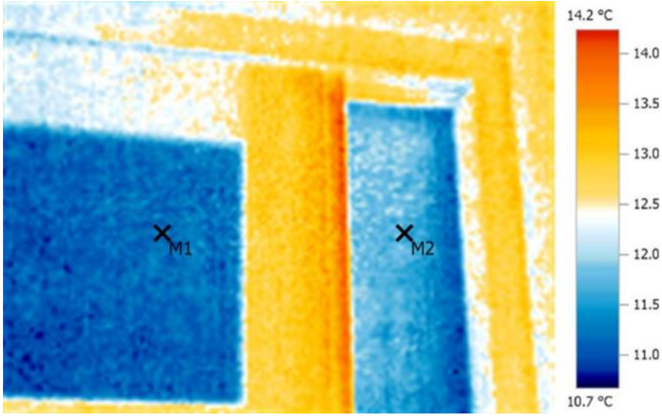
Images taken from outside living room



M1 (film) – 10.3ºC; M2 (no film) – 10.9ºC



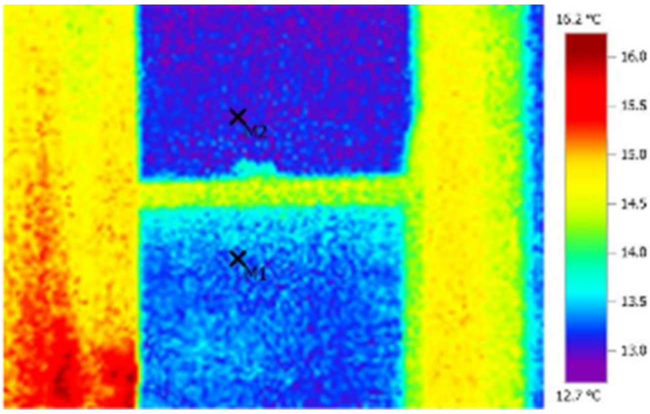
Images taken from inside



M1 (no film) – 11.2ºC; M2 (film) – 11.7ºC

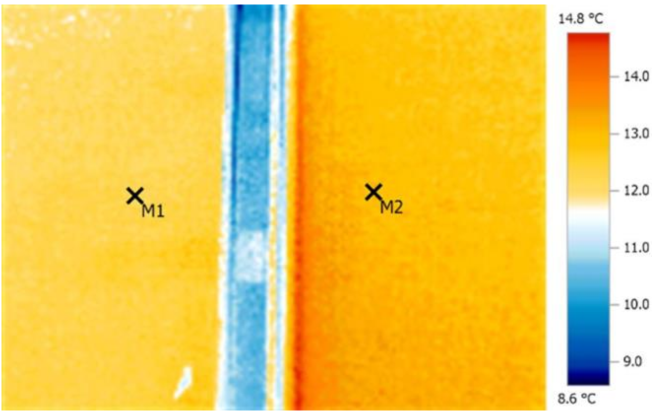
House WF6

Images taken from inside



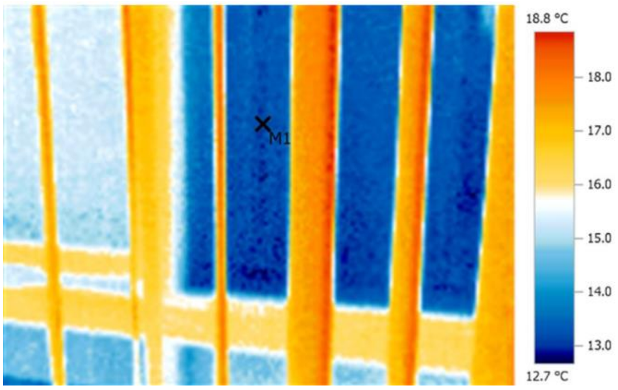
M1 (film) 13.7ºC; M2 (no film) – 12.9ºC

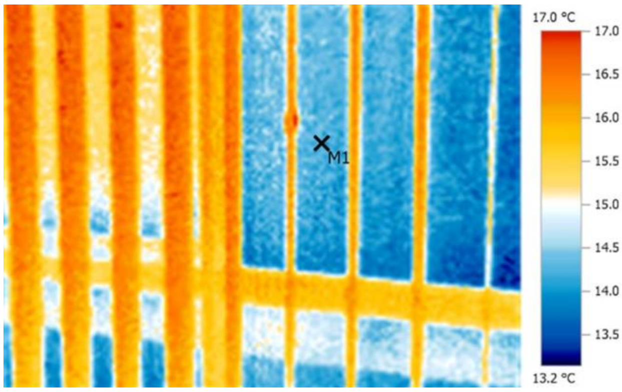
Images taken from outside



M1 (film) – 12.3ºC; M2 (no film) – 13.0ºC

House WF7





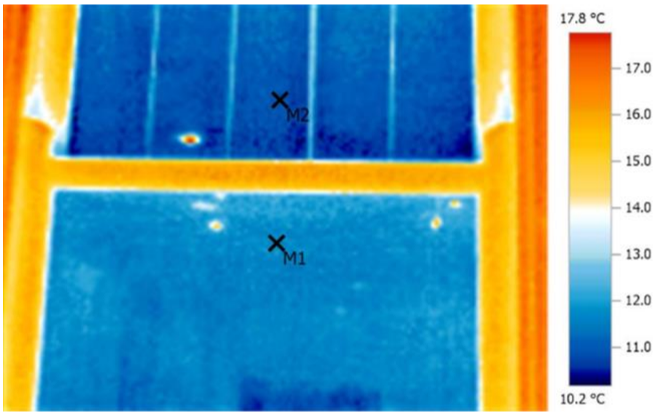
M1 (no film) – 13.1ºC

Images taken from inside

M1 (film) – 14.3ºC

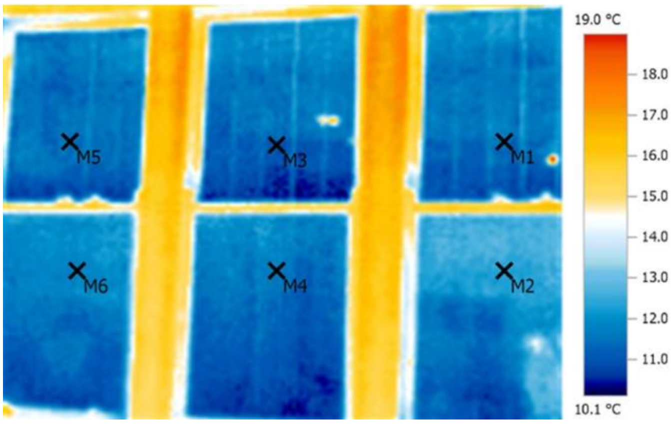
House WF8

Images taken from inside



M1 (film) – 11.7ºC; M2 (no film) – 10.9ºC

Images taken from inside



M1 (no film) – 11.5ºC; M2 (film) – 12.3ºC; M3 (no film) – 11.0ºC; M4 (film) – 11.7ºC; M5 (no film) – 11.4ºC; M6 (film) – 11.8ºC

A2: Detailed householder survey results

Introduction

Surveys were conducted before and after the window film 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 A1: HOUSEHOLDER RATING OF THERMAL COMFORT, BEFORE AND AFTER RETROFIT

House No.	*Consumer Perception (1 to 5)*			Comments
	Before	After	Change	
WF1	3	4	1	***After*** – Better now with window glazing. More comfortable in the lounge room.
WF2	4	4	0	***Before*** – Lots of efficiency measures but gets cold if heater is not on. ***After*** – Feels like it is easier to keep heat in and heats up quicker. Kitchen stays comfortable for longer when the heater is turned off.
WF3	3	3	0	***Before*** – We keep it comfortable by increasing the temperature when necessary. ***After*** – Feel that there is a difference in heat exchange. The house heats up quicker and can feel the heat more after the window film installation. The back corner of the lounge room is warmer and less draughty.
WF4	3	3.75	0.75	***Before*** – Lounge room is warmest when the sun is out. Other rooms, especially bedrooms are shadiest and coolest. ***After*** – Lounge room seems warmer since window film installation, and retains the heat more.
WF5	3	4	1	***Before*** – Depends on the occupants. Some feel the cold more than others. ***After*** – Some areas are still draughty.
WF6	3	3	0	***Before*** – Can feel cool draughts. ***After*** – Always colder in the kitchen. The lounge is reasonably comfortable.
WF7	2.5	3	0.5	***After*** – Takes a while for the house to heat up.
WF8	3	4	1	***Before*** – Would like the house to be warmer. Warm in rear area but cold in other places. Takes a long time to heat. ***After*** – A lot more comfortable with the window film.
Average	**3.1**	**3.6**	**0.5**	

Following the retrofits the householders were asked to comment on whether or not there had been any change in the comfort of their houses since the retrofits. The responses are provided in Table A2.

TABLE A2: HOUSEHOLDER PERCEPTIONS OF CHANGE IN THERMAL COMFORT FOLLOWING RETROFIT

House No.	Comments
WF1	The back living area is a bit warmer and easier to heat.
WF2	Definitely less breezy, air flow is reduced. Improved comfort in the living room.
WF3	Less draughts in the back corner. Makes the room more comfortable. The house heats up quicker.
WF4	The lounge is more comfortable. Retains heat more.
WF5	Comfort level has improved in the living space. The upstairs living space is more comfortable to sit in. Draughts are the major issue. Downstairs it has improved slightly, but still quite cold.
WF6	Not sure. Not noticeable. We still notice large fluctuations in temperature if it is a cold night or day.
WF7	The house is heating up a bit quicker. Seems to be retaining heat better in the lounge room. Sitting in front of the TV in the sitting area is more pleasant, not as cold.
WF8	Less draughty and fewer cold patches in the house. The heater doesn't seem to be turning itself on as often. When sitting on the couch there is no draught on neck. The living space is definitely more comfortable

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 DIFFICUTY OF HEATING QUESTION, BEFORE AND AFTER RETROFIT

House No.	*Householder rating (1 to 5)*			Comments
	Before	After	Change	
WF1	3	1	-2	***After*** – Very east to heat the house - doesn't take long to heat.
WF2	4	1	-3	***Before*** – Takes a long time to heat in the morning. Can feel a breeze in the house. ***After*** – Back rooms heat up a lot quicker.
WF3	2	1	-1	***Before*** – Time to heat up is an issue ***After*** – Very easy to heat.
WF4	2	2	0	***Before*** – Not too difficult to heat but need heater on constantly. ***After*** – Relatively easy to heat the house.
WF5	4	2	-2	***Before*** – If house is not heated during the day I find it takes a while to get comfortable heating in the lounge, kitchen, TV and dining rooms. ***After*** – Heats up quickly – ducting system is good for living and bedrooms.
WF6	4	2	-2	***Before*** – Heater seems to warm more than necessary and cools down reasonably quickly, particularly in the kitchen. ***After*** – Trying to save on bills so try to keep it down a bit.
WF7	2	2	0	***Before*** – Heat is inefficient. ***After*** – Takes a lot of energy to heat. Thermostat takes care of the house.
WF8	4	4	0	***Before*** – Patchy, warm in the rear of the house, cold in other places. ***After*** – Heating has to go on quite hard (21oC) to get the house consistently warm.
Average	**3.1**	**1.9**	**-1.3**	

Retention of heat

Following the retrofits the householders were asked if there was any change to the retention of heat in certain rooms following the installation of the window film. The responses are provided in Table A4.

TABLE A4: COMMENTS ON ANY CHANGES TO HEAT RETENTION SINCE THE WINDOW FILM INSTALLED

House No.	Comments
WF1	The lounge room retains the heat for longer.
WF2	Yes. Living space retains heat a lot better. The heater doesn't go on for as long. The house heats up quicker, a lot quicker.
WF3	No change noticed.
WF4	Yes. The lounge room retains more heat since the window film was installed.
WF5	Yes, there is better heat retention but the house still cools down quite quickly.
WF6	No change.
WF7	Yes, the lounge room. Seems to retain heat better.
WF8	The living space stays warmer now.

Changes in use of the heating

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 A5: COMMENTS ON ANY CHANGES TO THE USE OF THE GAS HEATING

House No.	Comments
WF1	All stayed the same.
WF2	No change. Heater turned off when leave the lounge now because the weather has been mild.
WF3	No change. Replaced thermostat.
WF4	No. The thermostat is the same as before.
WF5	No changes.
WF6	Have tried setting the temperature at 19.5ºC rather than 20ºC as a trial to reduce gas usage. On very cold nights set it back to 20ºC.
WF7	No change in the central heater settings.
WF8	Still leave it on. Turned the heater lower overnight – used to leave it on. Now turn the heater low when out of the house. Before it would be working all the time.

Householders were also asked whether or not there had been any other behavioural changes following the installation of the window film. The responses are provided in Table A6.

TABLE A6: COMMENTS ON OTHER BEHAVIOURAL CHANGES SINCE THE INSTALLATION OF THE WINDOW FILM

House No.	Comments
WF1	All stayed the same.
WF2	Sometimes leave the windows open at night. Before would have closed up the house because of the cold. We were going to install pelmets, but not anymore.
WF3	No change.
WF4	None.
WF5	No change.
WF6	None.
WF7	None.
WF8	Yes. I used to take the baby into the other room to play, but now spend more time in the living room.

Unexpected benefits

Following the retrofits the householders were asked whether or not there had been any unexpected benefits sine the installation of the window film. The responses are provided in Table A7.

TABLE A7: COMMENTS ON ANY UNEXPECTED BENEFITS SINCE THE WINDOW FILM WAS INSTALLED

House No.	Comments
WF1	None.
WF2	Condensation has been reduced on a number of windows. All windows used to get condensation, but not anymore.
WF3	The condensation at the bottom of the windows is gone. This is a big positive for window film. We will install it on other windows in the bedrooms because of this.
WF4	Not that we have noticed.
WF5	The girls' bathroom has mould still.
WF6	Yes definitely. No condensation on the windows with window film compared to other windows.
WF7	No. No previous issues.
WF8	None.

Appearance of the window film

Following the retrofits the householders were asked whether the appearance of the window film had caused any issues for them. The responses are provided in Table A8.

TABLE A8: COMMENTS ON WHETHER THE APPERANCE OF THE WINDOW FILM HAS IMPACTED ON THE HOUSEHOLD IN ANY WAY

House No.	Comments
WF1	No.
WF2	Sometimes it can be a bit distorting. There is more glare / reflection since installed. It doesn't really impact on us though.
WF3	No. People comment that they don't notice the film. At night you can notice it more. There are some minor flaws in the film – streaks across the film.
WF4	Yes. Expected the film to be clearer. Can notice it, textures in the film.
WF5	No, it's good.
WF6	No.
WF7	Chalk textas were used on the film and was cleaned off easily with no mess.
WF8	No.

Problems or issues

Following the retrofits the householders were asked whether or not any issues or problems had been created by the installation of the window film. The responses are provided in Table A9.

TABLE A9: COMMENTS ON ANY ISSUES OR PROBLEMS CAUSED BY THE INSTALLATION OF THE WINDOW FILM

House No.	Comments
WF1	None.
WF2	Some windows have peeled. They have since been replaced. Condensation has formed on several windows. Water may be trapped in the window. Will need to replace.
WF3	The film has peeled off in some places. Stronger tape has now been used in these spots.
WF4	None. Our young boy likes to poke at the film and try to peel it off, but it hasn't peeled off yet.
WF5	None.
WF6	The window film has peeled on two windows, which have since been rectified.
WF7	A couple of windows have peeled and been fixed. We have to be careful not to puncture the door film when opening the doors.
WF8	None.

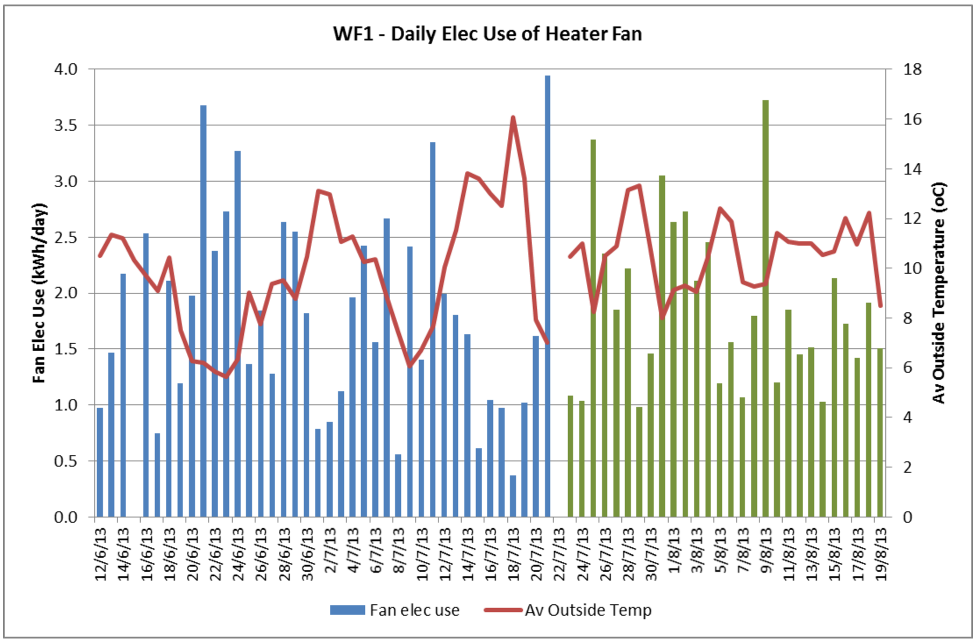
A3: Monitoring results for each house

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 *Window Film Secondary Glazing 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:

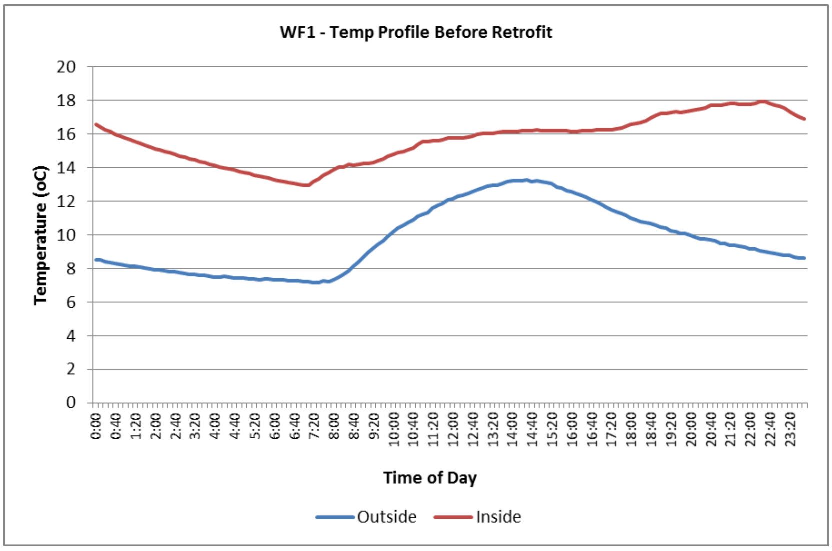
- A graph which shows the daily electricity consumption of the gas ducted heater in kWh per day (when the fan is operating) throughout the entire monitoring period, plotted against the average daily outside temperature. The daily electricity consumption before the retrofit is shown in blue and the daily 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 window film 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 window film retrofits;
- A graph which compares the average daily internal temperature profiles of the houses before and after the window film 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 in heated areas of the houses 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 with line of best fit which shows the relationship between average heater power consumption and temperature difference, before and after the retrofits. Individual data points are based on time periods when the gas ducted heater is cycling on and off in a fairly even manner.

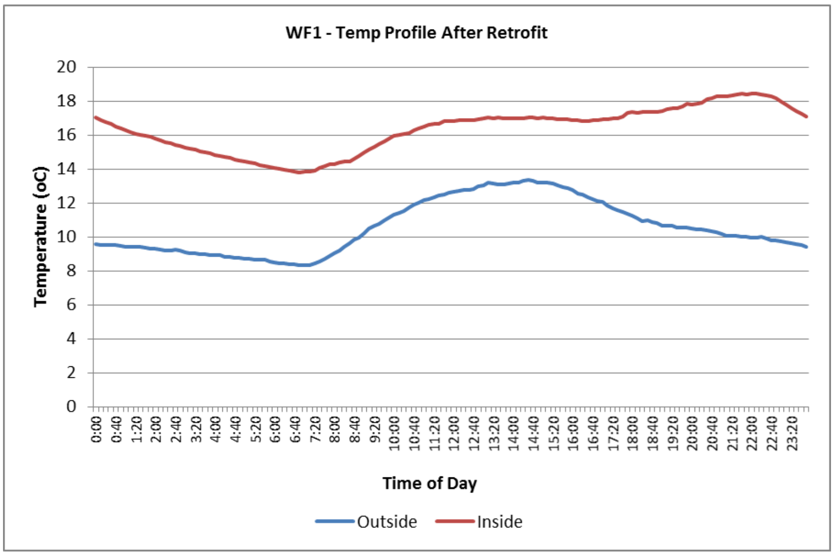
House WF1

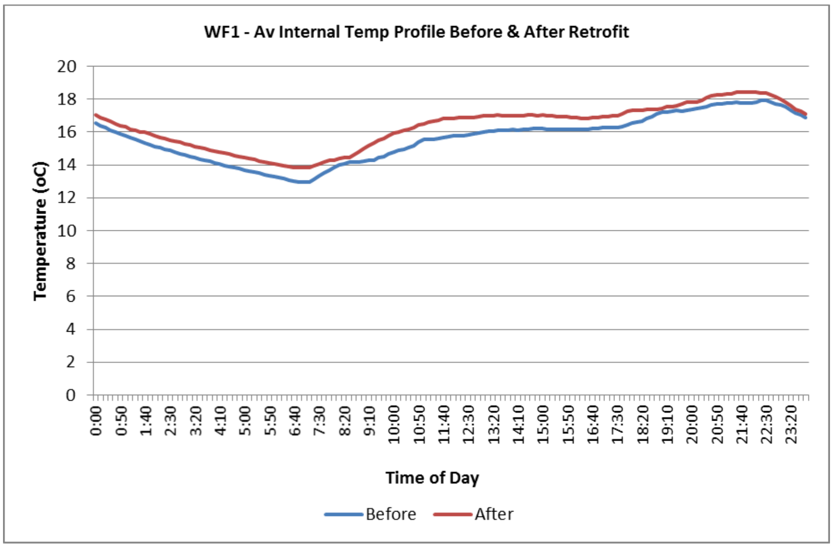
Parameter	Details
Approx. age of house (yrs)	90
House construction details	Walls – weatherboard; Floor – suspended timber; Some of the ceiling insulated.
Floor area (m^2)	130
Number of house occupants	2 people
Type of windows and coverings	Wooden frame, many with leadlight. Venetian blinds and some drapes.
Location of windows & area retrofitted (m^2)	Kitchen / Living room – 8.5 m^2
Main heating details	Omega 2000 gas ducted heater, 2 Stars, 19 years old Est. system conversion efficiency of 46.8% Est. gas consumption of 41,813 MJ per year
Date monitoring started	12/6/13
Date retrofit undertaken	22/7/13
Date monitoring completed	19/8/13
Heater operation before retrofit	Time – 7.29 hours per day; Energy - 1.82 kWh per day;
Av. temperature difference before retrofits	8.05ºC
Heater operation after retrofit	Time – 8.30 hours per day; Energy - 1.87 kWh per day;
Av. temperature difference after retrofits	7.08ºC

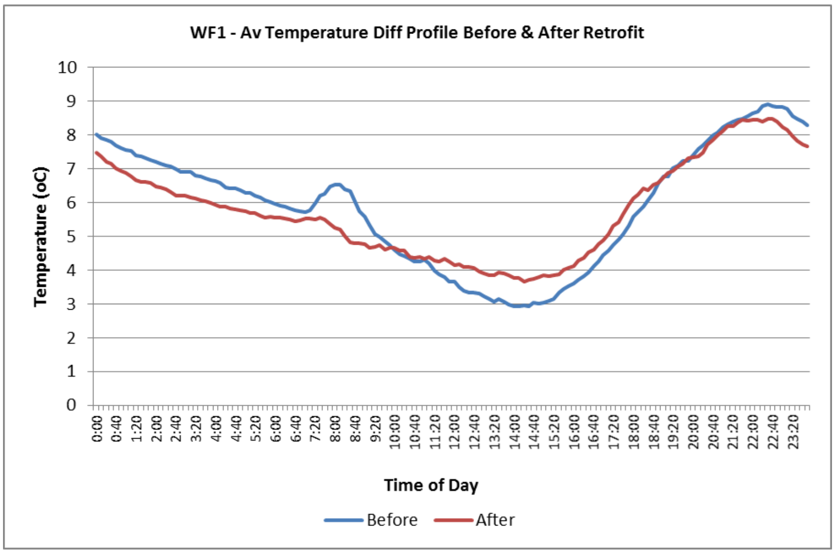


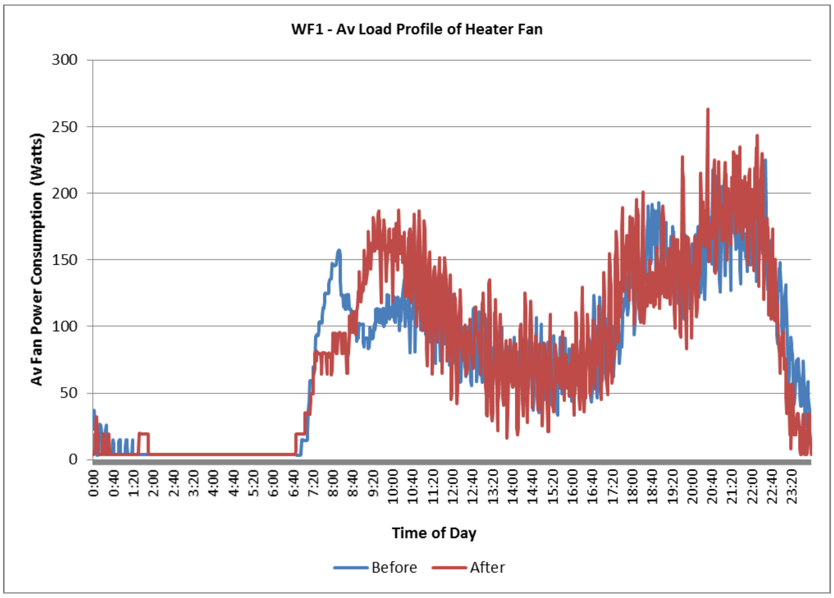
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

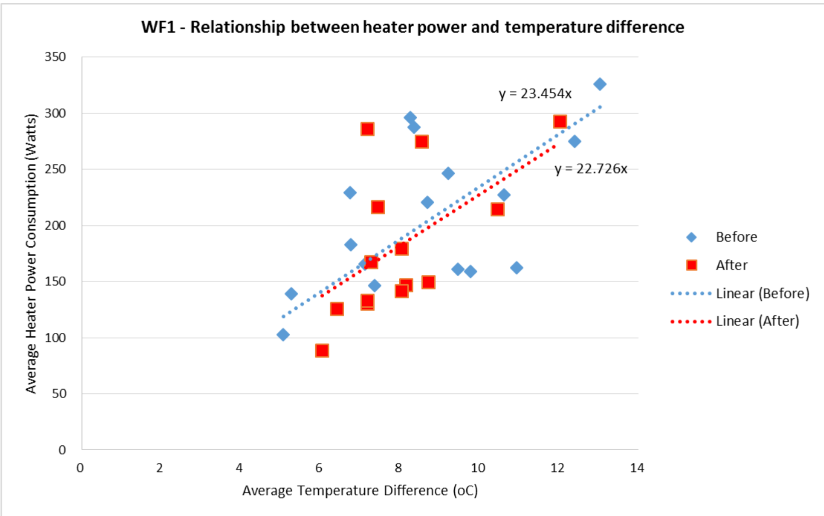

WF1 - Temp Profile Before Retrofit
Temperature (oC)
20
18
16
14
12
10
8
6
4
2
0
0:00 0:40 1:20 2:00 2:40 3:20 4:00 4:40 5:20 6:00 6:40 7:20 8:00 8:40 9:20 10:00 10:40 11:20 12:00 12:40 13:20 14:00 14:40 15:20 16:00 16:40 17:20 18:00 18:40 19:20 20:00 20:40 21:20 22:00 22:40 23:20
Time of Day
Outside
Inside


WF1 - Temp Profile After Retrofit
Temperature (oC)
20
18
16
14
12
10
8
6
4
2
0
0:00 0:40 1:20 2:00 2:40 3:20 4:00 4:40 5:20 6:00 6:40 7:20 8:00 8:40 9:20 10:00 10:40 11:20 12:00 12:40 13:20 14:00 14:40 15:20 16:00 16:40 17:20 18:00 18:40 19:20 20:00 20:40 21:20 22:00 22:40 23:20
Time of Day
Outside
Inside


WF1 - Av Internal Temp Profile Before & After Retrofit
Temperature (oC)
20
18
16
14
12
10
8
6
4
2
0
0:00 0:50 1:40 2:30 3:20 4:10 5:00 5:50 6:40 7:30 8:20 9:10 10:00 10:50 11:40 12:30 13:20 14:10 15:00 15:50 16:40 17:30 18:20 19:10 20:00 20:50 21:40 22:30 23:20
Time of Day
Before
After

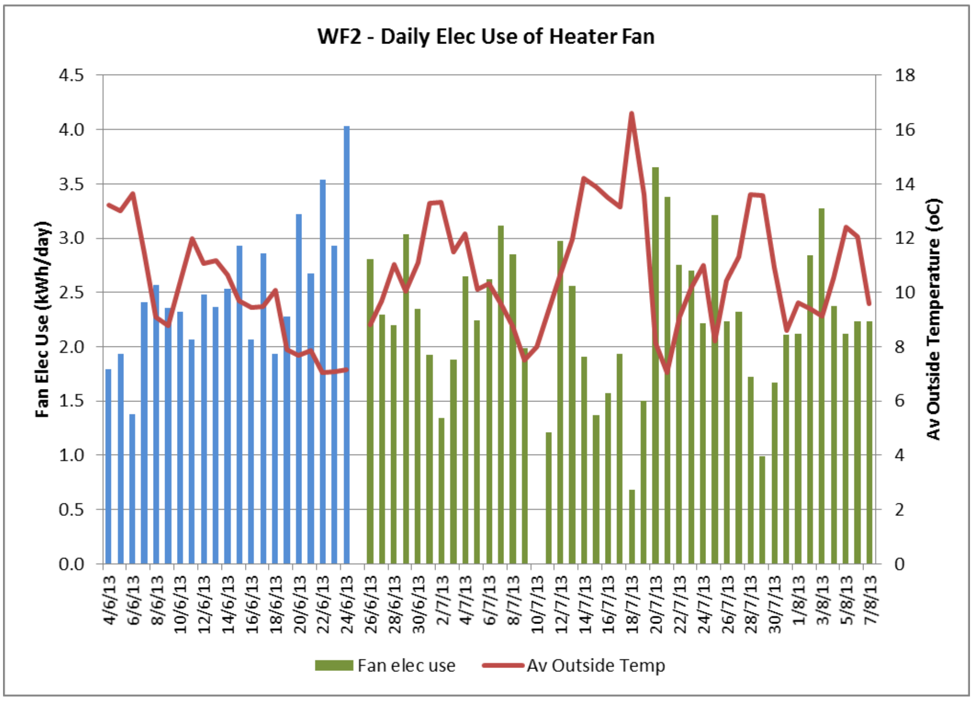

WF1 - Av Temperature Diff Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF1 - Av Load Profile of Heater Fan
Av Fan Power Consumption (Watts)
Time of Day
Before
After

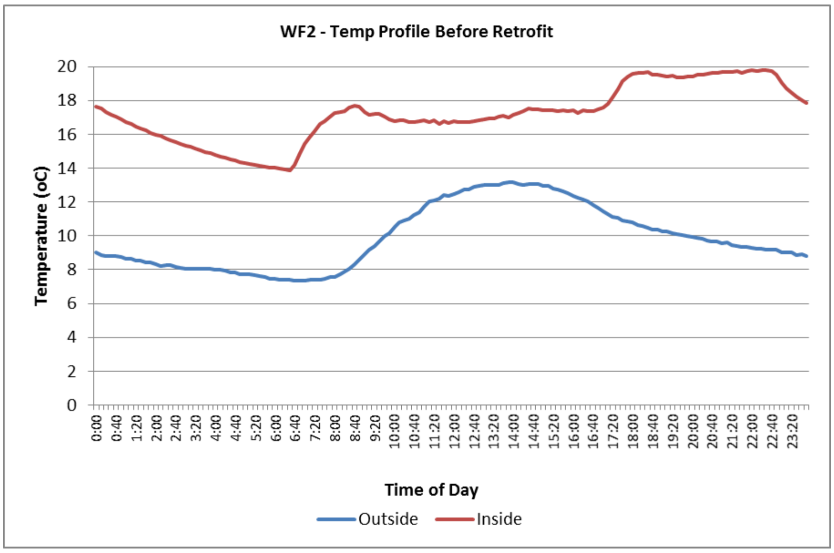

WF1 - Relationship between heater power and temperature difference
y = 23.454x
y = 22.726x
Average Heater Power Consumption (Watts)
Average Temperature Difference (oC)
Before
After
Linear (Before)
Linear (After)

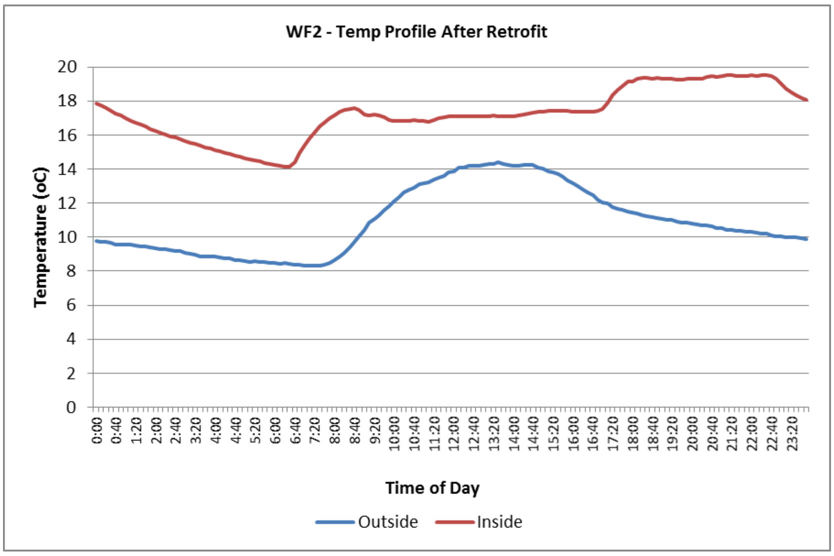
House WF2

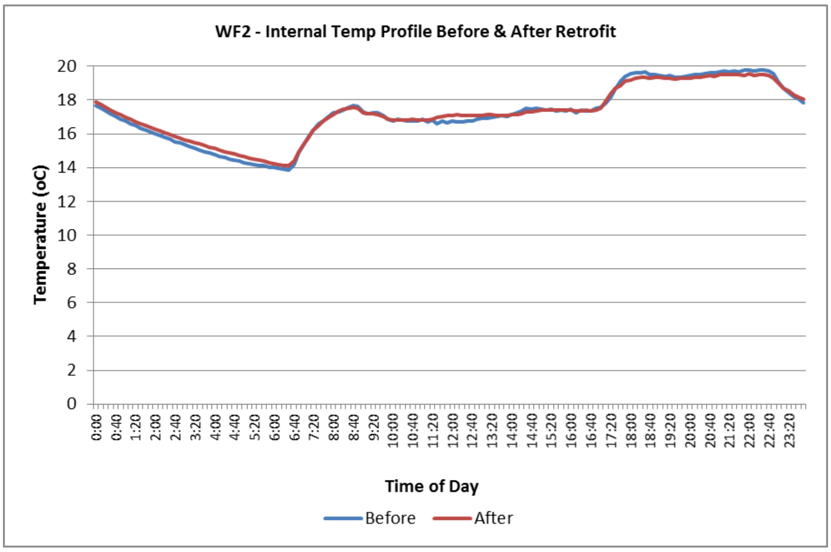
Parameter	Details
Approx. age of house (yrs)	55
House construction details	Walls – brick veneer; Floor – suspended timber Ceiling and walls insulated
Floor area (m^2)	70
Number of house occupants	4
Type of windows and coverings	Steel frame. Drapes on curtain rail. No pelmet.
Location of windows & area retrofitted (m^2)	Kitchen / Living room – 10.4 m^2
Main heating details	Brivis Buffalo B20 gas ducted heater, 2 stars, 19 years old Est. system conversion efficiency of 46.8% Est. gas consumption of 82,141 MJ per year
Date monitoring started	4/6/13
Date retrofit undertaken	25/6/13
Date monitoring completed	7/8/13
Heater operation before retrofit	Time – 12.11 hours per day ; Energy – 2.51 kWh per day
Av. temperature difference before retrofits	8.47°C
Heater operation after retrofit	Time – 11.15 hours per day; Energy – 2.27 kWh per day
Av. temperature difference after retrofits	7.57°C

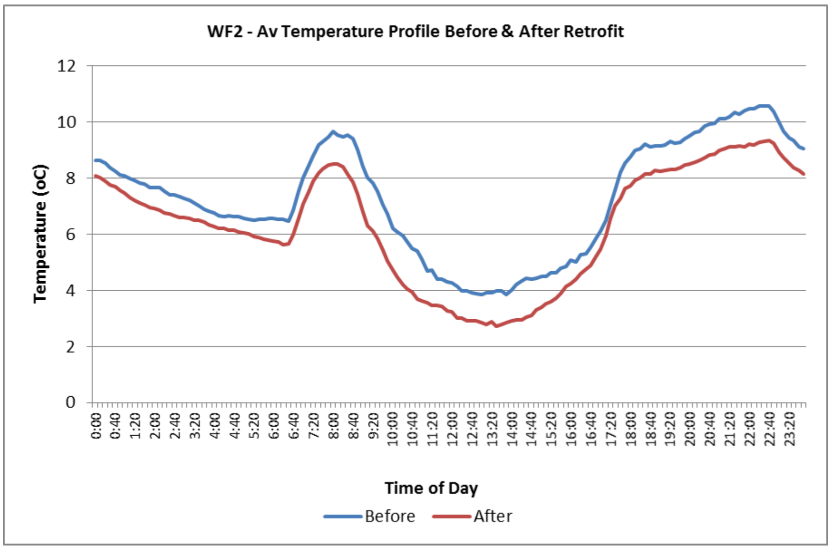


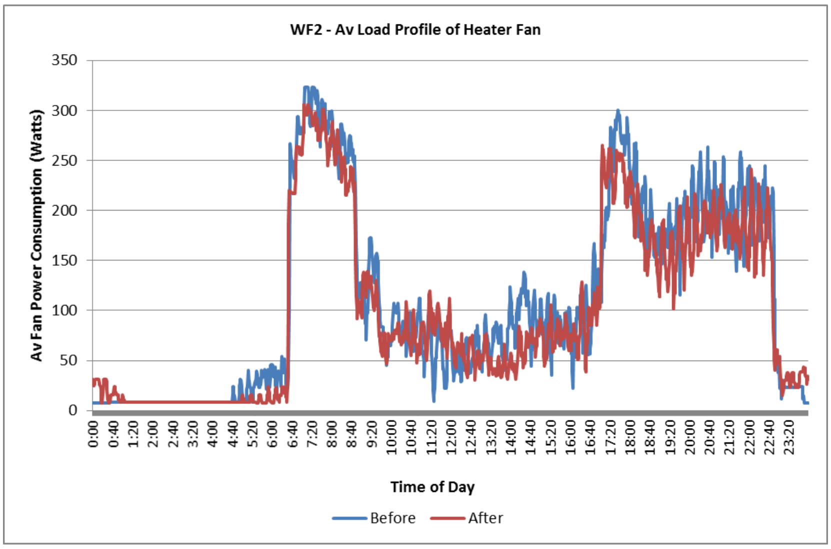
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

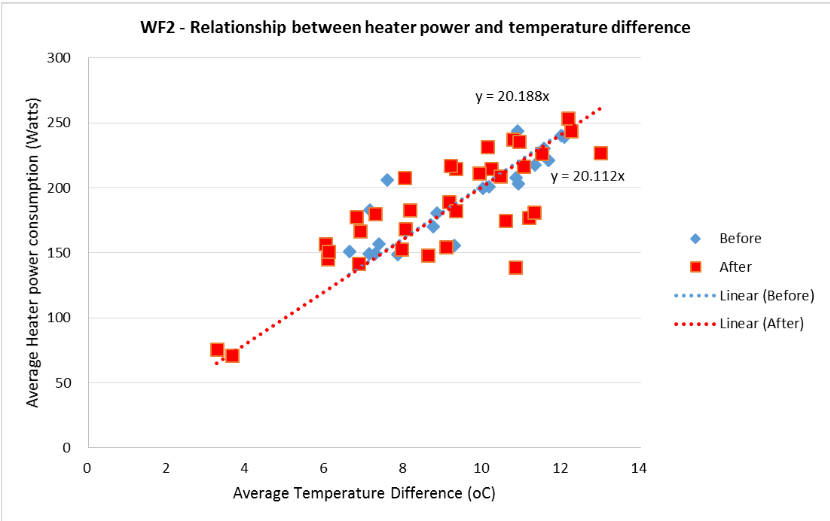

WF2 - Temp Profile Before Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF2 - Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF2 - Internal Temp Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After

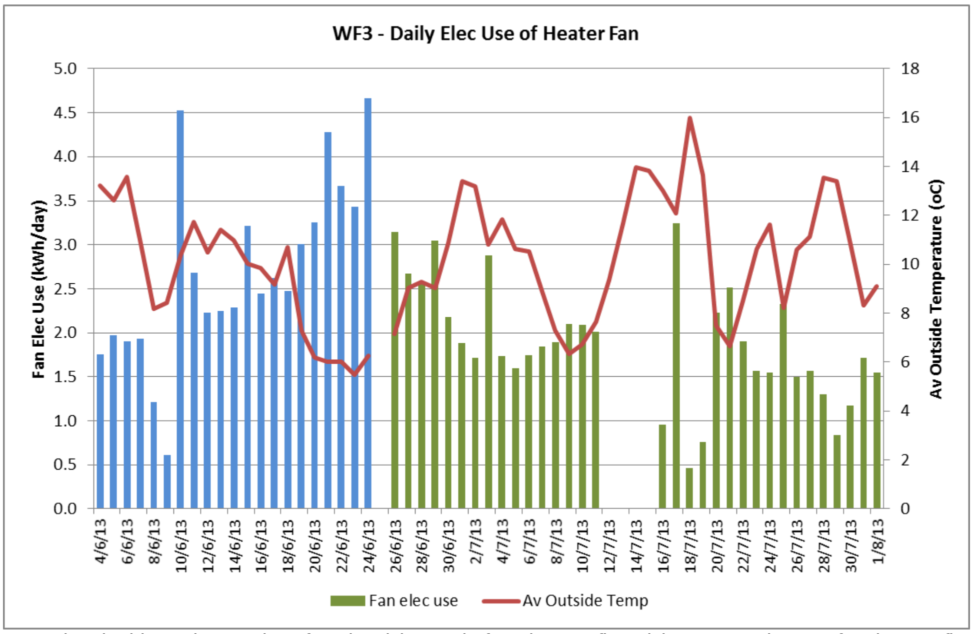

WF2 - Av Temperature Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF2 - Av Load Profile of Heater Fan
Av Fan Power Consumption (Watts)
Time of Day
Before
After

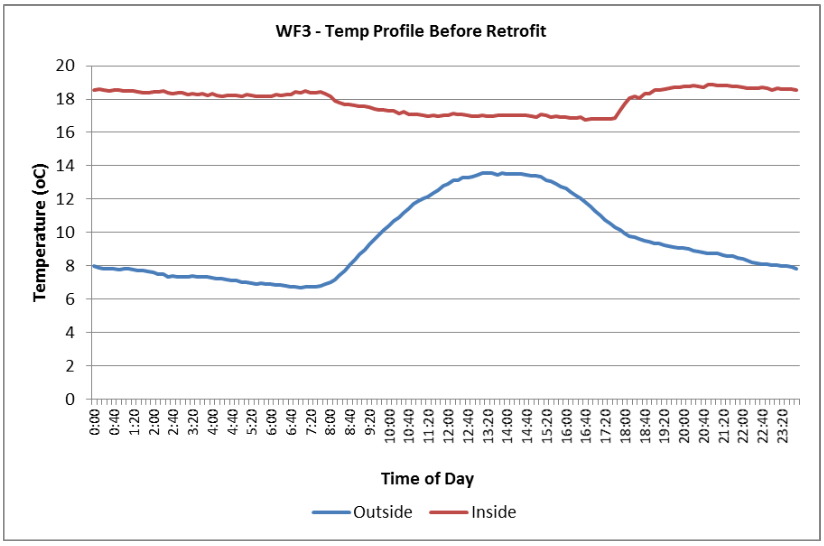

WF2 - Relationship between heater power and temperature difference
Average Heater power consumption (Watts)
Average Temperature Difference (oC)
y = 20.188x
y = 20.112x
Before
After
Linear (Before)
Linear (After)

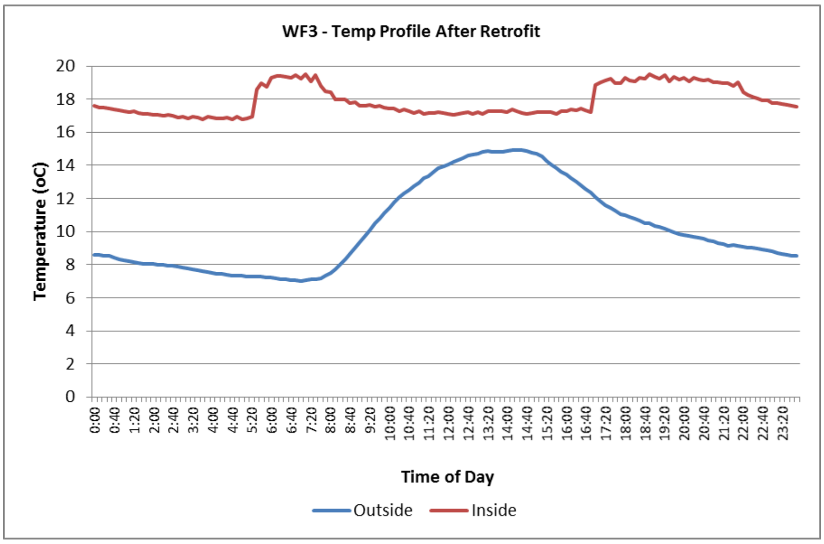
House WF3

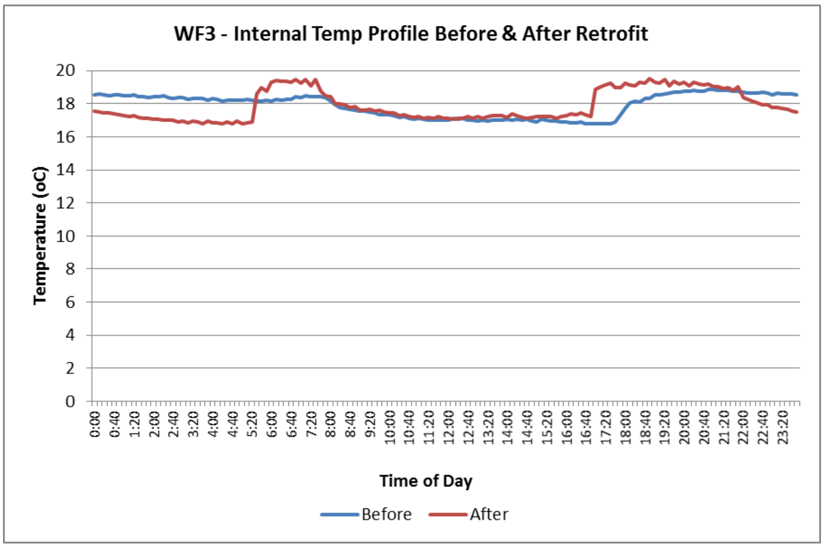
Parameter	Details
Approx. age of house (yrs)	50
House construction details	Walls – brick veneer; Floor – suspended timber Ceiling insulated
Floor area (m^2)	120
Number of house occupants	4
Type of windows and coverings	Steel frame. Some bare windows and some with Roman blinds
Location of windows & area retrofitted (m^2)	Kitchen / Living room – 10.5 m^2
Main heating details	Vulcan C-X 901 gas ducted heater, 2 stars, 25 years old Est. heating system efficiency of 45.0% Est. gas consumption of 59,357 per year
Date monitoring started	4/6/13
Date retrofit undertaken	25/6/13
Date monitoring completed	1/8/13
Heater operation before retrofit	Time – 15.6 hours per day ; Energy – 2.69 kWh per day
Av. temperature difference before retrofits	10.3°C
Heater operation after retrofit	Time – 12.03 hours per day ; Energy -1.89 kWh per day
Av. temperature difference after retrofits	9.75°C

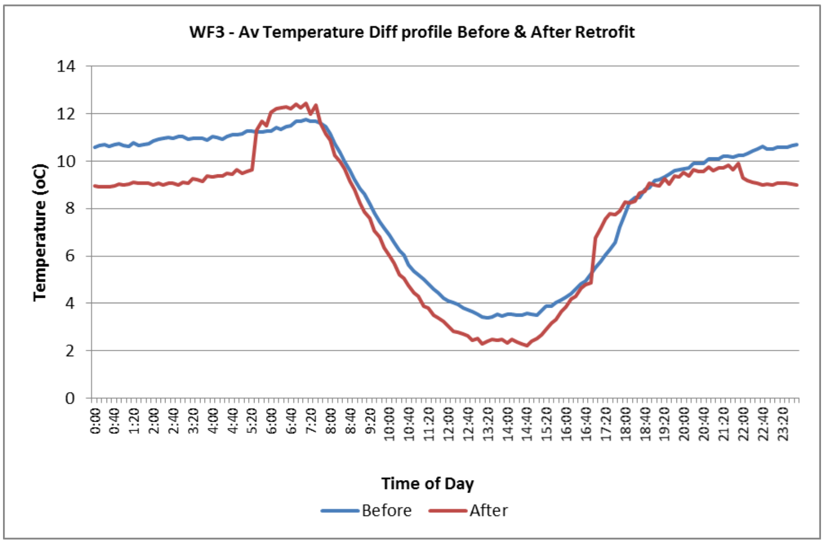


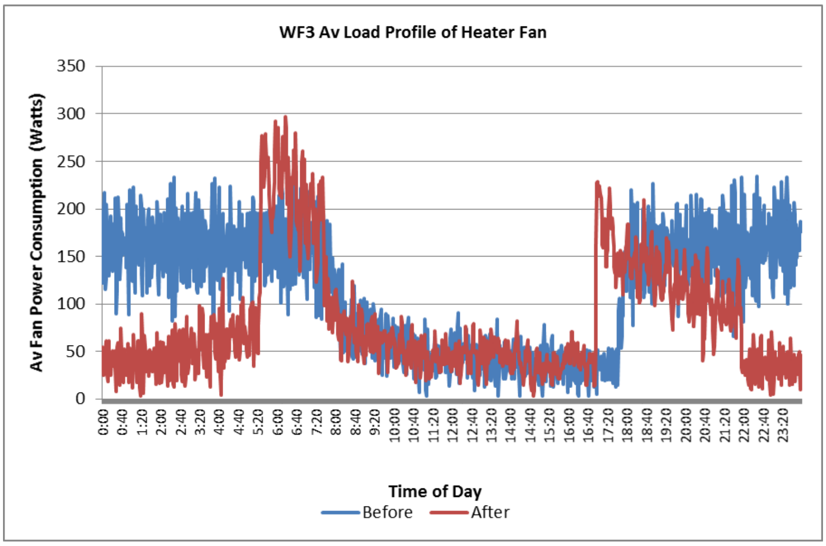
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

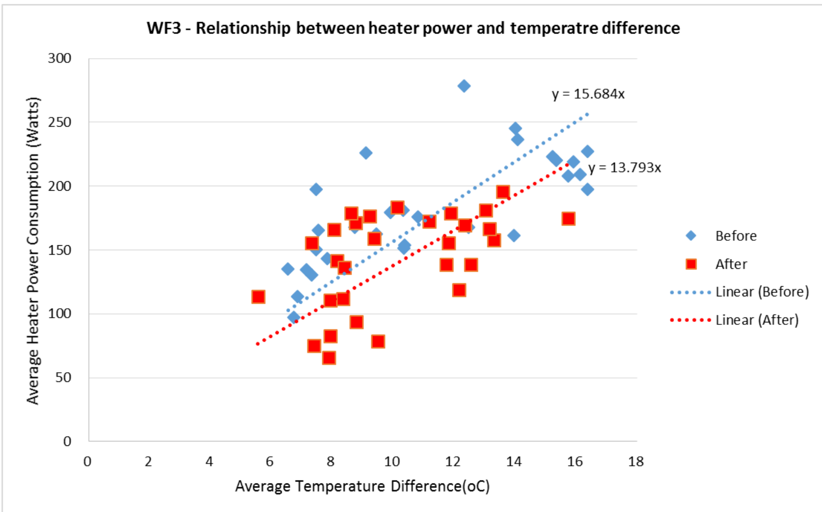

WF3 - Temp Profile Before Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF3 - Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF3 - Internal Temp Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After

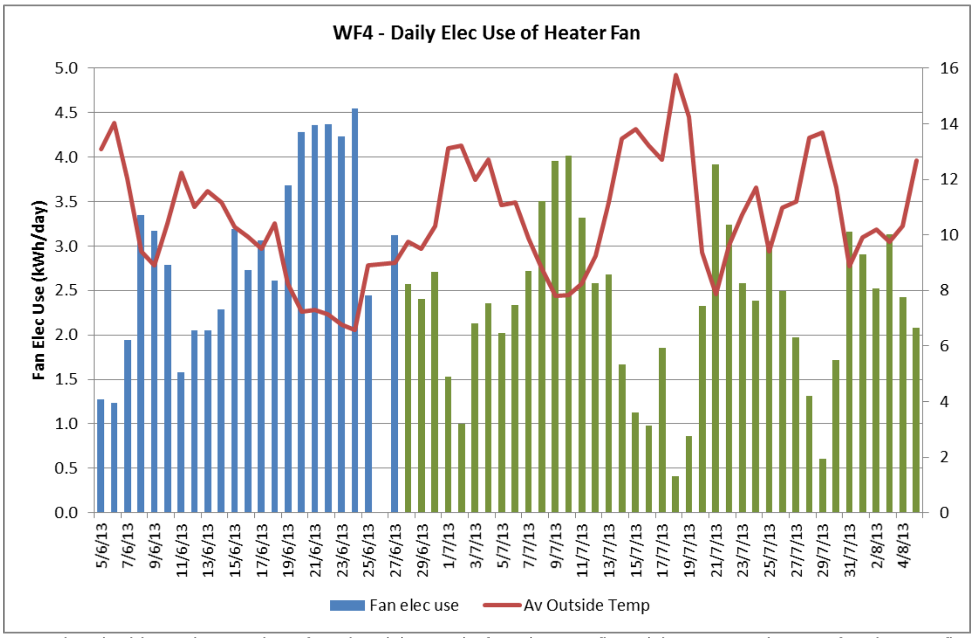

WF3 - Av Temperature Diff profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF3 Av Load Profile of Heater Fan
Av Fan Power Consumption (Watts)
Time of Day
Before
After

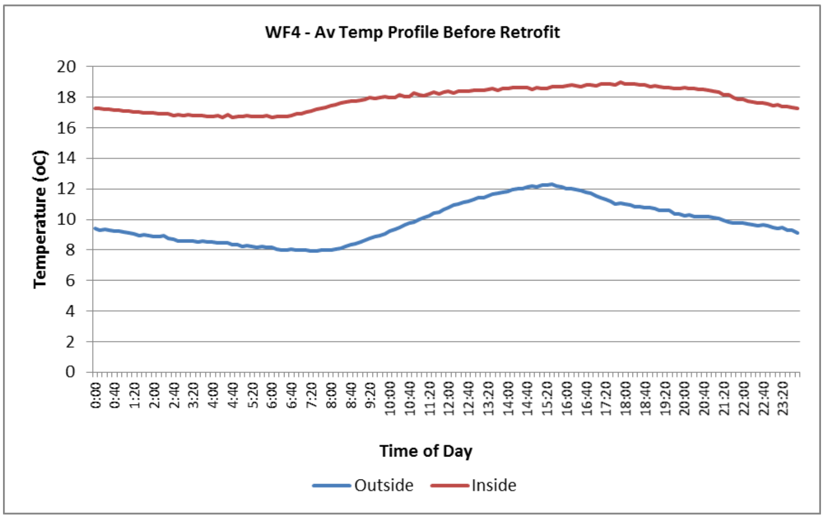

WF3 - Relationship between heater power and temperatre difference
Average Heater Power Consumption (Watts)
Average Temperature Difference(oC)
y = 15.684x
y = 13.793x
Before
After
Linear (Before)
Linear (After)

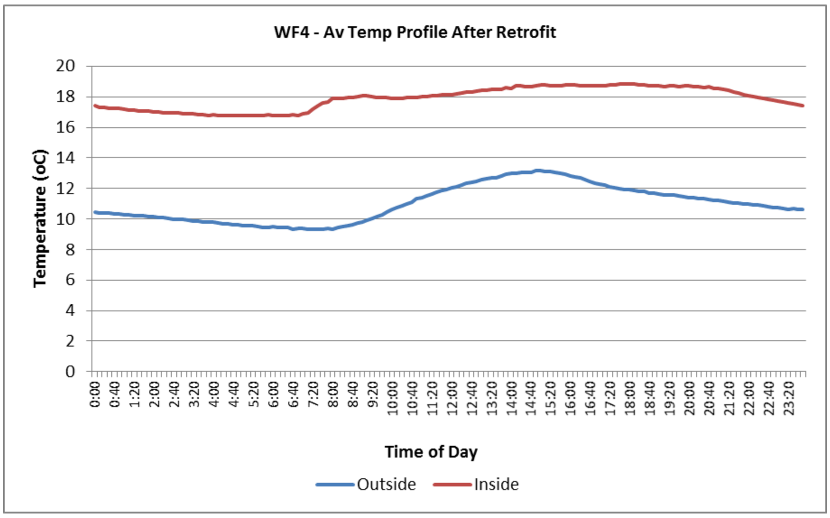
House WF4

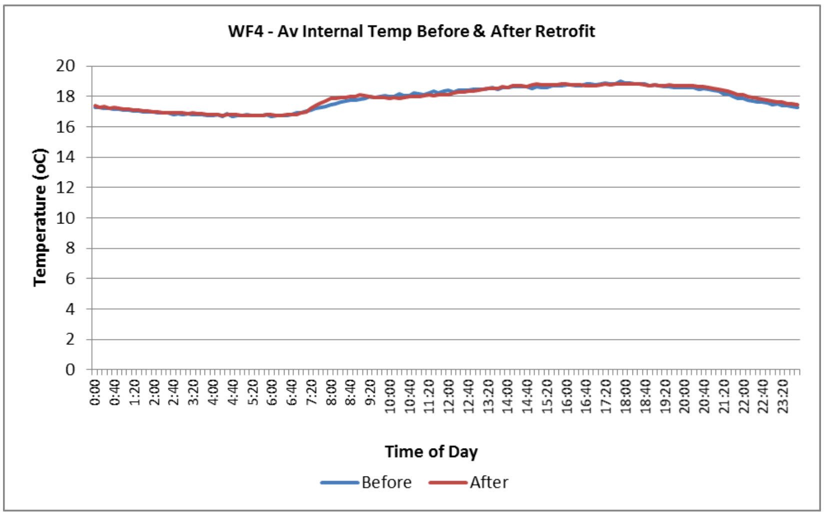
Parameter	Details
Approx. age of house (yrs)	75
House construction details	Walls – brick veneer; Floor – suspended timber Ceiling insulated
Floor area (m^2)	200
Number of house occupants	4
Type of windows and coverings	Steel frame. Inner and outer drapes, capped at the top
Location of windows & area retrofitted (m^2)	Lounge – 12.6 m^2
Main heating details	Brivis Buffalo gas ducted heater, 2 stars, 32 years old Est. heating system efficiency of 42.9% Est. annual gas consumption of 69,269 MJ per year
Date monitoring started	5/6/13
Date retrofit undertaken	26/6/13
Date monitoring completed	5/8/13
Heater operation before retrofit	Time – 19.5 hours per day; Energy -2.92 kWh per day
Av. temperature difference before retrofits	8.57°C
Heater operation after retrofit	Time – 18.02 hours per day; Energy – 2.34 kWh per day
Av. temperature difference after retrofits	7.46°C

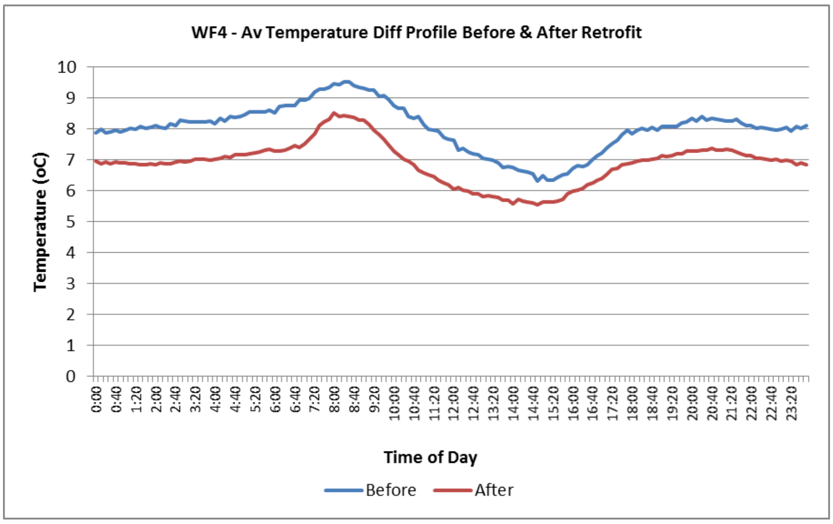


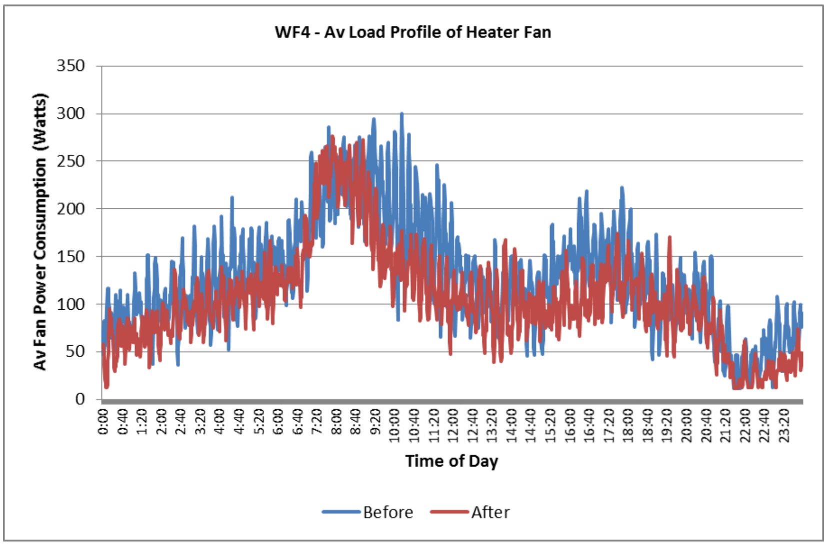
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

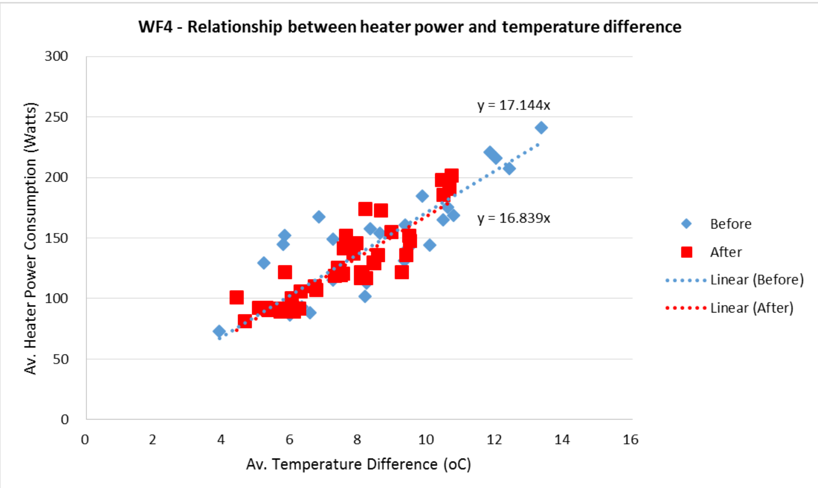

WF4 - Av Temp Profile Before Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF4 - Av Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF4 - Av Internal Temp Before & After Retrofit
Temperature (oC)
Time of Day
Before
After

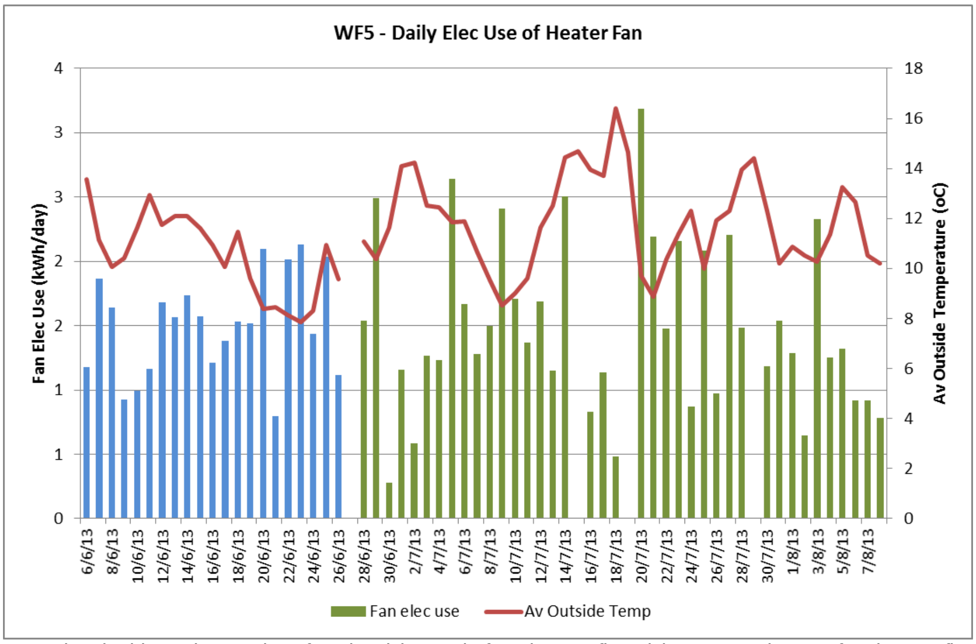

WF4 - Av Temperature Diff Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF4 - Av Load Profile of Heater Fan
Av Fan Power Consumption (Watts)
Time of Day
Before
After

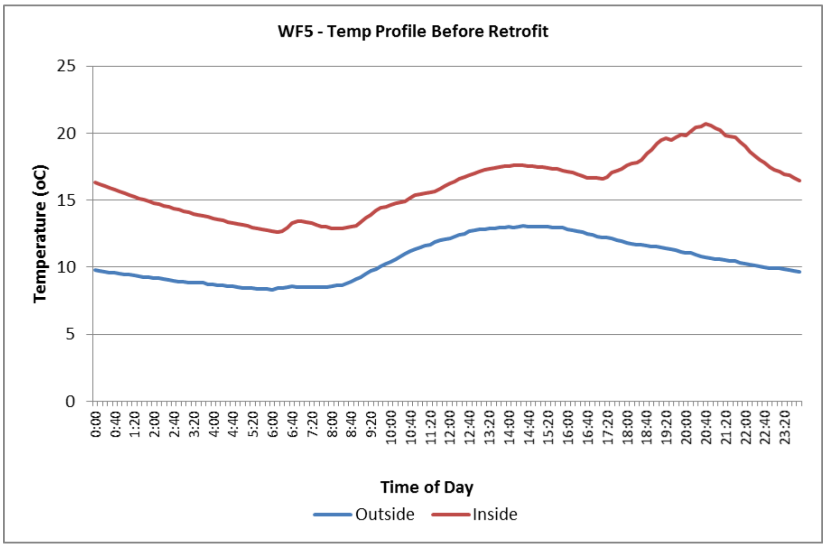

WF4 - Relationship between heater power and temperature difference
Av. Heater Power Consumption (Watts)
Av. Temperature Difference (oC)
y = 17.144x
y = 16.839x
Before
After
Linear (Before)
Linear (After)

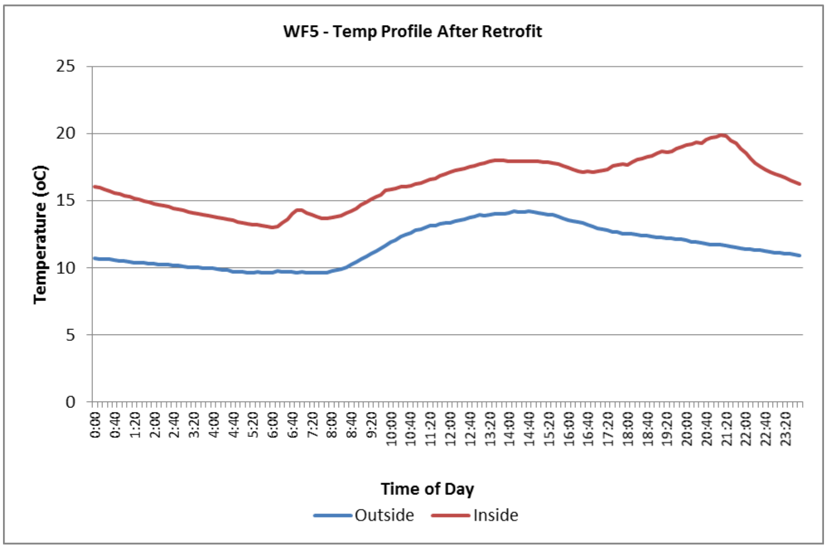
House WF5

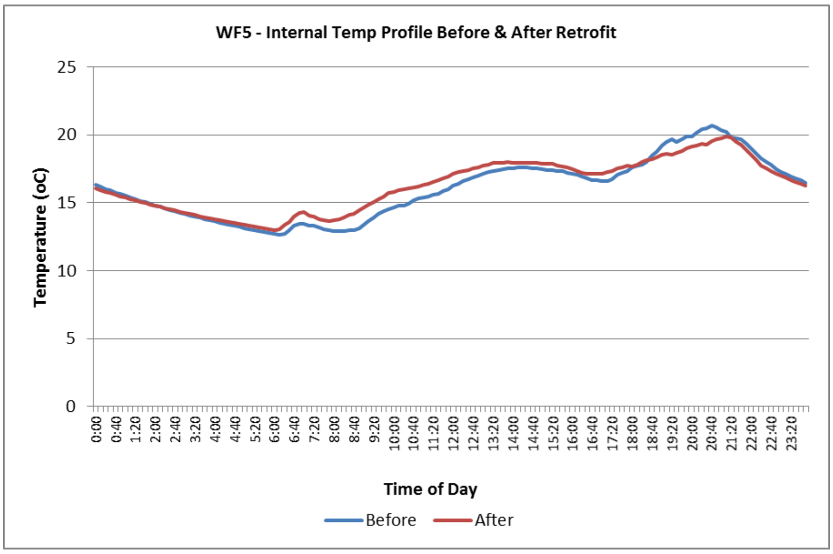
Parameter	Details
Approx. age of house (yrs)	8
House construction details	Walls – weatherboard; Floors – suspended timber Ceiling and walls insulated
Floor area (m^2)	205
Number of house occupants	4
Type of windows and coverings	Wooden frame Holland blinds
Location of windows & area retrofitted (m^2)	Upstairs living room and downstairs hallway – 10.1 m^2
Main heating details	Braemar TH320 gas ducted heater, 3 Stars, 8 years old Est. heating system efficiency of 57.8% Est annual gas consumption of 43,964 MJ per year
Date monitoring started	6/6/13
Date retrofit undertaken	27/6/13
Date monitoring completed	8/8/13
Heater operation before retrofit	Time – 4.03 hours per day; Energy – 1.50 kWh per day
Av. temperature difference before retrofits	8.99ºC
Heater operation after retrofit	Time – 3.96 hours per day; Energy -1.48 kWh per day
Av. temperature difference after retrofits	7.84ºC

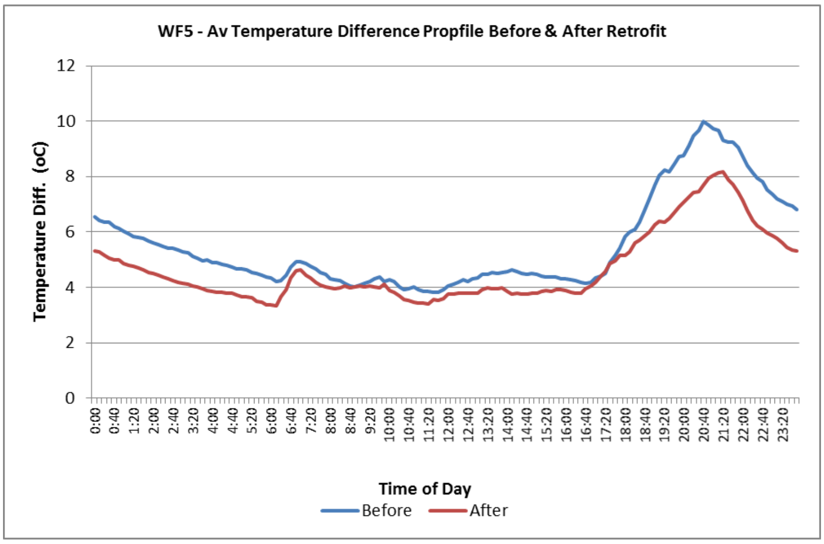


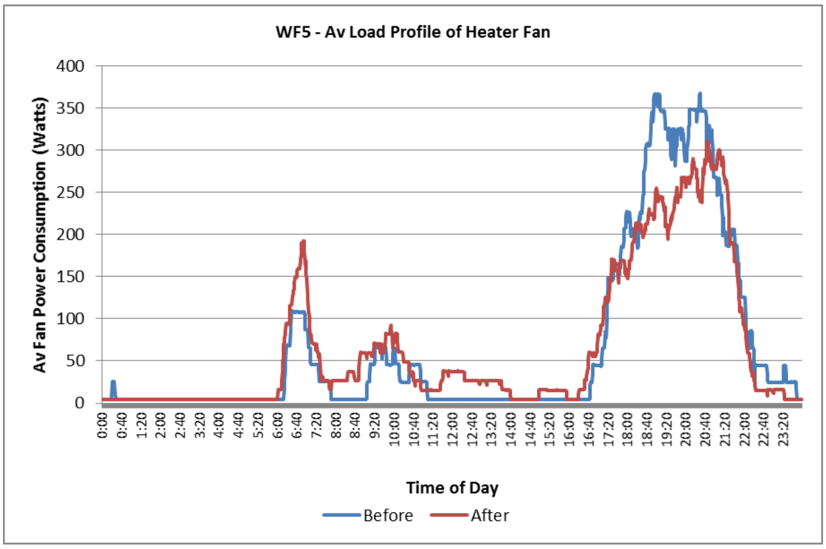
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits


WF5 - Temp Profile Before Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF5 - Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF5 - Internal Temp Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After

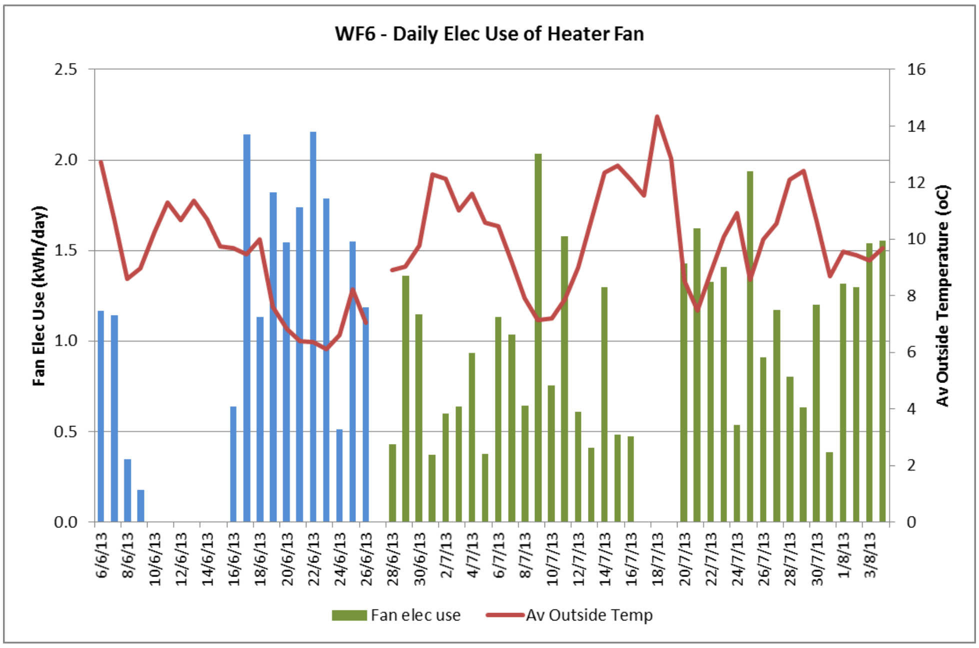




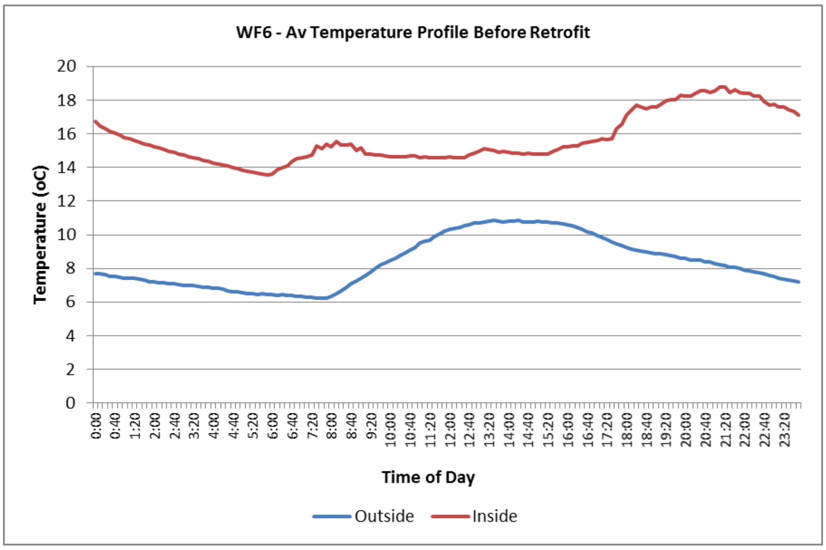
Note that the data collected was not suitable for preparing an estimate of the technical energy saving. The heater displayed very little cycling behaviour, and there was not enough suitable data points to prepare a plot of the average heater electrical power consumption against the average temperature difference.

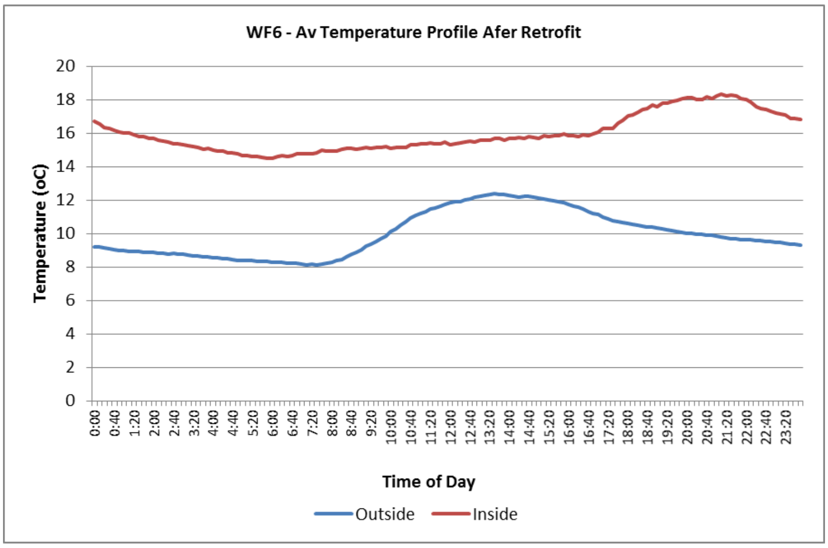
House WF6

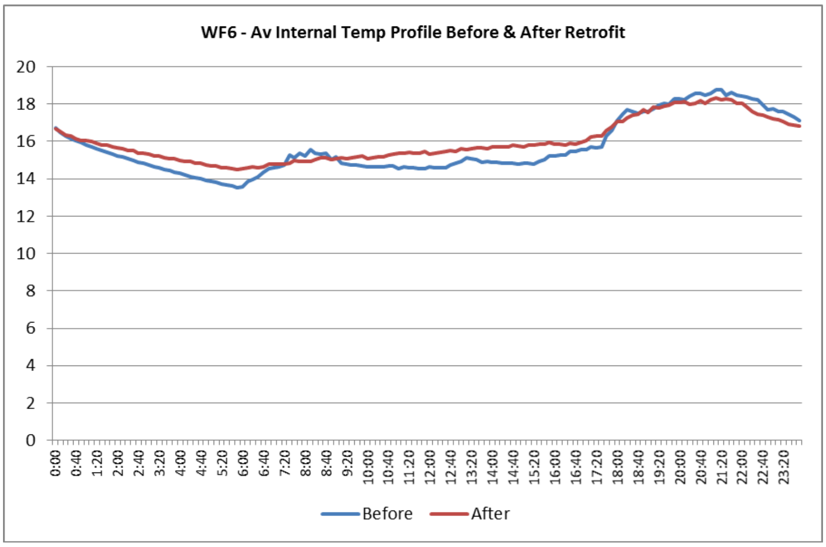
Parameter	Details
Approx. age of house (yrs)	85
House construction details	Walls – weatherboard; Floor – suspended timber Ceiling and some of wall and floor insulated
Floor area (m^2)	120
Number of house occupants	1
Type of windows and coverings	Aluminium and some wooden frame windows Most windows have drapes.
Location of windows & area retrofitted (m^2)	Kitchen, living room and front entrance (7.5 m^2)
Main heating details	Vulcan C-X 901 gas ducted heater, 2 star, 34 years old Est. heating system efficiency of 42.3% Est. gas consumption of 40,149 MJ per year
Date monitoring started	6/6/13
Date retrofit undertaken	27/6/13
Date monitoring completed	4/8/13
Heater operation before retrofit	Time – 5.91 hours per day; Energy – 1.27 kWh per day
Av. temperature difference before retrofits	11.2ºC
Heater operation after retrofit	Time – 5.77 hours per day; Energy – 1.01 kWh per day
Av. temperature difference after retrofits	8.9ºC

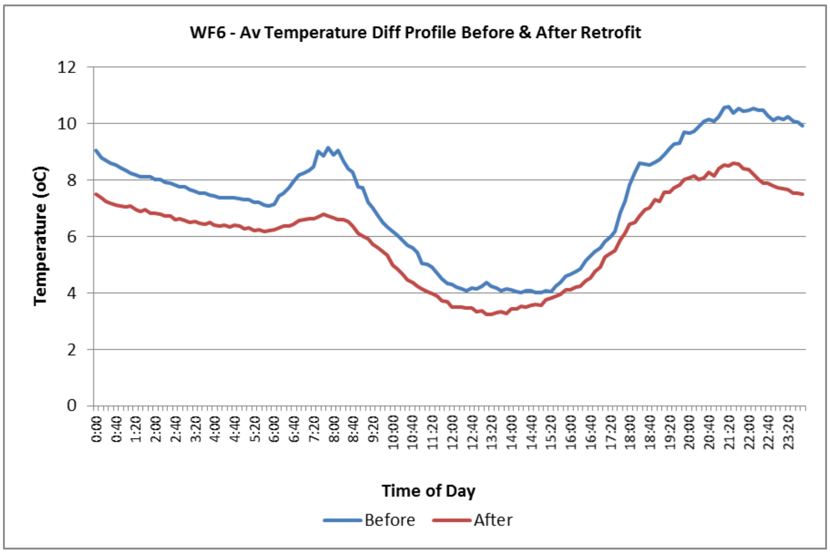


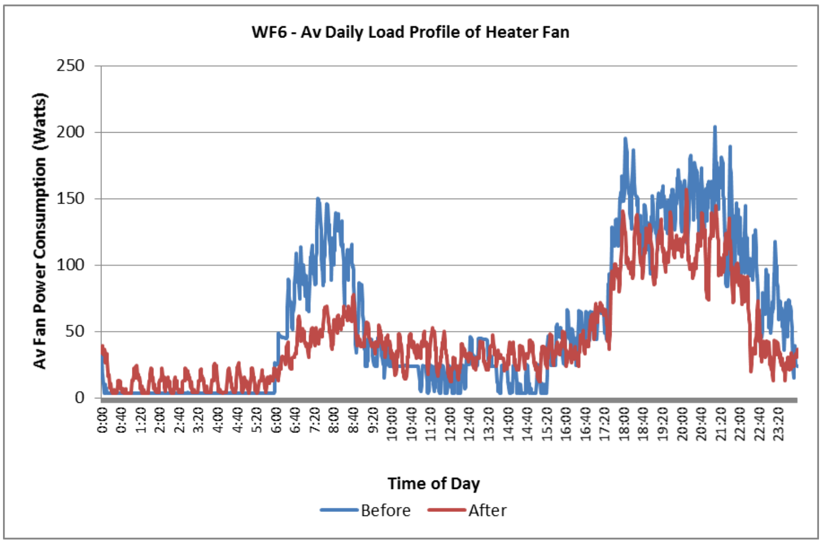
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

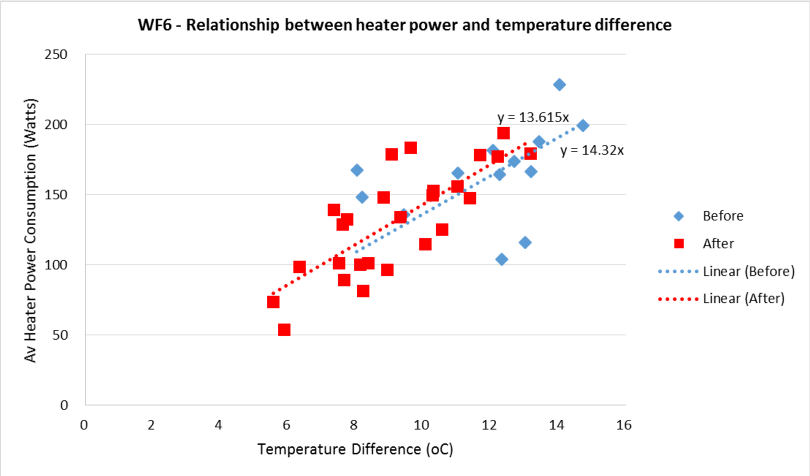

WF6 - Av Temperature Profile Before Retrofit
Temperature (oC)
20
18
16
14
12
10
8
6
4
2
0
0:00
0:40
1:20
2:00
2:40
3:20
4:00
4:40
5:20
6:00
6:40
7:20
8:00
8:40
9:20
10:00
10:40
11:20
12:00
12:40
13:20
14:00
14:40
15:20
16:00
16:40
17:20
18:00
18:40
19:20
20:00
20:40
21:20
22:00
22:40
23:20
Time of Day
Outside
Inside


WF6 - Av Temperature Profile Afer Retrofit
Temperature (oC)
20
18
16
14
12
10
8
6
4
2
0
0:00
0:40
1:20
2:00
2:40
3:20
4:00
4:40
5:20
6:00
6:40
7:20
8:00
8:40
9:20
10:00
10:40
11:20
12:00
12:40
13:20
14:00
14:40
15:20
16:00
16:40
17:20
18:00
18:40
19:20
20:00
20:40
21:20
22:00
22:40
23:20
Time of Day
Outside
Inside


WF6 - Av Internal Temp Profile Before & After Retrofit
20
18
16
14
12
10
8
6
4
2
0
0:00
0:40
1:20
2:00
2:40
3:20
4:00
4:40
5:20
6:00
6:40
7:20
8:00
8:40
9:20
10:00
10:40
11:20
12:00
12:40
13:20
14:00
14:40
15:20
16:00
16:40
17:20
18:00
18:40
19:20
20:00
20:40
21:20
22:00
22:40
23:20
Before
After

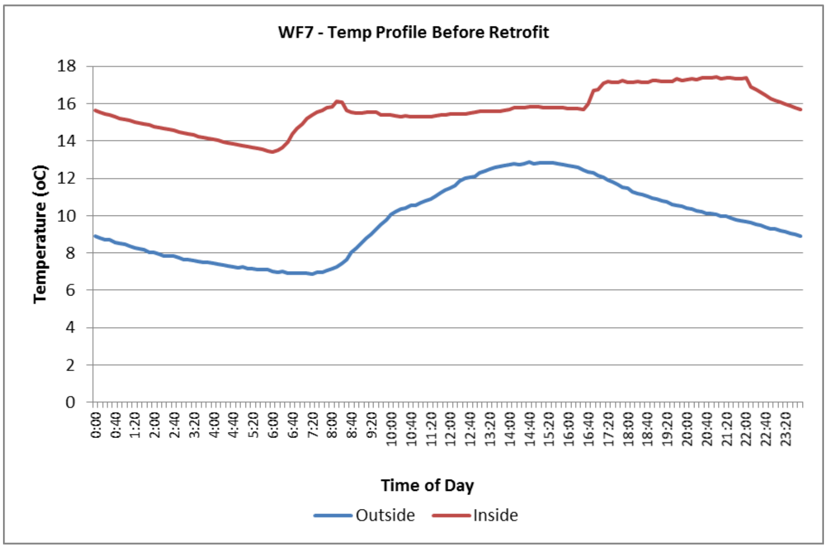

WF6 - Av Temperature Diff Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After

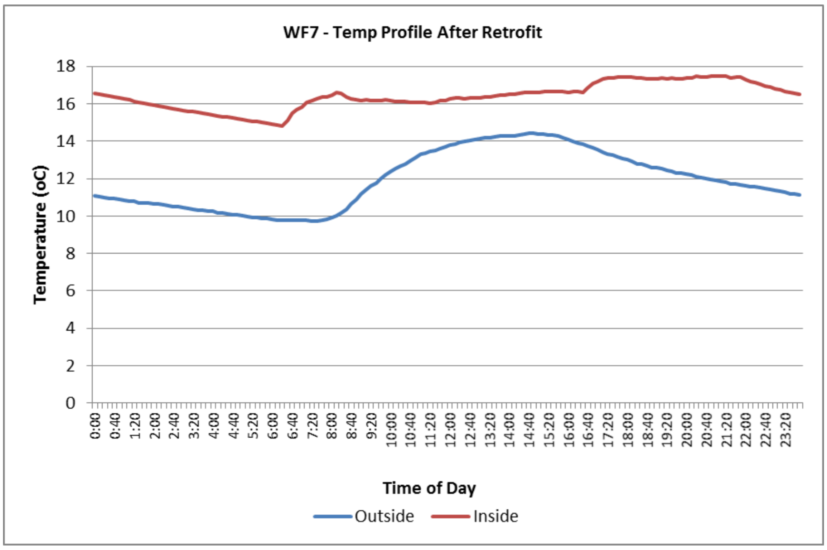

WF6 - Av Daily Load Profile of Heater Fan
Av Fan Power Consumption (Watts)
Time of Day
Before
After

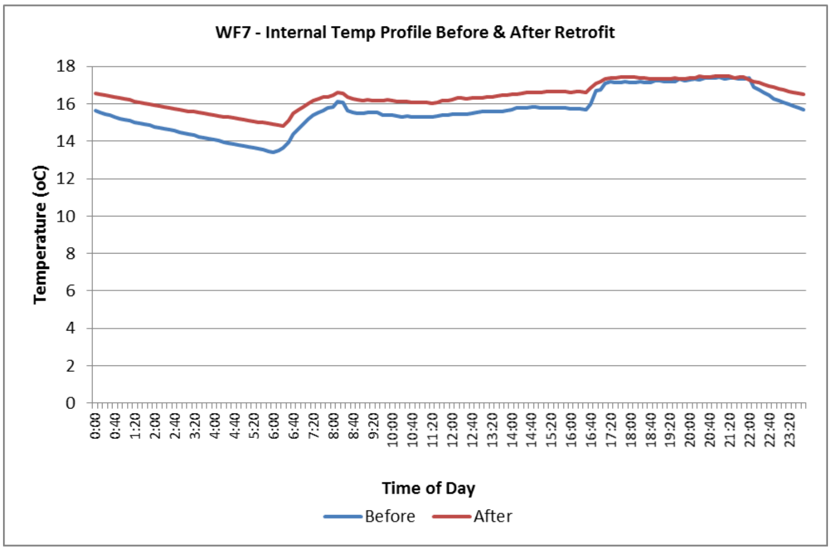

WF6 - Relationship between heater power and temperature difference
Av Heater Power Consumption (Watts)
Temperature Difference (oC)
y = 13.615x
y = 14.32x
Before
After
Linear (Before)
Linear (After)

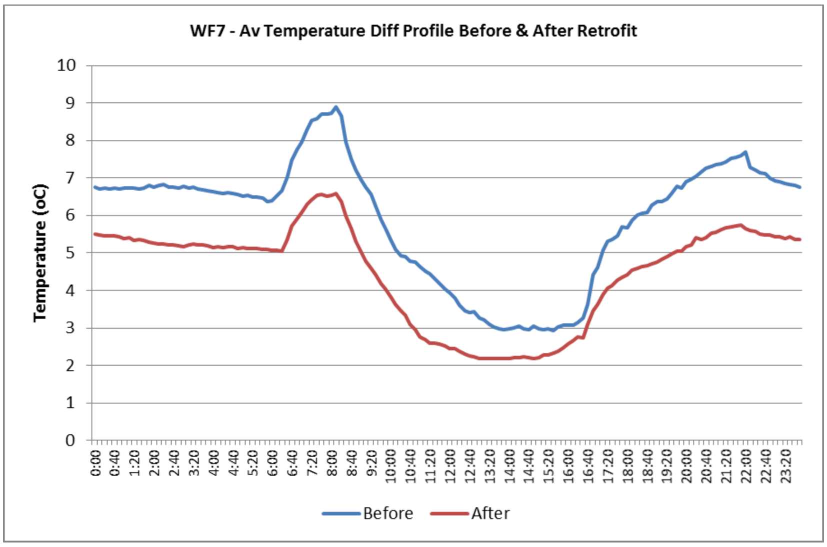
House WF7

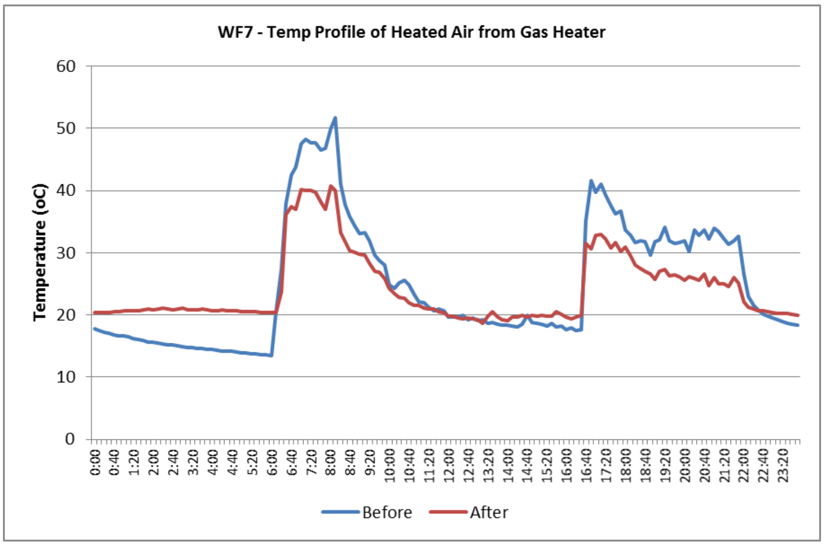
Parameter	Details
Approx. age of house (yrs)	50
House construction details	Walls – cavity brick; Floor – suspended timber Ceiling and some floor insulated
Floor area (m^2)	220
Number of house occupants	6
Type of windows and coverings	Wooden frame Vertical blinds
Location of windows & area retrofitted (m^2)	Kitchen, living room and lounge – 14.5 m^2
Main heating details	Premier PGH-210-34 gas ducted heater, 2 stars, 25 years old Est. heating system efficiency of 45% Est. gas consumption of 59,935 per year
Date monitoring started	8/6/13
Date retrofit undertaken	27/6/13
Date monitoring completed	6/8/13
Heater operation before retrofit	No data available as not possible to install electrical meter on the gas ducted heater at this house. A temperature sensor was installed to monitor the air temperature at one of the heater outlets, and this provided some data on the operating times of the heater (see below).
Av. temperature difference before retrofits	
Heater operation after retrofit	
Av. temperature difference after retrofits	




WF7 - Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside

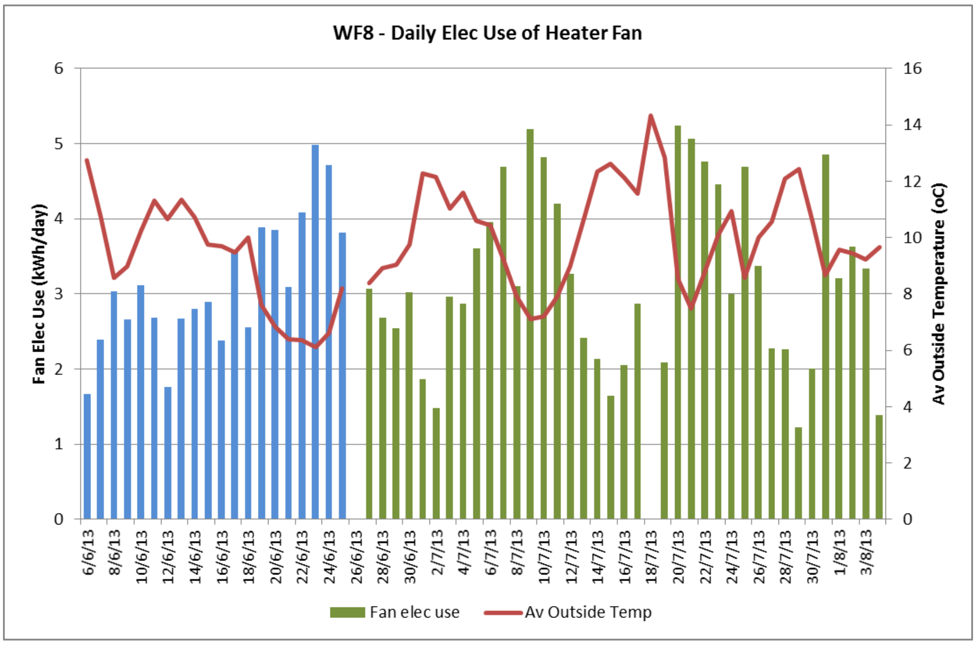

WF7 - Internal Temp Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF7 - Av Temperature Diff Profile Before & After Retrofit
Temperature (oC)
Before
After

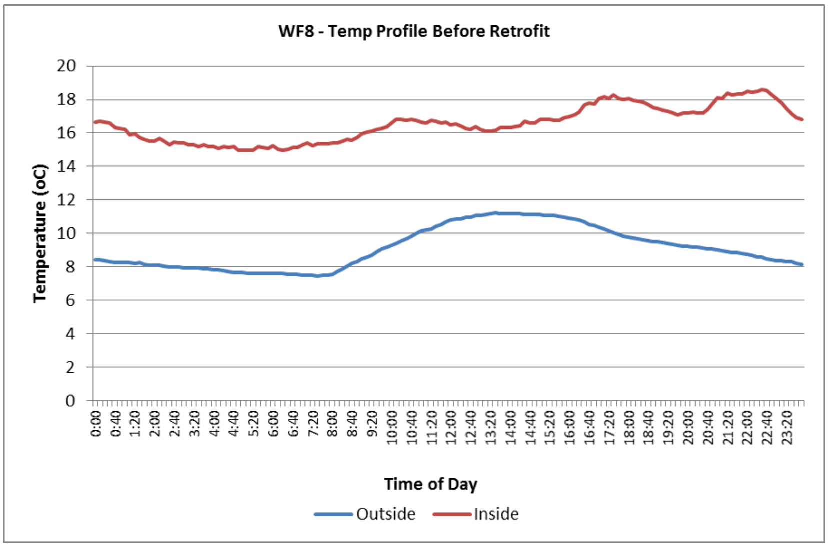

WF7 - Temp Profile of Heated Air from Gas Heater
Temperature (oC)
60
50
40
30
20
10
0
0:00
0:40
1:20
2:00
2:40
3:20
4:00
4:40
5:20
6:00
6:40
7:20
8:00
8:40
9:20
10:00
10:40
11:20
12:00
12:40
13:20
14:00
14:40
15:20
16:00
16:40
17:20
18:00
18:40
19:20
20:00
20:40
21:20
22:00
22:40
23:20
Before
After

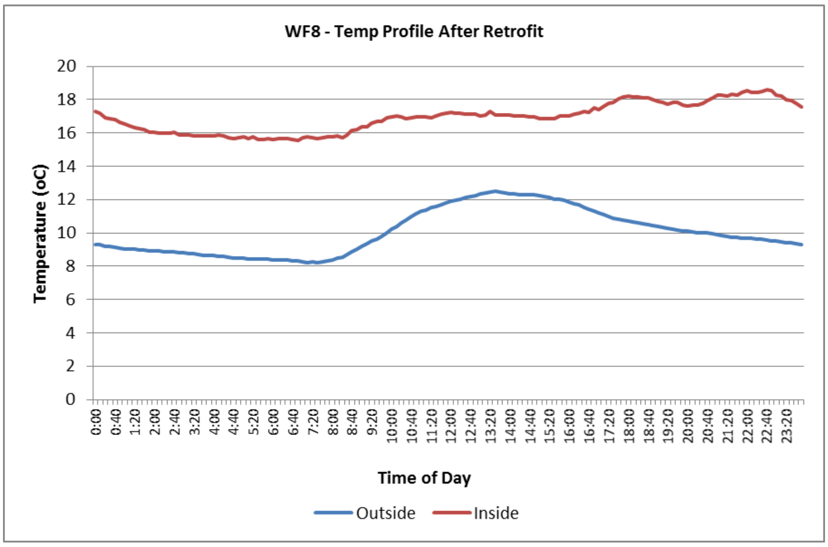
House WF8

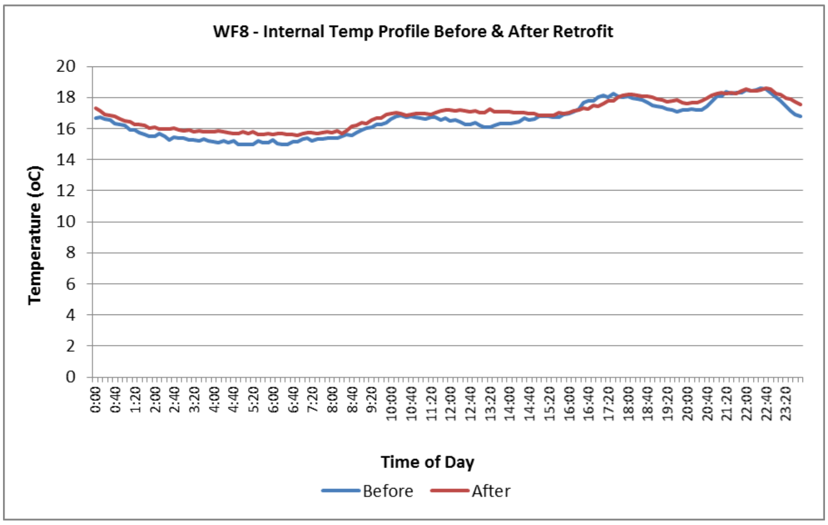
Parameter	Details
Approx. age of house (yrs)	80
House construction details	Walls – weatherboard; Floor – suspended timber
Floor area (m^2)	140
Number of house occupants	3
Type of windows and coverings	Wooden frame, double sash. Some bare windows and some with venetian blinds.
Location of windows & area retrofitted (m^2)	Kitchen and lounge – 7.6 m^2
Main heating details	Brivis StarPro Max HX23 gas ducted heater, 5.8 stars, 10 years old Est. heating system efficiency of 75.1% Est. gas consumption of 23,366 MJ per year
Date monitoring started	6/6/13
Date retrofit undertaken	26/6/13
Date monitoring completed	4/8/13
Heater operation before retrofit	Time – 15.31 hours per day; Energy – 3.13 kWh per day
Av. temperature difference before retrofits	8.45ºC
Heater operation after retrofit	Time – 15.04 hours per day; Energy – 3.19 kWh per day
Av. temperature difference after retrofits	7.97ºC

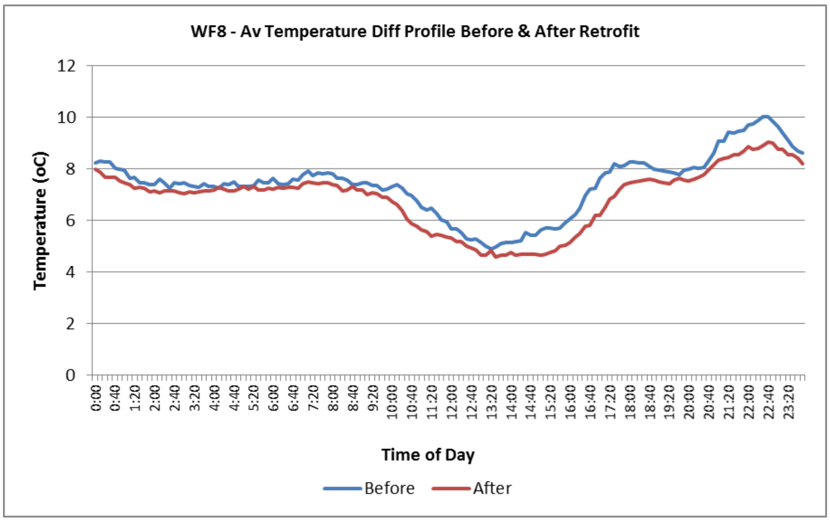


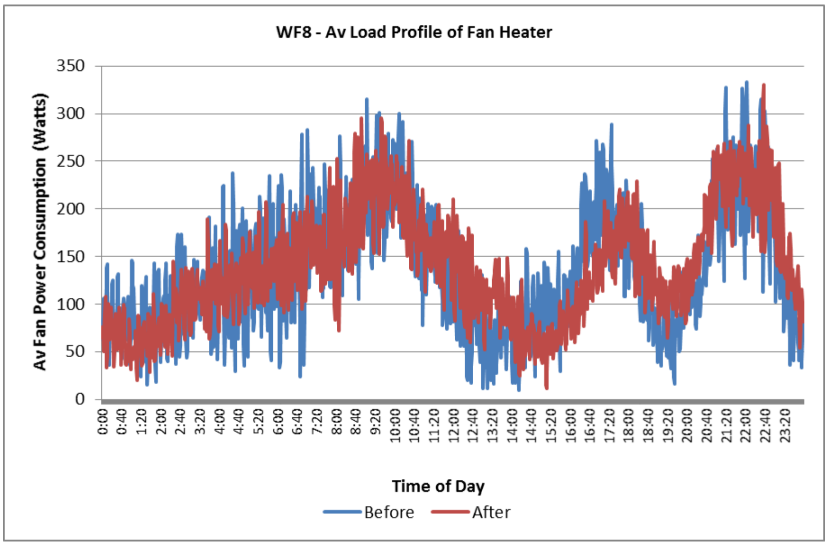
Note that the blue columns show fan electricity use before the retrofit and the green columns after the retrofits

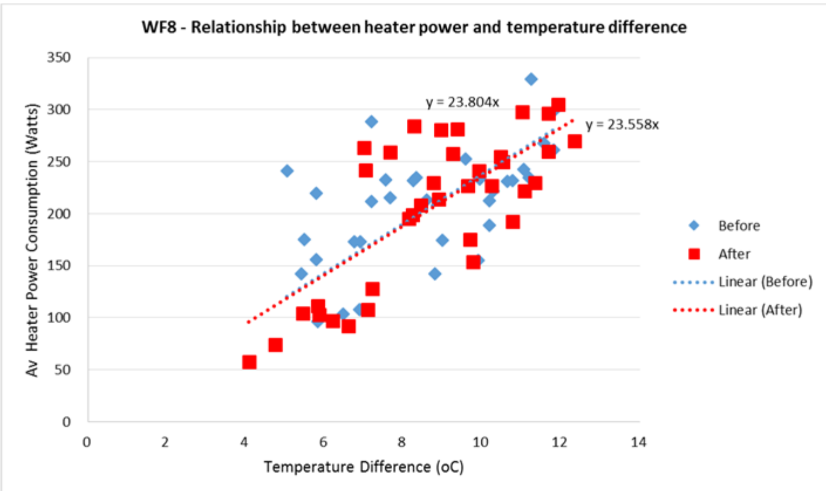

WF8 - Temp Profile Before Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF8 - Temp Profile After Retrofit
Temperature (oC)
Time of Day
Outside
Inside


WF8 - Internal Temp Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF8 - Av Temperature Diff Profile Before & After Retrofit
Temperature (oC)
Time of Day
Before
After


WF8 - Av Load Profile of Fan Heater
Av Fan Power Consumption (Watts)
Time of Day
Before
After


WF8 - Relationship between heater power and temperature difference
Av Heater Power Consumption (Watts)
Temperature Difference (oC)
y = 23.804x
y = 23.558x
Before
After
Linear (Before)
Linear (After)

Sustainability Victoria
Level 28, Urban Workshop,
50 Lonsdale Street, Melbourne, VIC 3000
Phone (03) 8626 8700
Sustainability.vic.gov.au

Published by Sustainability Victoria
Window Film Secondary Glazing Retrofit Trial

Sustainability Victoria
Level 28, Urban Workshop,
50 Lonsdale Street, Melbourne, VIC 3000
Phone (03) 8626 8700
Sustainability.vic.gov.au

Published by Sustainability Victoria
Window Film Secondary Glazing Retrofit Trial