On-Ground Assessment of the Energy Efficiency Potential of Victorian Homes

Report on Pilot Study

Prepared by Moreland Energy Foundation Limited
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Foreword

There is a general recognition that the existing housing stock represents the largest potential for greenhouse abatement in the residential sector. However, few, if any, 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.

Sustainability Victoria has commenced a program of work to address these information gaps. The aim of the project is to undertake on-ground assessments of the energy efficiency of existing Victorian houses so that a more accurate estimate of the potential energy and greenhouse savings can be prepared, as well as estimates of the likely costs for upgrading the existing housing stock to a higher level of energy efficiency. This information will be an important evidence base to inform the development of policies and programs which aim to reduce residential energy consumption and greenhouse emissions.

As a first step, in 2009 Sustainability Victoria commissioned the Moreland Energy Foundation Limited (MEFL) to undertake a pilot On-Ground Assessment Project based on 15 existing houses located in Melbourne. While such a small sample of houses cannot be representative of the whole of the Victorian housing stock, this initial study provides a useful insight into the current level of energy efficiency of the housing stock constructed prior to 1980, as well as the most cost-effective methods for achieving greenhouse abatement.

A key aim of this pilot project was to develop and trial methodologies which can be used in an expanded study. A preliminary analysis based on the analysis of the gas bills of some households involved in the study suggests that the heat load estimation methodology used in this pilot project over-estimates heating energy use, and therefore overestimates the savings. Sustainability Victoria is currently working with MEFL to review the existing methodology and to develop a more accurate heat load estimation methodology.

The learnings from this initial project, and the revised heat load estimation methodology, will be used in an expanded On-Ground Assessment Project which will be undertaken in 2010. The data collected in this expanded study will be combined with data collected in the pilot study to obtain a more comprehensive insight into the energy efficiency of the existing Victorian housing stock.

This report, prepared by MEFL, sets out the approach used in the pilot study and the results which have been obtained to date. We welcome your feedback[1] on the measurement and analysis methodologies used in the pilot study, as it will assist us to improve the methodologies used in the expanded study.

[1] Feedback can be provided to Ian McNicol via e-mail at ian.mcnicol@sustainability.vic.gov.au

Acknowledgements

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Govind Maksay was the main author of this report on the pilot study, with significant contributions from Sustainability Victoria and EnergyConsult. MEFL would like to especially thank Ian McNicol from Sustainability Victoria for his assistance during this project.

MEFL would also like to thank the 15 Melbourne households that participated in this initial pilot project for providing access to their homes.

A team of sub-contractors also undertook vital aspects of the project, as follows:

- Air Barrier Technology: air leakage testing of the houses
- EnergyConsult: contribution to project design, data analysis and final report
- Mitsuori Architects: assisted the development of the FirstRate5 checklists, architectural measure up, and drawings of the floor plans
- Peter Kennedy, Kevin Fregon and Ross Mulder: energy audits
- Greencheck: FirstRate5 inputs
- Nycole Wood: AccuBatch and FirstRate5 modelling
- Tony Isaacs: advice on AccuBatch and FirstRate5 modelling
- Anthony Morey: building shell and appliance cost data research.

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1. Executive summary

The residential sector contributes 17.5% of Victoria's total greenhouse gas emissions. If Victoria is to significantly reduce greenhouse gas emissions and its reliance on non-renewable energy sources there is an imperative to improve the energy efficiency of its housing stock. An essential part of this process will be improving the performance of existing houses, as they will constitute a significant proportion of housing stock over the next 50 - 80 years. A significant proportion of existing homes throughout the state have an energy rating well below the current 5 star standard for new homes.

While improving the building shell of existing houses to make them more thermally efficient increases the energy rating of houses and reduces the overall demand for heating and cooling, to minimise energy use and greenhouse emissions it is also important to ensure that energy efficient fixed and non-fixed appliances and lighting are installed in the houses. This is especially important in regard to water heaters, refrigerators, heaters and lighting, and is becoming increasingly important for televisions. The goal of reducing greenhouse gas emissions and energy use from the residential sector therefore needs a coordinated and cost-effective approach to building shell and appliance and lighting upgrades.

This pilot project conducted on-ground research on 15 typical Victorian homes built before the 1990s, to assess the potential for upgrading their level of energy efficiency. While actual upgrades and improvements were not undertaken, modelling, using FirstRate5 was employed to determine the energy rating improvements and estimate the energy, greenhouse gas and financial savings that could be achieved by applying a range of building shell upgrades consisting of ceiling, floor and wall insulation, draught sealing, double glazing, drapes and pelmets, and external window blinds. An analysis of the existing fixed and non-fixed appliances was also undertaken to determine the potential impact of efficiency improvements.

A summary of the results from the building shell upgrades modelled are as follows:

- The average house energy rating of the 15 existing houses was 1.3 stars. Four houses had star ratings between 0 and 1. Only two houses had a star rating of above 2.
- The application of the building shell upgrades significantly improved the energy rating of all 15 houses, achieving an average energy rating of 4.3 stars. Two-thirds of the houses achieved an energy rating of 4 stars or above once all building shell upgrades had been applied. The highest energy rating achieved was 5.3 stars. With the remaining one-third, it was not possible to increase their energy rating to 4 stars or above due to orientation and the construction characteristics. However, these houses still benefited from the upgrades, with one house increasing its star rating from 0 to 3.9 stars.

- The modelling suggests that building shell upgrades would result in an average greenhouse gas reduction of 3.2 tonnes/yr and annual energy cost saving of over $600/yr.
- Comprehensive draught sealing, and ceiling, wall and floor insulation delivered the greatest energy and greenhouse gas savings at the lowest cost, as well as the greatest improvements in house energy ratings. On average wall, ceiling and floor insulation upgrades each resulted in approximately a one tonne annual reduction in greenhouse gas emissions and an annual energy cost saving of over $200 per house. Comprehensive draught sealing also performed strongly, resulting in an average annual greenhouse gas saving of over 600 kg/yr and an annual energy cost saving of over $135/yr per house.
- Overall, 80 % of greenhouse gas reductions from building shell upgrades could be achieved by implementing the wall, ceiling and floor insulation upgrades and comprehensive draught sealing across the 15 houses. Significantly, the insulation and comprehensive draught sealing upgrades only constituted 25 % of the total upgrade cost, averaging, as a package, under $7,000 per house.
- Preliminary analysis based on energy bill analysis suggests that the modelled energy savings are higher than could be achieved in practice. It is recommended that further detailed work be undertaken to explore this issue and to develop a modelling methodology which more accurately estimates actual energy use and savings from building shell and heating upgrades.

A summary of the results from the modelled appliance and lighting upgrades are as follows:

- Upgrading existing hot water heaters with high efficiency gas storage or gas boosted solar hot water systems resulted in average annual greenhouse gas savings of either 476 kg/yr or 985 kg/yr, and annual energy cost savings of either $50/yr or $148/yr respectively. The results support the view that householders in gas reticulated areas should be highly encouraged to install gas boosted solar hot water heaters when replacing existing water heaters.
- The analysis revealed that upgrading old inefficient heaters would also deliver significant energy and greenhouse gas savings. This was especially the case for centrally conditioned houses. The heater upgrades undertaken at four centrally conditioned houses were estimated to result in an average annual greenhouse gas saving of 2.2 tonnes/yr and annual energy cost saving of over $400/yr.
- Replacing incandescent lamps and low voltage halogen downlights with compact fluorescent lamps resulted in significant savings in some houses. The modelling shows that significant gains can be made in addition to the recently introduced minimum energy performance standards for incandescent (general lighting service) lighting.

- The long payback time associated with most appliance upgrades highlights the importance of effective information, incentives and programs to influence consumer decisions when their existing appliances reach end of useful life and need to be replaced. Upgrading to a more energy efficient appliance is always more cost effective at end of life when the cost of upgrading is simply the differential cost between the standard and more efficient appliance.

The results from this pilot project suggest that significant reductions in residential greenhouse gas emissions can be achieved at a reasonable cost. The initial results demonstrate the potential of this type of modelling to better inform government policies, such as regulations for residential building energy performance, and the development of rebates and incentives to increase the uptake of residential energy efficiency upgrades.

This report recommends that further research is undertaken to expand upon the methodology and initial results of this pilot project. In particular it is recommended that on-ground testing be undertaken to verify thermal modelling results and the impact of blow-in wall insulation and comprehensive draught sealing.

2. Introduction

It is widely recognised that technologies, appliances and products exist which, if applied to the existing housing stock in Victoria, could considerably improve the level of energy efficiency. Various estimates of the potential to improve the energy efficiency of existing housing stock have been made, but there has been a lack of accurate data concerning the real current efficiency of typical Victorian homes, what it would cost to improve their efficiency to a certain level, and the level of savings which could be achieved.

The aim of this project was to undertake an initial study based on an on-ground assessment of the energy efficiency of existing houses in Victoria, so that a more accurate estimate of the potential energy and greenhouse gas (GHG) savings could be prepared, as well as estimates of the likely costs for upgrading the existing housing stock to a higher level of energy efficiency. This information will be an important evidence base to inform the development of programs aiming to reduce residential energy consumption and GHG emissions.

A secondary aim of the project was to develop and test methodologies which could be used to undertake energy efficiency assessments of a sample of stand-alone and semi-detached houses located in Melbourne. This initial pilot study may form the basis of a larger and longer-term study to develop a more comprehensive and accurate picture of the current energy efficiency and energy saving potential of existing Victorian housing stock.

It is important to note that upgrades were not actually undertaken, but modelled and analysed as a desktop study of the energy efficiency potential of the houses. The main steps in this project, described in more detail in the methodology section, are shown below.

1. Detailed on-ground surveys were undertaken of the 15 participating houses to collect data on household demographics, house design, construction, and energy efficiency characteristics, as well as equipment ownership, type, energy efficiency status, and usage.
2. Fan pressurisation tests (blower door tests) were conducted to measure the air leakage rate of the houses, and the main sources of air leakage in each house were identified.
3. Energy billing data was collected where possible.
4. FirstRate5 assessments of the houses were undertaken to determine their current level of energy efficiency, to estimate the base energy use (MJ/Yr) required for heating and cooling to maintain comfort conditions, as well as the level of energy efficiency improvement which could be achieved through basic and advanced energy efficiency upgrades of the building shell.
5. Options were identified for increasing the energy efficiency of heaters, air conditioners, key energy using appliances and lighting, by replacing the existing equipment with high efficiency versions.

6. Practical costs and savings (energy, financial and GHG emissions) were assessed for the modelled energy efficiency upgrades of the building shell and appliances and lighting.
7. Individual reports for each house and a final summary report were prepared.

3. Methodology

The main stages of the project consisted of:

1. Recruiting participants and booking the audits of participating households.
2. Conducting the onsite surveys, consisting of a measure-up by an architect in order to generate a floor plan, an energy audit, and a fan pressurisation test to measure air leakage rates.
3. Undertaking a FirstRate5 analysis of the existing houses and their energy efficiency potential after the application of a range of building shell energy efficiency upgrades.
4. Researching the costs of proposed building and appliance upgrades, and the efficiency of existing and high efficiency appliances.
5. Analysing the FirstRate5 and appliance data to estimate existing energy use and potential energy efficiency benefits and costs.
6. Reporting the modelling analysis outcomes for individual houses and across the group of houses.

The methodology of each project stage is discussed in more detail below.

3. 1 Recruiting and booking household participants

The budget allocated for this initial pilot project enabled 15 houses to be assessed. It was recognised that this would not be a representative sample of all existing Victorian homes, but would be sufficient to see if the approach could yield useful results. Five of the houses were recruited from Sustainability Victoria while the remaining ten were recruited from Moreland Energy Foundation Limited's (MEFL) existing contacts. All households were volunteers and, as far as possible, were selected to represent a cross-section of suburban Melbourne homes.

Once the households were recruited, the scheduling of the site surveys for the blower test, architectural measure-up and walk-through energy audits were undertaken. The fan pressurisation tests (or blower door tests) and the walk-through energy audits took approximately 1.5 hours each to complete and these assessments were scheduled together. Three houses were assessed per day. The architectural measure-ups took approximately two hours to complete but could not be scheduled to coincide with the other two assessments because the architect was only available to work on weekends. The architect visited three houses per day on the weekends.

Since all three assessments take approximately the same amount of time it would have been possible to schedule all three at once if the availability of the architect was not a restricting factor. The site surveys were conducted from 22 May 2009 through to 16 July 2009.

3.2 FirstRate5 house surveys, energy audits and fan pressurisation testing

As outlined above, the on-site house surveys consisted of an architectural measure-up, energy audit survey and the fan pressurisation (or blower door) test.

The architectural measure-up was required so that accurate floor plans of the houses could be developed to facilitate data input into the FirstRate5 thermal modelling and house energy rating program. All required construction details were noted either on the floor plan, a window and room schedule, or a site survey checklist. The locations of fixed heaters, fixed cooling systems, central heating and cooling system outlets were also noted on the floor plan.

The details of the energy audits were negotiated with Sustainability Victoria prior to the surveys being conducted. Energy audit details were collected by the auditors on personal digital assistants (PDAs), so the data could be directly entered into a spreadsheet, downloaded and then analysed later.

The energy audits consisted of a survey of the main fixed and non-fixed appliances, as well as the lighting. Details collected about appliances included type, energy source, age, brand, model number, condition, operating modes and, where appropriate, size. Information was also collected on the presence and type of insulation, lighting systems and general construction characteristics. Photos of appliances, ducting, insulation etc were obtained where possible.

A contractor was engaged to undertake the fan pressurisation testing of the 15 houses to quantify the volume of air leakage through the building envelope. An air leakage audit of the building envelopes was also conducted to identify the main sources of air leakage so the cost of retrofitting the dwellings and the potential energy savings of doing so could be estimated.

The houses were depressurised and pressurised at different pressures in a 15 - 60 pascals (Pa) range and both the air changes per hour at 50 Pa (ACH@50) and air changes per hour at 4 Pa (ACH@4) were determined. The ACH@50 figure represents how many times the total volume of air in the house changes in one hour at a 50 Pa pressure differential from inside to outside the house (which is equivalent to a 35 kilometre per hour (km/h) wind blowing on all sides of the house). This is a value used internationally and therefore allows the results from the Victorian study to be compared with international studies (See Appendix D). The ACH figure was used as the basis for data input into FirstRate5 to account for the air leakage of the houses.

3.3 FirstRate5 analyses

Undertaking the FirstRate5 analyses involved:

- Clearly defining what building shell upgrades were to be modelled, the characteristics of the upgrades, and the order in which they were to be undertaken.
- Choosing the parameters which would be used for the FirstRate5 modelling.
- Undertaking the analyses.

3.3.1 Defining building shell upgrades

The eight upgrades that Sustainability Victoria was interested in modelling for this study were as follows:

Basic upgrade

1. Ceiling insulation – either top-ups or installation of insulation onto a bare ceiling, as required – in homes with easy access to the roof space.
2. Comprehensive draught sealing consisting of sealing wall vents, skirting boards, recessed downlights, exhaust fans, and doors and windows, with the aim of reducing the air change rate to 0.5 ACH.
3. Underfloor insulation in the case of houses with suspended timber floors with adequate access to allow installation.

Advanced upgrade (all basic upgrades plus the following upgrades)

4. Drapes and pelmet on windows to reduce heat loss.
5. External awnings or blinds on unshaded windows facing north, east and west.
6. Ceiling insulation where the installation is not straightforward (e.g. flat-raked ceilings).
7. Wall insulation to the external wall cavity.
8. Double glazed windows to replace existing single glazed windows.

The basic upgrade package consisted of upgrades which were assumed to be more cost effective and less costly to implement than the advanced upgrade package.

For the FirstRate5 modelling, the eight upgrades were progressively applied in the order listed above to eliminate ‘additionality’, or the double-counting which occurs if measures are assumed to be applied independently of each other. This meant that upgrades implemented later in the list may have less effect, as the previously implemented upgrades would have already reduced the energy used by the houses, resulting in less energy available to be saved. The order was chosen based on the anticipated cost effectiveness of the upgrades.

3.3.2 FirstRate5 thermal modelling approach

FirstRate5 is a thermal modelling software program that can be used to model the thermal efficiency of a house, estimate the energy required to heat or cool conditioned zones to maintain pre-determined thermal comfort conditions and determine its star rating under the National House Energy Rating Scheme (NatHERS). When house design, construction and site details are entered into FirstRate5, the different areas of the house (e.g. kitchen, living area, bedrooms) are defined as discrete zones that are individually set as conditioned or non-conditioned zones. This means that in FirstRate5 it is possible to model different heating and cooling profiles for a house (i.e. space conditioned or centrally conditioned) in addition to the standard zoning protocol that must be followed to generate an energy rating.

In addition to assessing the thermal efficiency of the houses' building shells, the focus of this project was to estimate the actual energy used for conditioning houses to allow a cost benefit analysis of upgrades to be completed. This meant that only zones that had fixed heaters, central heating outlets, evaporative cooling outlets, or air conditioning systems were set as conditioned zones in FirstRate5 when calculating heating and cooling energy requirements. Hallways were also conditioned as it was assumed that doors leading into these areas are often left open.

In the case of space conditioned[2] houses, the zones that were set as "conditioned" when estimating heating and cooling energy requirements for the cost benefit analysis needed to be altered in order to determine the house energy rating. This was necessary because a standard zoning protocol must be followed In FirstRate5 when undertaking house energy ratings and this corresponds closely to a centrally conditioned house. This approach is taken when determining house energy ratings in order to ensure that all houses – both centrally conditioned and space conditioned - are compared in a standard manner regardless of individual conditioning profiles and that all main zones of a house are tested for thermal efficiency. Refer to Appendix A for a complete discussion of the methodology used when undertaking the FirstRate5 modelling for this project.

The individual house reports (contained in Appendix C) include a floor plan showing the different zones that were set as conditioned in "star rating" mode and the "actual conditioning" mode used as the basis of estimating actual heating and cooling energy use. Zones set as conditioned in the actual conditioning mode are coloured blue. Zones set as conditioned in star rating mode include both blue and green coloured zones. In the case of centrally conditioned houses, only blue zones are shown because the zones that are set as conditioned in star rating mode and actual conditioning mode are the same. In the case of space conditioned houses the blue coloured zone indicates the zone set as conditioned for estimating heating and cooling energy use, and the green and blue zones together are the zones set as conditioned in star rating mode.

[2] "Space conditioning" refers to a heater or cooler which conditions a room or defined open plan area, as opposed to a central or "whole house" heating/cooling system.

Results from the fan pressurisation tests were used to calculate ACH at ambient air pressure by dividing ACH@50 by 20. This is a commonly used method to provide an approximation of ACH at ambient air pressure. The ACH at ambient air pressure was then translated into an equivalent number of unsealed ceiling exhaust fans using a method developed by Sustainability Victoria (see Appendix A). In FirstRate5, houses were first assumed to be totally sealed (i.e. all windows and doors weather-stripped and all other ventilation removed) and then the calculated number of unsealed ceiling exhaust fans were distributed throughout the house in an attempt to model the actual air leakage measured during the fan pressurisation test. To model the impact of draught sealing, the appropriate number of unsealed ceiling exhaust fans was then removed to bring the house down to 0.5 air changes per hour at ambient air pressure.

3.3.3 Approach to applying building shell upgrades

It was recognised that the modelled energy efficiency upgrades needed to be applied in a manner so that both house energy ratings (measured in stars) and actual energy used for conditioning houses could be determined. This was especially important in the case of space conditioned houses where there is a significant difference between zones that are heated in practice and zones that need to be set as conditioned to generate an energy rating.

The decision was taken to apply all upgrades in a manner so that meaningful energy ratings for space conditioned houses could be generated after each upgrade. Table 1 sets out the manner in which the building shell upgrades were applied in FirstRate5 so this could be achieved. The decision as to whether an upgrade was modelled depended upon the existing condition of the house (e.g. current level of insulation) and its structural characteristics.

Table 1: Description of building shell upgrades modelled

Upgrade description	Zones upgrade applied to
Installation of ceiling insulation where the roof space is easily accessible. Addition of R3.5 to an uninsulated ceiling and a top-up to R3.5 in situations where there is currently R2.0 or less	All Zones
House taken from measured level of air tightness to 0.5 air changes per hour	All Zones
Installation of R1.5 floor insulation batts to suspended floors, where sub-floor space is readily accessible	All Zones
Installation of thick drapes and boxed pelmets to windows	All windows in zones conditioned under star rating mode, excluding bathroom and laundry windows, kitchen windows above

Upgrade description	Zones upgrade applied to
	cooking/cleaning areas, glazed doors, door sidelights and high windows that cannot be easily reached
Installation of external awnings to all unshaded east, west and north facing windows	All inadequately shaded windows in zones conditioned under star rating mode, excluding glazed doors, door sidelights and high windows that cannot be easily reached
Installation of R2.5 ceiling insulation where access is not straightforward (e.g. flat/raked ceilings)	All difficult-to-access ceiling spaces
Installation of blow-in hydrophobic granulated rockwool wall insulation to all external walls. R1.5 added to brick veneer and double brick walls. R2.5 added to weatherboard and cement sheeting walls	All external walls
Installation of double glazed windows	All windows in zones conditioned under star rating mode, excluding partially glazed doors, and door sidelights

The manner in which the building shell upgrades were applied to the FirstRate5 models had implications for the upgrade costs used to undertake the cost benefit analysis for space conditioned houses. It was recognised that the energy savings achieved by the building shell upgrades would mainly be limited to the conditioned areas. This meant that if the *full* building shell upgrade cost was used for space conditioned houses this would generally result in much longer payback periods compared to centrally conditioned houses. After discussion with Sustainability Victoria, it was decided that the following approach would be used to determine upgrade costs for houses for the cost-benefit analysis:

- If households undertook insulation or draught sealing upgrades they would most likely upgrade the whole house, and so the full upgrade cost was used for the cost benefit analysis regardless of whether the house was space conditioned or centrally conditioned.
- With external and internal window treatments and double glazing it was assumed that households would most likely only undertake upgrades in zones that are actually conditioned. Therefore, in these cases only the costs of undertaking upgrades in zones that were actually conditioned were used for the cost benefit analysis.

This meant that for space conditioned houses different costs were used for window upgrades when undertaking the cost benefit analysis and when determining the cost associated with upgrading the star rating of these houses. In centrally conditioned houses, the costs were exactly the same as there was no difference between the zones conditioned in star rating mode and actual conditioning mode.

3.3.4 Undertaking the FirstRate5 modelling

The building shell, construction and orientation details contained in the architectural floor plans were entered into FirstRate5 to create files that represented the houses in their current conditions. The following procedure was then followed to complete the FirstRate5 analysis:

- modify the zoning of FirstRate5 files to reflect the actual conditioning profile of the houses in order to model actual energy required for space conditioning
- determine the current level of energy efficiency, in the form of a house energy rating
- apply upgrades as set out in Table 1
- save the scratch file [3] and FirstRate5 file after each upgrade
- reopen the FirstRate5 files and save them as new files
- modify the zoning of the newly saved FirstRate5 files to comply with standard star rating protocols
- run each new FirstRate5 file and record the house energy rating improvement (measured in stars) after the application of each upgrade, and
- save the scratch file and the FirstRate5 file after the star ratings are determined.

At the request of Sustainability Victoria, the software program AccuBatch[4] was used to run the scratch files generated when the house was in actual space conditioning mode with altered thermostat and occupancy settings to reflect a ‘home all day’ scenario and an ‘away during work’ scenario. This was done to more accurately simulate the real usage patterns of households. The results from the two scenarios were weighted (55 % ‘home all day’ and 45 % ‘away during work’) to determine an overall weighted average which would approximate household occupancy across the existing housing stock[5]. The resultant schedule of hours of operation and thermostat settings is fully described in Appendix A.

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[3] A scratch file is produced each time FirstRate5 completes a simulation and is stored in the program files of the computer. This file contains all the necessary information to determine the energy requirements and star rating of a house. Importantly, scratch files can be used by the AccuBatch software program to determine energy requirements with altered occupancy and thermostat settings.

[4] AccuBatch is a batching software program originally developed by Sustainability Victoria. With AccuBatch it is possible to run scratch files generated by FirstRate5 with altered occupancy profiles and thermostat settings to determine energy used for conditioning. For this project it was necessary to use AccuBatch to estimate the actual energy used for conditioning in order to undertake the cost benefit analysis of the building shell, heater and air conditioner upgrades.

[5] This weighted average occupancy profile may not match the actual occupancy of the house being modelled, but was used as it was felt that this would make the results more reflective of what could be achieved across the entire stock.

The base heating and cooling load (expressed in mega joules per square meter per year ($MJ/m^2/yr$)) determined using scratch files generated when the houses were in actual conditioning profile, combined with heating and cooling appliance data, were used to calculate the energy, financial and GHG savings for each building shell upgrade. These results were then combined with information on the costs of building shell upgrades and on heating and cooling appliances to estimate the payback for the various energy efficiency upgrades. The results generated when the house was in standard rating mode were only used to determine the house energy rating of the house after each upgrade.

3.4 Researching costs and efficiencies of upgrades

For the modelled upgrades to the houses, the costs generally varied according to the size of the area to be upgraded or the number and size of installations. This meant the variables affecting these costs needed to be researched and then methods of calculating probable costs for the upgrades determined.

The costs were researched initially by obtaining retail prices of relevant materials and quotes from suppliers and tradespeople to undertake a variety of upgrades. Standard building industry cost guides were also consulted as another reference. Costs used for the analysis are outlined in Appendix B. Costs were then developed for each of the 15 houses assessed.

High efficiency appliances were identified from appliance energy rating data obtained from the Equipment Energy Efficiency (E3) Program website – www.energyrating.gov.au and from the Australian Gas Association (AGA) certified product directory. For the appliances for which upgrades were examined (i.e. central and space heaters, air conditioners, hot water services, refrigerators, dishwashers and clothes washers), high efficiency models were chosen which approximately matched the size and type of those already installed in the houses. When a number of high efficiency appliances were available, the cheapest one available was chosen for the analysis. Information on the annual energy use of the high efficiency appliances was obtained from the AGA certified product directory, and E3 appliance energy rating data.

Information on the cost of high efficiency appliances was obtained by contacting appliance suppliers to obtain retail costs. For fixed appliances, information was also obtained on the costs to install the new appliances from suppliers (see Appendix B).

In addition, the energy consumption and efficiency of existing appliances in the homes surveyed needed to be obtained. This was obtained by examining appliance information from the E3 website, the AGA product directory, historical appliance databases supplied by Sustainability Victoria and by utilising information on the average energy performance characteristics of appliances sold in certain years contained in *Energy Use in the Australian Residential Sector 1986-2020* (EES, 2008). Efficiency and consumption data on each specific appliance in the homes was sought, but in some cases the appliances were too old or model data was not available to enable information for those appliances to be found. In such cases, information on the typical efficiency of similar appliances of the appropriate age was sought and used in the analyses.

Televisions and computers were also assessed for upgrading, but no computers and only two televisions were found to be suitable for an energy efficiency upgrade. For the televisions, the upgrade costs and energy use information were calculated using information obtained from the E3 website.

3.5 Analysing the FirstRate5 and appliances data

The impacts of the modelled building shell upgrade and heating and cooling appliance upgrades were analysed separately from the other fixed and non-fixed appliance upgrades.

3.5.1 Building shell upgrades

The analysis of the impact of the modelled building shell upgrades was conducted in a series of Excel worksheets. Most of the analyses for each house were undertaken separately in one work sheet, with the results for each house gathered into summary tables. This approach was used so the analyses could be varied when the upgrades to the houses were changed from one house to the next.

The following processes were used in the analyses:

- Input of general factors, such as tariff rates and GHG emission factors (see Table 2 below). An average annual occupancy rate of 97 % was also assumed.
- Input of FirstRate5 results for all homes, copied from the AccuBatch outputs. These results included estimates of the base heating and cooling load requirements (MJ/m^2/yr) of each home in its existing state, and also after the implementation of each of the proposed building shell upgrades.
- Conversion of the FirstRate5 heating and cooling load results into the annual heating and cooling energy load (MJ/yr) for each home, by multiplying the conditioned floor area of each house indicated by FirstRate5.
- Input of the building shell upgrade costs for each house surveyed (see Appendix B).
- Input of the efficiency of the existing heating and cooling appliances and of the proposed high efficiency appliances for each house.
- Progressive calculation of the base heating and cooling energy savings of each upgrade, by comparing the predicted energy requirements for heating and cooling at each building shell upgrade with the requirements predicted before the upgrade occurred. These savings were then divided by the efficiency of the heating and cooling appliance to determine total actual energy saving of the houses for heating and/or cooling. It should

be noted that the impact of external awnings was only analysed for houses that actually had cooling systems installed. This was necessary because, in order to calculate the financial and GHG savings, a cooling system that uses energy needs to be present in a house.

- GHG emission savings were calculated from the energy savings from each upgrade, allowing for the fuel type saved. Full fuel-cycle greenhouse coefficients were used for each fuel, and the marginal greenhouse coefficient has been used for electricity.
- Calculation of energy cost savings was obtained by multiplying energy savings by the relevant energy tariffs.
- Payback periods were calculated by dividing the cost of each upgrade by the energy cost savings from each upgrade.
- The results for each house were then transferred into summary tables for reporting.

Table 2: Energy tariffs and GHG emission factors used

Fuel	Greenhouse gas emission factors		Tariffs	
	kg/MJ	kg/kWh	c/MJ	c/kWh
Electricity - Peak	0.304	1.094	4.72	17
Electricity - Off peak	0.304	1.094	2.22	8
Natural gas	0.05583	0.201	1.1	3.96

Source: GWA, 2005

3.5.2 Heating and cooling loads used for heater and air conditioner upgrades

For the purposes of assessing the impact of the modelled heater and air conditioner upgrades, the heating and cooling load used was that which applied after the application of the basic upgrade package (the first three building shell upgrades listed in Table 1). The conversion efficiency of the existing and upgraded appliances was used to calculate the annual energy demand, and energy savings were calculated as the difference between the energy consumption of the existing and the high efficiency appliances. For the five advanced building shell upgrades the energy savings were calculated using the efficiency of the upgraded heaters and air conditioners.

3.5.3 Appliance and lighting upgrades

The calculation of the impacts of the modelled hot water and non-fixed appliance upgrades was also conducted in a series of worksheets in Excel, with a different worksheet allocated to each appliance. An overview of the processes used in the analysis for the appliances is as follows:

- input of general factors, such as tariff rates, GHG emission factors, occupation rates etc.
- for each appliance type, input the efficiency of the existing appliances
- input the efficiency and the costs of the high efficiency appliances which would be relevant to an upgrade
- calculate the energy savings, GHG savings, energy cost savings and payback periods, and
- Transfer results into summary tables for reporting.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the total upgrade cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated, taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10 % of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described below.

Adjusted paybacks for all appliance upgrades except the SWH upgrade were calculated by dividing the adjusted capital cost by the annual energy cost saving. Adjusted paybacks were used when compiling cost curves for appliance upgrades, and when comparing paybacks of the appliance upgrades with the building shell upgrades, as it was felt that this would give the most accurate impression of the relative cost effectiveness of appliance upgrades[6].

The following formula was used to calculate the adjusted upgrade cost for all appliances except SWHs:

Cost = FC x (1-Age/Life)

Where: Cost = adjusted upgrade cost

FC = full capital cost

Life = typical life of appliance type

Age = age of existing appliance

Note that the lower limit of the adjusted upgrade cost is 10 % of FC.

Table 3 lists the typical appliance life used to calculate the adjusted costs and paybacks for appliances. The information was supplied by Sustainability Victoria.

Table 3: Typical appliance life

Appliance type	Typical life (years)
Clothes Washer	12
Dishwasher	12
Refrigerator	17
Hot water heater	12
Central gas heater	20
Gas space heater	14
Refrigerative air conditioner	13

Adjusted paybacks for the SWH upgrades were calculated by dividing the adjusted upgrade cost by the annual energy cost savings. As above, adjusted paybacks were used when compiling cost curves for the SWH upgrade as it was felt that this would give the most accurate impression of the relative cost effectiveness of this upgrade.

When the age of the existing water heater was 11 years or less, the following formula was used to calculate the adjusted upgrade cost for the SWH upgrade:

Cost = FCs – ((FCg/Life) x Age)

Where: Cost = adjusted upgrade cost

FCs = full capital cost of SWH upgrade

[6] In practice, most appliance upgrades are likely to be undertaken at or near end of life.

FCg = full capital cost of 5 star gas water heater

Life = typical life of hot water heater

Age = age of existing hot water heater

When the age of the existing water heater was 12 years or greater the following formula was used to calculated the adjusted upgrade cost for the SWH upgrade:

Cost = FCs – FCg

Where: Cost = adjusted upgrade cost

FCs = full capital cost of SWH upgrade

FCg = full capital cost of 5 star gas water heater

The part of the analysis process which varied for the different appliances related to the calculation of the energy efficiency of the existing and replacement appliances. These values were calculated as follows:

- **Lighting**: The number of lamps which could be converted to compact fluorescent lamps (CFLs) was identified during the energy audits. As Minimum Energy Performance Standards (MEPS), which ban the sale of inefficient 240 volt general service incandescent lamps, were implemented in November 2009, it was assumed that high efficiency incandescent (240 volt halogen) lamps would be the standard lamp installed in homes still using incandescent lighting: High efficiency incandescent lamps are now available in 28W, 42W, 53W and 72W and are direct replacements for the old 40W, 60W, 75W and 100W incandescent lamps. The incandescent lamps were replaced by CFLs. Low voltage (12 volt) halogen downlights were assumed to use an additional nine watts for their transformers, and all were assumed to be 50W lamps, the most common wattage. Lamps in living areas were assumed to be used 2.2 hours per day throughout the year. Lamps in non-living areas were assumed to be used for 1 hour per day throughout the year. Energy savings were calculated for each lamp as the difference between the existing lamps wattage and wattage of a CFL with comparable light output multiplied by the appropriate number of hours/day and then by 365 days to obtain the annual saving per lamp in kilowatt hours per year (kWh/yr). The total savings were the sum of the savings from all lamps replaced.
- **Dishwashers**: The comparative energy consumption (CEC) value from the energy rating label for each appliance was obtained from an historical energy rating appliance database supplied by Sustainability Victoria. The CEC is the estimated annual energy use (kWh/yr) for dishwashers based on one load cycle per day or seven loads per week. Data from the Department of Human Services (Roy Morgan Research, 2008) suggests average usage in Victoria is 3.7 uses per week. Consequently the energy

saving calculated from the CEC value was reduced to 53 % of the CEC value, i.e. 3.7/7. Energy savings were calculated as the difference between the energy consumption of the existing and the high efficiency dishwashers.

- **Clothes washers**: The CEC value for each clothes washer was obtained from an historical energy rating appliance database supplied by Sustainability Victoria. The CEC is the estimated annual energy use (kWh/yr) for the appliance based on one wash per day on a warm wash cycle, and includes the energy used for both the motor and electrics as well as the energy used to heat water (which represents the majority of energy used). As 2008 Department of Human Services data (Roy Morgan Research, 2008) suggests that average usage of clothes washers in Victoria is five times per week, the CEC value was adjusted to take this into account. It was further adjusted to reflect that many households now wash on a cold wash cycle (60 % of cold water wash cycles was assumed for this study). The actual energy required to heat hot water was calculated using the efficiencies of hot water systems installed to replace existing hot water systems. This was done because the payback for replacing hot water systems was much shorter than that of replacing clothes washers, so it was assumed that hot water systems would be replaced before clothes washers. Energy savings were calculated as the difference between the adjusted hot water energy consumption of the existing and the high efficiency clothes washers.
- **Refrigerators:** The annual energy consumption as determined for the appliance energy rating label was the basis of the refrigerator calculations. CEC values (in kWh/yr) were obtained from an historical energy rating database supplied by Sustainability Victoria. It was assumed that, in Melbourne, refrigerators use only 85 % of the stated CEC value and consumption of the existing and high efficiency refrigerators was adjusted accordingly. In addition, it was assumed that the energy consumption of refrigerators older than five years increased by 1.5 % for every year in age they exceeded five years, as a result of degradation. Energy savings were calculated as the difference between the adjusted energy consumption of the existing and the high efficiency refrigerators.
- **Hot Water Systems**: The majority of existing systems were gas water heaters. The efficiencies of the hot water systems (HWSs) were either obtained from the AGA certified product directory, energy rating labels still present on the existing systems, or by using the age of the HWSs to estimate efficiency from information contained in Appendix E of *Energy Use in the Australian Residential Sector 1986-2020* (EES, 2008). Energy consumption was based on 150 litres of hot water (at 60^{o}C) per day using a method that took into account the conversion efficiency of the existing systems and appropriate daily maintenance losses. It was assumed that the gas boosted SWH would consist of a 3 star gas storage system and flat plate solar collectors. An average solar gain of

70 % per year was chosen for the analysis. It was assumed that 65 kWh/yr of electricity would be used for pumping. Energy savings were calculated as the difference between the adjusted energy consumption of the existing and the high efficiency hot water systems.

- **Heaters**: The majority of existing heaters were either gas ducted or gas room heaters. Where possible the efficiencies for heaters were either obtained from the AGA certified product directory or manufacturer data. However, in many cases the appliances were old or model data was not available, which meant information for those appliances could not be found. In such cases, information on the typical efficiency of similar appliances of the appropriate age was used in the analyses. Central heaters were assumed to have a baseline of 20 % ducting losses, with the losses staying constant for the first five years and then increasing one % per annum. The estimated energy consumption was based upon the base heating load requirements modelled using FirstRate5, and assumed a weighted average occupancy profile[7]. For the purposes of assessing the impact of a heating upgrade, the heating load used was that after the application of the basic upgrade package and the efficiency of the existing and upgraded heaters were used to calculate the annual energy demand. Energy savings were calculated as the difference between the energy consumption of the existing and the high efficiency heaters.
- **Air conditioners**: The efficiencies for refrigerative air conditioners were obtained either from the air conditioner database that can be downloaded from the E3 website (www.energyrating.gov.au/appsearch/download.asp) or from an historical data base of energy labelling information supplied by Sustainability Victoria. Where an exact match could not be made, typical efficiencies of similar appliances of the appropriate era was sought and used in the analyses. For this project it was assumed that refrigerative air conditioners have no degradation in performance for the first five years, but after this their efficiency degrades by 1.0 % per annum. All evaporative air conditioners were assumed to have an effective energy efficiency ratio (EER[8]) of 13, based on advice from Sustainability Victoria. Upgrades were not considered for evaporative air conditioners as they were considered to already be quite energy efficient[9]. For refrigerative air conditioners, energy savings were calculated as the difference between the energy consumption of the existing and the high efficiency units. The estimated energy consumption was based upon the base cooling load requirements modelled using FirstRate5, and assumed

[7] Assumes that 55% of households are occupied all day, and 45% are unoccupied during the working day, but occupied at other times.

[8] Energy Efficiency Ratio (EER) is the ratio of rated cooling output divided by rated power input.

[9] There is some variation in the efficiency of evaporative cooling models, and inverter technology is now available which can lead to somewhat higher efficiency at lower fan speeds. However, there is no readily available database of evaporative cooler energy performance as they are not required to have energy rating labels.

a weighted average occupancy profile[10]. For the purposes of assessing the impact of an air conditioner, the cooling load used was that after the application of the basic upgrade package and the efficiency of the existing and upgraded air conditioners were used to calculate the annual energy demand. Energy savings were calculated as the difference between the energy consumption of the existing and the high efficiency air conditioners.

3.6 Reporting the analysis outcomes

Using the analyses output, individual reports were prepared for each surveyed house, providing a description of the home, its current level of building shell efficiency (expressed as a house energy rating) and also its existing appliances. These reports document the potential energy, GHG and energy cost savings that would occur if the various modelled building and appliance upgrades were undertaken. The cost of these upgrades and their payback periods are also reported. A summary of these reports are provided as an attachment in Appendix C: Individual house reports.

The overall results for the project are provided in this report. Findings across all houses are summarised. The report also outlines the key lessons learnt, as well as recommendations for the conduct of a larger, more comprehensive study.

[10] Assumes that 55% of households are occupied all day, and 45% are unoccupied during the working day, but occupied at other times.

4. Results

The following sets of results are reported for the 15 houses surveyed:

- FirstRate5 house energy rating assessments of the overall efficiency of the houses, expressed as star ratings, before and after modelled building shell upgrades, based on the standard house energy rating protocols.
- Impacts of the modelled building shell upgrades expressed as energy savings, GHG emission reductions, energy costs and payback periods, based on the actual way in which the house is conditioned.
- Estimated efficiency and energy use of existing appliances in the homes.
- Impacts of modelled high efficiency upgrades of the fixed and non-fixed appliances and lighting, expressed as energy savings, GHG emission reductions, energy costs and payback periods.

4.1 Building shell upgrade results

4.1.1 Description of participating houses

Fifteen houses participated in this pilot project. Table 4 sets out the basic characteristics of each house, including its house energy rating before any upgrades were modelled. The existing insulation level and air leakage status is listed in the far right hand column, as is the percentage of total floor area set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure.

The houses were chosen to provide a broad cross-section of construction type, age and size, although all houses were located in Melbourne. It was recognised that, with only 15 participating houses, it was not possible to get a completely representative sample of Victorian housing stock, but this was not regarded as a significant constraint as a key focus of this project was to test an assessment method and see if it could yield useful results.

All houses were single-storey with the exception of House 13 which was double-storey. In regard to wall construction type, seven of the houses were brick veneer, five weatherboard, one brick cavity, one a combination of weatherboard and cement sheeting and one a combination of brick cavity and brick veneer. The date of construction for the 15 houses ranged from the early 1900s through to the 1970s.

The average energy rating of the existing houses was 1.3 stars, indicating just how much less efficient typical existing houses are compared to newly built houses that need to comply with current 5 star building regulations. Houses 3, 6 and 8 had no ceiling insulation, and consequently had the lowest energy ratings of the group. House 5 had a low energy rating even though it had R3.0 ceiling insulation installed, probably due to having the highest rate of air leakage in the study. House 7 had the highest energy rating, possibly because it is a semi-detached brick cavity house with an insulated ceiling. FirstRate5 generally gives semi-detached houses a better energy rating score because there is less exposed building envelope.

Table 4: Summary of house characteristics

House number	Construction characteristics	Approx Year Built	Floor area (m^2)	Existing star rating	Main type of heating	Main type of cooling	Percentage of total floor area conditioned	Existing insulation and air leakage status
1	-Single storey -Detached -Brick veneer -Suspended timber floor	1970s	175.3	1.5	Gas central heating	Evaporative cooling	100%	• R0.5 ceiling insulation • 1.16 ACH
2	-Single storey -Semi-detached -Weatherboard -Suspended timber floor	1910s	88.7	1.5	Gas space heating	N/A	67%	• R2.0 ceiling insulation except in flat roof • 1.09 ACH
3	-Single storey -Detached -Brick veneer -Suspended timber floor	1950s	139	0	Gas central heating	N/A	98%	• No ceiling insulation • 1.71 ACH
4	-Single storey -Detached -Brick veneer -Suspended timber floor	1970s	97.3	1.6	Gas space heating	Evaporative cooling	52%	• R1.5 ceiling insulation • 2 .00 ACH
5	-Single storey -Detached -Weatherboard -Suspended timber floor	1950s	83.8	0.8	Gas space heating	N/A	29%	• R3.0 ceiling insulation except in flat roof • 2.67 ACH

House number	Construction characteristics	Approx Year Built	Floor area (m^2)	Existing star rating	Main type of heating	Main type of cooling	Percentage of total floor area conditioned	Existing insulation and air leakage status
6	-Single storey -Semi-detached -Brick veneer -Suspended timber floor	1960s	75.1	0.7	Reverse cycle air conditioner	Reverse cycle air conditioner	32%	• No ceiling insulation • 1.82 ACH
7	-Single storey -Semi-detached -Brick cavity -Suspended timber floor/ concrete slab on ground	1930s	114.3	2.6	Gas space heating	N/A	47%	• R2.5 ceiling insulation except in flat roof • 1.43 ACH
8	-Single storey -Detached -Weatherboard -Suspended timber floor	1910s	157.5	0	Gas central heating	N/A	96%	• No ceiling insulation • 1.14 ACH
9	-Single storey -Detached -Weatherboard -Suspended timber floor	1900s	139.2	1.1	Gas space heating	Reverse cycle air conditioner	58%	• R3.0 ceiling insulation except in flat roof • 0.87 ACH
10	-Single storey -Detached -Brick veneer -Suspended timber floor	1950s	124.2	1.8	Gas central heating	Refrigerative air conditioner	74%	• R3.0 ceiling insulation • 1.68 ACH

House number	Construction characteristics	Approx Year Built	Floor area (m^2)	Existing star rating	Main type of heating	Main type of cooling	Percentage of total floor area conditioned	Existing insulation and air leakage status
11	-Single storey -Detached -Brick veneer -Suspended timber floor	1970s	149.8	2.4	Gas central heating	Refrigerative air conditioner (cooling only)	92%	• R2.5 ceiling insulation • 0.85 ACH
12	-Single storey -Detached -Weatherboard/ cement sheeting -Suspended timber floor/ concrete slab on ground	1930s	108	1.2	Gas space heating	N/A	50%	• R2.5 ceiling insulation • 1.4 ACH
13	-Double storey -Detached -Brick veneer -Suspended timber floor	1960s	226.3	1.6	Gas central heating	N/A	79%	• R2.0 ceiling insulation • 1.65 ACH
14	-Single storey -Detached -Weatherboard -Suspended timber floor	1940s	123.4	1.8	Gas space heating	Refrigerative air conditioner (cooling only)	33%	• R2.5 ceiling insulation • 1.35 ACH
15	-Single storey -Detached -Brick cavity/brick veneer -Suspended timber floor/ concrete slab on ground	1930s	134.4	1.4	Gas space heating	Reverse cycle air conditioner	52%	• No ceiling insulation in pitched roof • R2.5 ceiling insulation in flat roof • 0.98 ACH

House number	Construction characteristics	Approx Year Built	Floor area (m^2)	Existing star rating	Main type of heating	Main type of cooling	Percentage of total floor area conditioned	Existing insulation and air leakage status
Average			**129**	**1.3**			**64%**	

4.1.2 Impact of modelled upgrades on the energy ratings of houses

Energy ratings were generated for each house in its existing condition and after each modelled building shell upgrade. It should be remembered that in space conditioned houses zones were set as conditioned to comply with standard NatHERS rating protocols. This means that the conditioning profile used in rating mode of "space conditioned"[11] houses does not correspond with how these houses are actually conditioned in practice. As described in the methodology section, this step is necessary in order to generate energy ratings that are comparable across the housing stock.

The summarised individual house reports contained in Appendix C include house floor plans that show the areas that were set as conditioned in FirstRate5 when generating energy ratings, and also when estimating actual heating and cooling energy requirements. Examining these will give a good understanding of the differences between zones conditioned in standard rating mode and in actual conditioning mode for space conditioned houses.

The energy ratings generated for each house in its existing condition and after each building shell upgrade are shown in Table 5. The following information is displayed:

- the modelled upgrades applied to the houses
- the resultant star ratings after each upgrade
- the estimated cost of the upgrades.

Whether or not a particular upgrade was applied in the modelling depended upon the existing condition of the house, and also if it was practically possible to apply the upgrade to the house (e.g. sufficient sub-floor access for floor insulation). The manner in which upgrades were applied to the fifteen houses is explained in the methodology section.

In Table 5, under 'Upgrade 1 ceiling insulation (easy)', an asterisk next to 'Yes' indicates that the upgrade was a ceiling insulation top-up only. If an asterisk is not present this means that the upgrade consisted of insulation added to a previously uninsulated ceiling. It should be noted that House 1 only had R0.5 installed while the other houses that received ceiling insulation top-ups had either R1.5 or R2.0 already installed (refer to Table 4 for the current insulation status of houses). This explains why House 1 had such a significant improvement in its energy rating from receiving a top-up in comparison to the other houses that received ceiling insulation top-ups.

In the case of 'Upgrade 6 ceiling insulation (advanced)', it was assumed that there was no insulation installed in all flat roof constructions that received this upgrade, so this upgrade always consisted of applying insulation to a bare ceiling.

[11] In this report we use the term "space conditioning" to apply to heating/cooling a single room or open plan area, as opposed to central (ducted) heating or cooling.

When considering the improvement in house energy ratings it should be remembered that the order in which the upgrades are applied to the houses will have an impact upon the energy rating improvement achieved for each upgrade. It is reasonable to expect that upgrades applied to houses later in the process will deliver less improvement in the energy rating as there is less energy to be saved. For example, the application of heavy drapes and pelmets before double glazing is likely to have reduced the potential improvement that double glazing could deliver. This fact means that the results presented in this report should be interpreted with the overall range of influencing factors in mind.

After all eight building shell efficiency upgrades were applied in the modelling, 11 houses achieved a house energy rating of between 4.1 and 5.3 stars. The remaining four houses achieved an energy rating of between 3.5 and 3.9 stars. The average cost for the total upgrade package across the 15 houses was assessed at $22,591.

It can be seen from Table 5 that ceiling, underfloor and wall insulation had, on average, quite a large impact upon the energy rating of a house. Wall insulation had a significant impact, on average increasing the house energy rating by over 1.5 stars. Draught sealing also performed strongly, increasing the rating on average by almost half a star. The impact of ceiling insulation was also significant but, as expected, had by far the greatest impact when placed on an existing uninsulated ceiling. The overall impact of ceiling insulation was reduced due to the high number of households which already had an adequately insulated ceiling.

Table 5: House energy rating improvements and costs resulting from the building shell upgrades

House number		Existing house	Upgrade 1: Ceiling insulation (easy)	Upgrade 2: Draught sealing	Upgrade 3: Underfloor insulation	Upgrade 4: Drapes and pelmets	Upgrade 5: External awnings	Upgrade 6:Ceiling insulation (advanced)	Upgrade 7: Wall insulation	Upgrade 8: Double glazed windows
1	Measure applied (Y/N)	N/A	*Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Star	1.5	2.2	2.7	3.2	3.7	3.7	N/A	4.9	5.3
	Cost	N/A	$2,029	$1,090	$2,401	$6,398	$5,270	N/A	$2,248	$26,288
2	Measure applied (Y/N)	N/A	*Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
	Star	1.5	1.5	1.8	N/A	2	2	2.5	3.8	4.1
	Cost	N/A	$437	$635	N/A	$2,419	$1,806	$507	$1,596	$8,294
3	Measure applied (Y/N)	N/A	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Star	0	1.6	2.4	N/A	2.5	2.5	N/A	4.2	4.4
	Cost	N/A	$1,166	$1,098	N/A	$3,740	$596	N/A	$2,885	$14,633
4	Measure applied (Y/N)	N/A	*Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Star	1.6	1.7	2.4	2.8	3.1	3.1	N/A	4.4	4.9
	Cost	N/A	$932	$1,050	$1,332	$1,300	$2,017	N/A	$1,551	$16,263
5	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	Star	0.8	N/A	1.5	N/A	1.6	1.6	2.2	3.8	3.9
	Cost	N/A	N/A	$578	N/A	$1,251	$719	$566	$1,986	$4,947

House number		Existing house	Upgrade 1: Ceiling insulation (easy)	Upgrade 2: Draught sealing	Upgrade 3: Underfloor insulation	Upgrade 4: Drapes and pelmets	Upgrade 5: External awnings	Upgrade 6:Ceiling insulation (advanced)	Upgrade 7: Wall insulation	Upgrade 8: Double glazed windows
6	Measure applied (Y/N)	N/A	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Description	0.7	2.1	2.8	N/A	2.9	3	N/A	4.7	4.8
	Cost	N/A	$974	$456	N/A	$1,734	$282	N/A	$1,673	$5,881
7	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	Star	2.6	N/A	3.3	N/A	3.5	3.5	3.5	4.5	4.6
	Cost	N/A	N/A	$630	N/A	$1,965	$688	$213	$1,667	$5,371
8	Measure applied (Y/N)	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Description	0	0.8	1.1	1.4	1.5	1.6	2	3.7	3.9
	Cost	N/A	$1,716	$776	$2,157	$2,930	$2,922	$576	$3,535	$13,100
9	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	Star	1.1	N/A	1.3	N/A	1.5	1.5	2	3.3	3.5
	Cost	N/A	N/A	$426	N/A	$4,168	$2,716	$588	$3,002	$17,104
10	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	No	Yes	Yes
	Description	1.8	N/A	2.4	N/A	2.6	2.6	N/A	3.8	4.3
	Cost	N/A	N/A	$458	N/A	$2,180	$521	N/A	$2,112	$14,289

House number		Existing house	Upgrade 1: Ceiling insulation (easy)	Upgrade 2: Draught sealing	Upgrade 3: Underfloor insulation	Upgrade 4: Drapes and pelmets	Upgrade 5: External awnings	Upgrade 6:Ceiling insulation (advanced)	Upgrade 7: Wall insulation	Upgrade 8: Double glazed windows
11	Measure applied (Y/N)	N/A	No	Yes	Yes	Yes	No	No	Yes	Yes
	Star	2.4	N/A	2.5	3	3.2	N/A	N/A	4.5	4.8
	Cost	N/A	N/A	$505	$2,051	$3,248	N/A	N/A	$2,380	$10,446
12	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	No	Yes	Yes
	Description	1.2	N/A	1.5	N/A	1.6	1.6	N/A	3.5	3.7
	Cost	N/A	N/A	$620	N/A	$2,329	$1,895	N/A	$2,087	$11,455
13	Measure applied (Y/N)	N/A	*Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Star	1.6	1.7	2.3	N/A	2.7	2.7	N/A	4	4.3
	Cost	N/A	$915	$795	N/A	$5,833	$2,257	N/A	$4,394	$18,699
14	Measure applied (Y/N)	N/A	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	Description	1.8	N/A	2.1	N/A	2.3	2.3	2.4	3.5	3.8
	Cost	N/A	N/A	$404	N/A	$3,551	$1,283	$376	$2,261	$12,470
15	Measure applied (Y/N)	N/A	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Star	1.4	2.3	2.7	N/A	3	3	N/A	4.4	4.6
	Cost	N/A	$1,170	$747	N/A	$4,000	$3,565	N/A	$3,360	$18,925

* = ceiling insulation top-up only.

Table 6 summarises the costs and impact on house energy ratings after the modelled application of the basic upgrade package (1-3) and also the full upgrade package (1-8), which includes the advanced upgrades (4 – 8). The table lists the modelled upgrades that were applied to each house. An asterisk next to upgrade 1 (under basic upgrades applied and all upgrades applied) means this upgrade consisted of a ceiling insulation top-up.

Table 6: Energy rating impacts and cost of basic and advanced building shell upgrade packages

House number	Star rating existing house	Star rating basic upgrade	Basic upgrades applied	Cost of basic upgrades	Star rating full upgrade	All upgrades applied	Cost of full upgrade
1	1.5	3.2	1*,2,3	$5,519	5.3	1*,2,3,4,5,7,8	$45,723
2	1.5	1.8	1*,2	$1,072	4.1	1*,2,4,5,6,7,8	$15,694
3	0	2.4	1,2	$2,264	4.4	1,2,4,5,7,8	$24,118
4	1.6	2.8	1*,2,3	$3,314	4.9	1*,2,3,4,5,7,8	$24,446
5	0.8	1.5	2	$578	3.9	2,4,5,6,7,8	$10,048
6	0.7	2.8	1,2	$1,430	4.8	1,2,4,5,7,8	$11,001
7	2.6	3.3	2	$630	4.6	2,4,5,6,7,8	$10,535
8	0	1.4	1,2,3	$4,649	3.9	1,2,3,4,5,6,7,8	$27,712
9	1.1	1.3	2	$426	3.5	2,4,5,6,7,8	$28,004
10	1.8	2.4	2	$458	4.3	2,4,5,7,8	$19,560
11	2.4	3	2,3	$2,556	4.8	2,3,4,7,8	$18,631
12	1.2	1.5	2	$620	3.7	2,4,5,7,8	$18,386
13	1.6	2.3	1*,2	$1,710	4.3	1*,2,4,5,7,8	$32,894
14	1.8	2.1	2	$404	3.8	2,4,5,6,7,8	$20,346
15	1.4	2.7	1,2	$1,917	4.6	1,2,4,5,7,8	$31,767
Average	**1.3**	**2.3**	**--**	**$1,837**	**4.3**	**--**	**$22,591**

* = ceiling insulation top-up.

The results presented in Table 6 indicate that the improvement in the house energy rating, and hence the thermal efficiency, of existing houses can be achieved with a relatively small expenditure. The basic upgrade package resulted in an average improvement of 1.0 star for an average cost of $1,837. The full upgrade package was much more expensive at an average of $22,591, but resulted in an average 3 star improvement, lifting the overall average across the 15 houses from 1.3 to 4.3 stars.

However, the way in which the basic and advanced upgrade packages are grouped in Table 6 does not reveal the impact that individual upgrades had upon the total improvement in house energy rating and also how much of the total upgrade cost they constitute. Table 7 below shows the average percentage contribution each upgrade made to the improvement in house energy rating and the total upgrade cost. It can be seen that double glazing and external and internal window treatments constituted a significant percentage of the total cost while only delivering a small percentage of total house energy rating improvement. The reverse is true for the insulation upgrades and draught sealing.

On average 84% of the overall house energy rating improvement was achieved through the installation of ceiling insulation (both easy and advanced), wall insulation, underfloor insulation and comprehensive draught sealing. On average, this package of upgrades only constituted 20% of the total upgrade cost. While these results must be interpreted in the context of the manner in which the building shell upgrades were applied and modelled (e.g. drapes and pelmets applied before double glazed windows), the results still give a clear indication of the upgrades that would most likely deliver the greatest energy and GHG savings for the lowest cost. The overall implication is that the insulation and comprehensive draught sealing upgrades can deliver significant improvements in the energy rating of the 15 houses.

Table 7: Average contribution of upgrades to house energy rating improvement and costs

Upgrade	Number of houses receiving upgrade	Percentage of total upgrade cost	Percentage of total house energy rating improvement
Upgrade 1: Ceiling insulation (easy)	8	2.8%	12.5%
Upgrade 2: Draught sealing	15	3.0%	16.0%
Upgrade 3: Underfloor insulation	4	2.3%	3.8%
Upgrade 4: Drapes and pelmets	15	13.9%	7.1%
Upgrade 5: External awnings	14	7.8%	0.4%
Upgrade 6: Ceiling insulation (hard)	6	0.8%	4.7%
Upgrade 7: Wall insulation	15	10.8%	46.8%
Upgrade 8: Double glazed windows	15	58.5%	8.7%

4.1.3 Impact of building shell upgrades

Introduction

This section examines the impact of the building shell upgrades on energy consumption, energy costs and GHG emissions. The financial paybacks for upgrades are also examined.

As discussed in the methodology section, a different FirstRate5 modelling approach to the one used to determine the house energy ratings needed to be used for space conditioned houses to determine energy savings resulting from the modelled installation of building upgrades. The change in the FirstRate5 modelling approach also means that the upgrade costs used for drapes and pelmets, external awnings and double glazing are different to those used in the house energy rating section above, as upgrades were only applied in areas that were actually heated. In addition, the impact of external awnings was only analysed for houses that actually had cooling systems installed. This was necessary because, in order to calculate financial and GHG savings, a house needs to have a cooling system that uses energy needs. A detailed discussion about the FirstRate5 modelling approach used to determine energy required for space conditioning and the manner in which upgrade costs for this cost benefit analysis were determined can be found in the methodology section and also in Appendix A.

FirstRate5 calculates the energy required to maintain pre-determined thermal comfort conditions without taking the efficiencies of the heating and cooling systems into account. This means that, in order to estimate the impact that the upgrades are likely to have on energy use, energy costs and GHG emissions, it is necessary to take into account the efficiencies of the existing heating and cooling appliances of the houses concerned. This then enables the payback of the building shell upgrades to be calculated, with payback expressed as the number of years required to pay back the capital costs of the upgrades from energy savings. For the building upgrades, only simple payback periods were calculated as no discounting of the energy cost saving over time was performed.

Upgrades applied for impact analysis

Table 8 sets out the upgrades applied to the 15 houses as part of the building shell upgrade impact analysis. This will assist in understanding the information presented in the summary tables for the basic and advanced upgrade packages (Table 9 and Table 10). The following information is displayed in Table 8:

- upgrades applied to the houses
- description of the upgrades applied
- cost of the upgrades.

Under ‘Upgrade 1 ceiling insulation (easy)’, an asterisk next to ‘Yes’ indicates that the upgrade was a ceiling insulation top-up. If an asterisk is not present this means that the upgrade consisted of insulation added to a previously uninsulated ceiling.

In the case of 'Upgrade 6 ceiling insulation (advanced)', it was assumed that there was no insulation installed in all flat roof constructions that received this upgrade, so this upgrade always consisted of applying insulation to a bare ceiling.

Table 8: Upgrades applied for modelling impact analysis

House number		**Upgrade 1:** Ceiling insulation (easy)	**Upgrade 2:** Draught sealing	**Upgrade 3:** Underfloor insulation	**Upgrade 4:** Drapes and pelmets	**Upgrade 5:** External awnings	**Upgrade 6:**Ceiling insulation (advanced)	**Upgrade 7:** Wall insulation	**Upgrade 8:** Double glazed windows
1	**Measure applied (Y/N)**	*Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Description	175m^2 topped up from R0.5 to R3.5	Reduced from 1.16 ACH to 0.5 ACH	175m^2 of R1.5 floor insulation installed	39.8m^2 of drapes and 19m of pelmets installed	34.1m^2 of canvas awnings installed	No hard to access ceiling space	112m^2 of R1.5 wall insulation installed	45m^2 of double glazing installed
	Cost	$2,029	$1,090	$2,401	$6,398	$5,270	N/A	$2,248	$26,288
2	**Measure applied (Y/N)**	*Yes	Yes	No	Yes	No	Yes	Yes	Yes
	Description	59m^2 topped up from R2.0 to R3.5	Reduced from 1.09 ACH to 0.5 ACH	Sub-floor not accessible	7.6m^2 of drapes and 7.3m of pelmets installed	No air conditioner so no external awnings installed	22.1m^2 upgraded from no insulation to R2.5	79.8m^2 of R2.5 wall insulation installed	10.2m^2 of double glazing installed
	Cost	$437	$635	N/A	$1,605	N/A	$507	$1,596	$5,906
3	**Measure applied (Y/N)**	Yes	Yes	No	Yes	No	No	Yes	Yes
	Description	90m^2 upgraded from no insulation to R3.5	Reduced from 1.71 ACH to 0.5 ACH	Sub-floor not accessible	21.8m^2 of drapes and 12.6m of pelmets installed	No air conditioner so no external awnings installed	No hard to access ceiling space	144.2m^2 of R1.5 wall insulation installed	25.2m^2 of double glazing installed

House number		**Upgrade 1:** Ceiling insulation (easy)	**Upgrade 2:** Draught sealing	**Upgrade 3:** Underfloor insulation	**Upgrade 4:** Drapes and pelmets	**Upgrade 5:** External awnings	**Upgrade 6:**Ceiling insulation (advanced)	**Upgrade 7:** Wall insulation	**Upgrade 8:** Double glazed windows
	Cost	$1,166	$1,098	N/A	$3,740	N/A	N/A	$2,885	$14,633
4	**Measure applied (Y/N)**	*Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Description	97.3m^2 topped up from R1.5 to R3.5	Reduced from 2.00 ACH to 0.5 ACH	97.3m^2 of R1.5 floor insulation installed	7.1m of pelmets installed	11.3m^2 of canvas awnings installed	No hard to access ceiling space	77.6m^2 of R1.5 wall insulation installed	17m^2 of double glazing installed
	Cost	$932	$1,050	$1,332	$748	$1,736	N/A	$1,551	$9,880
5	**Measure applied (Y/N)**	No	Yes	No	Yes	No	Yes	Yes	Yes
	Description	R3.0 already installed	Reduced from 2.67 ACH to 0.5 ACH	Sub-floor not accessible	2.4m^2 of drapes and 1.5m of pelmets installed	No air conditioner so no external awnings installed	24.7m^2 upgraded from no insulation to R2.5	99.3m^2 of R2.5 wall insulation installed	2.4m^2 of double glazing installed
	Cost	N/A	$578	N/A	$423	N/A	$566	$1,986	$1,399
6	**Measure applied (Y/N)**	Yes	Yes	No	Yes	No	No	Yes	Yes
	Description	75.1m^2 upgraded from no insulation to R3.5	Reduced from 1.82 ACH to 0.5 ACH	Sub-floor not accessible	3m^2 of drapes installed	No unshaded windows in conditioned zones	No hard to access ceiling space	83.6m^2 of R1.5 wall insulation installed	2.9m^2 of double glazing installed
	Cost	$974	$456	N/A	$327	$0	N/A	$1,673	$1,718

House number		Upgrade 1: Ceiling insulation (easy)	Upgrade 2: Draught sealing	Upgrade 3: Underfloor insulation	Upgrade 4: Drapes and pelmets	Upgrade 5: External awnings	Upgrade 6:Ceiling insulation (advanced)	Upgrade 7: Wall insulation	Upgrade 8: Double glazed windows
7	**Measure applied (Y/N)**	No	Yes	No	Yes	No	Yes	Yes	Yes
	Description	R2.5 already installed	Reduced from 1.43 ACH to 0.5 ACH	Sub-floor not accessible	4.2m^2 of drapes and 2.5m of pelmets installed	No air conditioner so no external awnings installed	9.3m^2 upgraded from no insulation to R2.5	83.4m^2 of R1.5 wall insulation installed	5.7m^2 of double glazing installed
	Cost	N/A	$630	N/A	$737	N/A	$213	$1,667	$3,312
8	**Measure applied (Y/N)**	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
	Description	132.4m^2 upgraded from no insulation to R3.5	Reduced from 1.14 ACH to 0.5 ACH	157m^2 of R1.5 floor insulation installed	19.3m^2 of drapes and 7.5m of pelmets installed	No air conditioner so no external awnings installed	25.1m^2 upgraded from no insulation to R2.5	176.7m^2 of R2.5 wall insulation installed	22.5m^2 of double glazing installed
	Cost	$1,716	$776	$2,157	$2,930	N/A	$576	$3,535	$13,100
9	**Measure applied (Y/N)**	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	Description	R3.0 already installed	Reduced from 0.87 ACH to 0.5 ACH	Sub-floor not accessible	14.2m^2 of drapes and 5.1m of pelmets installed	6.9m^2 of canvas awnings installed	25.7m^2 upgraded from no insulation to R2.5	150.1m^2 of R2.5 wall insulation installed	17.3m^2 of double glazing installed
	Cost	N/A	$426	N/A	$2,105	$1,072	$588	$3,002	$10,073

House number		**Upgrade 1:** Ceiling insulation (easy)	**Upgrade 2:** Draught sealing	**Upgrade 3:** Underfloor insulation	**Upgrade 4:** Drapes and pelmets	**Upgrade 5:** External awnings	**Upgrade 6:**Ceiling insulation (advanced)	**Upgrade 7:** Wall insulation	**Upgrade 8:** Double glazed windows
10	**Measure applied (Y/N)**	No	Yes	No	Yes	Yes	No	Yes	Yes
	Description	R3.0 already installed	Reduced from 1.68 ACH to 0.5 ACH	Sub-floor not accessible	19.7m^2 of drapes installed	3.4m^2 of canvas awnings installed	No hard to access ceiling space	105.6m^2 of R1.5 wall insulation installed	24.6m^2 of double glazing installed
	Cost	N/A	$458	N/A	$2,180	$521	N/A	$2,112	$14,289
11	**Measure applied (Y/N)**	No	Yes	Yes	Yes	No	No	Yes	Yes
	Description	R2.5 already installed	Reduced from 0.85 ACH to 0.5 ACH	149.8m^2 of R1.5 floor insulation installed	23.6m^2 of drapes and 6m of pelmets installed	No unshaded windows in conditioned zones	No hard to access ceiling space	119m^2 of R1.5 wall insulation installed	18m^2 of double glazing installed
	Cost	N/A	$505	$2,051	$3,248	$0	N/A	$2,380	$10,446
12	**Measure applied (Y/N)**	No	Yes	No	Yes	No	No	Yes	Yes
	Description	R2.5 already installed	Reduced from 1.40 ACH to 0.5 ACH	Sub-floor not accessible	4.1m^2 of drapes installed	No air conditioner so no external awnings installed	Hard to access ceiling space already insulated	104.4m^2 of R2.5 wall insulation installed	8.6m^2 of double glazing installed
	Cost	N/A	$620	N/A	$456	N/A	N/A	$2,087	$4,988

House number		Upgrade 1: Ceiling insulation (easy)	Upgrade 2: Draught sealing	Upgrade 3: Underfloor insulation	Upgrade 4: Drapes and pelmets	Upgrade 5: External awnings	Upgrade 6:Ceiling insulation (advanced)	Upgrade 7: Wall insulation	Upgrade 8: Double glazed windows
13	**Measure applied (Y/N)**	*Yes	Yes	No	Yes	No	No	Yes	Yes
	Description	124.3m^2 topped up from R2.0 to R3.5	Reduced from 1.65 ACH to 0.5 ACH	Sub-floor not accessible	31.9m^2 of drapes and 21.9m of pelmets installed	No air conditioner so no external awnings installed	No hard to access ceiling space	219.7m^2 of R1.5 wall insulation installed	32.2m^2 of double glazing installed
	Cost	$915	$795	N/A	$5,833	N/A	N/A	$4,394	$18,699
14	**Measure applied (Y/N)**	No	Yes	No	Yes	No	Yes	Yes	Yes
	Description	R2.5 already installed	Reduced from 1.35 ACH to 0.5 ACH	Sub-floor not accessible	6m^2 of drapes installed	No unshaded windows in conditioned zones	16.4m^2 upgraded from no insulation to R2.5	113m^2 of R2.5 wall insulation installed	7.4m^2 of double glazing installed
	Cost	N/A	$404	N/A	$659	$0	$376	$2,261	$4,309
15	**Measure applied (Y/N)**	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Description	90.3m^2 upgraded from no insulation to R3.5	Reduced from 0.98 ACH to 0.5 ACH	Sub-floor not accessible	15.5m^2 of drapes and 6.7m of pelmets installed	17.5m^2 of canvas awnings installed	Hard to access ceiling space already insulated	168m^2 of R1.5 wall insulation installed	23m^2 of double glazing installed
	Cost	$1,170	$747	N/A	$2,429	$2,702	N/A	$3,360	$13,340

4.1.4 Costs and impacts of the basic and advanced upgrade packages

The costs of the basic upgrades, energy cost savings, GHG emissions savings and payback periods are presented in Table 9. The basic upgrade consists of three upgrades; (1) easy to install ceiling insulation, (2) comprehensive draught sealing and (3) underfloor insulation. All three upgrades were not applied to each house, as for some it was not necessary or possible due to the nature of the house. The upgrades applied to each house are shown in the table below. Under the 'Basic upgrades applied' column the letter 'a' next to upgrade 1 indicates that this was a ceiling insulation top-up. Under the 'House number' column a letter 'b' indicates that the house is centrally heated. Detailed results of the costs and impacts of the basic upgrades are presented for each house separately in the building shell upgrade cost curve section.

Table 9: Costs and impacts of basic upgrades

House number	Basic upgrades applied	Estimated cost of basic upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
1[b]	1[a],2,3	$5,519	$814	4,141	6.8
2	1[a],2	$1,072	$55	279	19.5
3[b]	1,2	$2,264	$738	3,747	3.1
4	1[a],2,3	$3,314	$205	1,041	16.2
5	2	$578	$107	543	5.4
6	1,2	$1,430	$229	1,165	6.3
7	2	$630	$104	526	6.1
8[b]	1,2,3	$4,649	$1,377	6,988	3.4
9	2	$426	$67	341	6.4
10[b]	2	$458	$132	673	3.5
11[b]	2,3	$2,556	$314	1,584	8.1
12	2	$620	$64	327	9.6
13[b]	1[a],2	$1,710	$477	2,423	3.6
14	2	$404	$53	273	7.6
15	1,2	$1,917	$199	1,020	9.7
Average		**$1,837**	**$329**	**1,671**	**5.6**

a = ceiling insulation top-up, **b** = central heating

The extent of the energy cost savings and GHG emission reductions varied considerably between houses, which is a reflection on the initial efficiency of the houses, the cost of the modelled upgrades for the specific house and the type of heating or cooling systems installed. However, with only two exceptions, the payback periods for the basic upgrades of the houses were ten years or less. This result is encouraging as it suggests that undertaking these basic upgrades would result in an improvement for most householders which was cost effective and could be paid for within a normal household occupancy period.

The two houses with the longer payback period received ceiling insulation top-ups and were space conditioned, so the impact of insulating the remainder of the ceiling for the upgrade resulted in fairly small energy savings. Also, for houses that are only space conditioned, insulating the full ceiling or underfloor space is less cost-effective than just insulation above or below the areas of the home which are space conditioned.

The costs of the full upgrade package, including the advanced upgrades, energy cost savings, emissions savings and payback periods are presented in Table 10. The full upgrade package consists of the basic package plus five further advanced upgrades: (4) drapes and pelmets, (5) external awnings, (6) hard to install ceiling insulation, (7) wall insulation and (8) double glazed windows. Under the 'Advanced upgrades applied' column the letter 'a' next to upgrade 1 indicates that this was a ceiling insulation top-up. Under the 'House number' column a letter 'b' indicates that the house is centrally heated. The detailed results of the costs and impacts of each of these five upgrades are presented for each house separately in the building shell upgrade cost curve section.

Table 10: Costs and impacts of full upgrade package

House number	Advanced upgrades applied	Estimated cost of advanced upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
1[b]	1[a],2,3,4,5,7,8	$45,723	$1,186	6,039	39
2	1[a],2,4,6,7,8	$11,856	$309	1,569	38
3[b]	1,2,4,7,8	$24,118	$1,179	5,982	20
4	1[a],2,3,4,5,7,8	$17,229	$328	1,669	53
5	2,4,6,7,8	$4,952	$228	1,157	22
6	1,2,4,7,8	$5,148	$293	1,494	18
7	2,4,6,7,8	$6,670	$210	1,064	32
8[b]	1,2,3,4,6,7,8	$27,712	$2,311	11,729	12
9	2,4,5,6,7,8	$17,266	$586	3,027	29
10[b]	2,4,5,7,8	$19,560	$430	2,187	45
11[b]	2,3,4,7,8	$18,631	$682	3,456	27
12	2,4,7,8	$8,665	$207	1,049	42
13[b]	1[a],2,4,7,8	$32,894	$1,057	5,365	31
14	2,4,6,7,8	$8,011	$165	851	49
15	1,2,4,5,7,8	$23,747	$388	2,000	61
Average		**$18,145**	**$637**	**3,243**	**28.5**

a = ceiling insulation top-up, **b** = central heating

The impacts of the additional upgrades included in the advanced upgrade package were modelled assuming that the existing heating and cooling appliances in the houses had been upgraded to high efficiency appliances, where the appliances were not already of a high efficiency standard. This was because it was expected that the paybacks for the heating and cooling appliance upgrades would generally be lower than the paybacks for the advanced building shell upgrades, and would therefore be more likely to be implemented first. This means that the reported impacts of the advanced building shell upgrades will generally be lower than they would be for the house if the efficiencies of the original heating and cooling appliances were used.

The results show that the more expensive advanced upgrade package resulted in significant energy costs savings for some houses and average greenhouse savings of 3.2 tonnes annually. The results also showed that the full upgrade package had an average payback of 28.5 years, which makes it generally difficult to justify on cost from the perspective of the consumer. However, examination of the impacts of the individual upgrades reveals that a number of measures in the advanced upgrade package (such as the insulation upgrades and comprehensive draught sealing) were much more effective than others. This is examined in detail in Table 11 and its accompanying section.

Table 11: Average costs and impacts of house upgrades

Upgrade	Number of houses receiving upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Ceiling insulation – top-up	3	$762	$21	109	36
Ceiling insulation - bare ceiling	5	$1,411	$394	2,051	3.6
Draught sealing	15	$685	$136	676	5.0
Underfloor insulation	4	$1,985	$215	1,088	9.2
Drapes and pelmets	15	$2,255	$40	206	56
External window treatment	5	$2,260	$2.7	17	843
Ceiling insulation (advanced)	6	$471	$68	347	6.9
Wall insulation	15	$2,449	$212	1,082	11.5
Double glazed windows	15	$10,159	$27	140	373

Table 11 shows the average costs, impacts and payback periods for the different upgrades. The main findings are:

- The average costs ranged from $471 to $10,159 for the different upgrades.
- Annual energy cost savings ranged from $2.7 to $394/yr.
- Average annual GHG savings ranged from 17 to 2,051 kg/yr.
- Insulation added to an uninsulated ceiling (easy or advanced), draught sealing, and underfloor insulation all had average payback periods of 10 years or less.
- Wall insulation had an average payback period of 11.5 years but resulted in annual GHG savings of over 1 tonne/yr and energy cost savings of $212/yr.
- Top-ups of ceiling insulation did not produce significant results and had an average payback of 36 years. Actual ceiling insulation top-ups, as opposed to modelled ones, may have a better outcome because existing

insulation may be poorly installed (e.g. there may be significant gaps in insulation) and not performing as expected.

- The measures with the widest applicability across the housing stock, based on this initial sample, are draught sealing, drapes and pelmets, wall insulation, and double glazing.

An inspection of the individual results for the different houses, though, shows a very wide variation in the impacts and paybacks for each action across the houses. Those which are most cost effective over-all, and particularly so in some houses, are:

- ceiling insulation (where the ceiling is currently uninsulated)
- draught sealing
- underfloor insulation, and
- wall insulation.

The implication is that upgrades need to be chosen according to the requirements of the individual houses. This suggests that any program, or individual householder, wanting to upgrade houses in a cost effective manner will need a reasonably sophisticated energy audit to be conducted to identify which upgrades are worthwhile.

4.1.5 Building shell upgrade cost curves

To provide a better understanding of the cost effectiveness of each of the different building shell upgrades which were modelled, 'cost curves' were developed for individual houses, different categories of energy efficiency upgrade, and for all energy efficiency measures and houses combined. The cost curves for individual houses are contained in Appendix C.

To develop the curves, individual measures were first ranked by payback. These payback points were then mapped against the cumulative GHG savings, starting from the upgrade with the lowest payback. The building shell upgrade cost curves are displayed in the figures below and show the extent of variation in the feasibility and effectiveness of the different building shell upgrades.

The building shell upgrade cost curves reveal that the paybacks for a significant proportion of houses were ten years or less for the following upgrade types:

- ceiling insulation, easy (where the ceiling is currently uninsulated)
- draught sealing
- advanced ceiling insulation
- wall insulation, and
- underfloor insulation.

Upgrades involving external window treatments, drapes and pelmets, and double glazing all had paybacks exceeding 25 years and often much longer. This reflected the relatively high cost and low energy savings of these measures. Also, it may be that the energy modelling tools used in this study do not fully capture the energy saving benefits achieved by these upgrades – in all cases they will increase occupant comfort, and this may mean that comfort conditions are achieved at lower thermostat settings for heating and higher thermostat settings for cooling.

For most upgrades, houses with central heating tended to have shorter payback periods than space conditioned houses. While this was expected it should be remembered that energy efficiency upgrades will improve the comfort of space conditioned houses in all areas but this cannot be captured in cost benefit analysis.

Below is a cost curve and explanatory table, and a brief summary of the main points that have emerged from the cost curve analysis for each type of building shell upgrade. In the tables accompanying the cost curves, houses with central heating are marked with an asterisk to assist with the interpretation of results.

Upgrade 1: Ceiling insulation (easy)

Ceiling insulation (with easy roof access) was modelled for eight houses in the study. The main points to emerge from Figure 1 and

Table 12 are the following:

- The five houses with the shortest payback periods and highest GHG and energy cost savings had insulation installed on ceilings that were either uninsulated or very poorly insulated (R0.5). The payback for these five houses was eight years or less with the lowest being two years.
- Overall, centrally conditioned houses had shorter paybacks and greater savings than space conditioned houses. This was the case for insulation added to a bare ceiling and also ceiling insulation top-ups.
- Ceiling insulation top-ups had much longer payback periods and lower GHG and cost savings than insulation added to uninsulated ceilings. This reflects the “law of diminishing returns” for ceiling insulation – once the ceiling is insulated to around R1.5, the addition of higher levels of insulation tends to have a fairly minor impact on energy savings.
- About 96% of GHG savings were achieved by the first five houses through insulating uninsulated or very poorly insulated ceilings.
- Even though ceiling insulation top-ups did not deliver the same benefit as insulating uninsulated ceilings, it should be remembered that currently installed insulation may be poorly installed (e.g. there may be gaps or some areas of very poor insulation cover) and actually may not be performing as well as it should. Given the low cost of ceiling insulation it may be beneficial for households to undertake ceiling insulation top-ups

to ensure that ceiling insulation is properly installed over the entire ceiling and performing at its best.

Figure 1: Cost curve for ceiling insulation (easy)

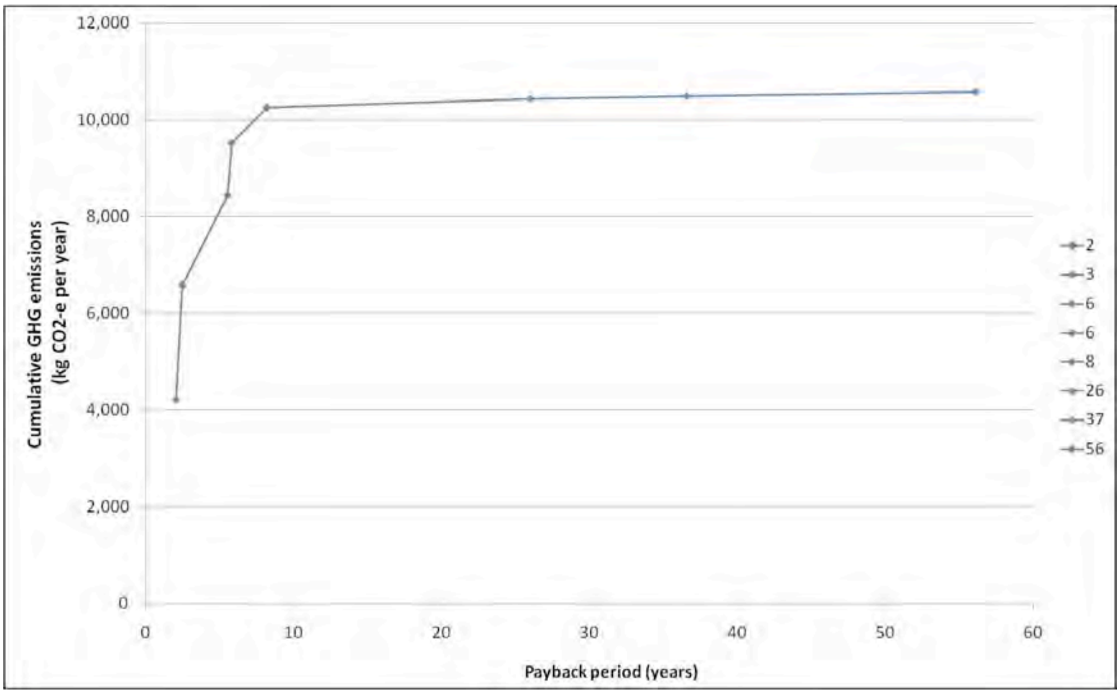


Table 12: Impacts of ceiling insulation (easy) ranked by payback period

House number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 8*	132.4m² upgraded from no insulation to R3.5	$1,716	$830	4,214	2.1
House 3*	90m² upgraded from no insulation to R3.5	$1,166	$466	2,366	2.5
House 1*	175m² topped up from R0.5 to R3.5	$2,029	$365	1,865	5.6
House 6	75.1m² upgraded from no insulation to R3.5	$974	$167	1,076	5.8
House 15	90.3m² upgraded from no insulation to R3.5	$1,170	$143	734	8.2
House 13*	124.3m² topped up from R2.0 to R3.5	$915	$35	179	26
House 2	59m² topped up from R2.0 to R3.5	$437	$12	61	37
House 4	97.3m² topped up from R1.5 to R3.5	$932	$17	86	56
Average		**$1,168**	**$254**	**1,323**	**4.6**

* = centrally heated house

Upgrade 2: Draught sealing

Draught sealing was applied to all 15 houses in the study. The air changes per hour (ACH) figures displayed in Table 13 are at ambient air pressure.[12] For the purposes of modelling it was assumed all houses could be reduced to 0.5 ACH, and upgrade costs were prepared on this basis based on advice from Air Barrier Technologies. The main points to emerge from Figure 2 and Table 13 are the following:

- Draught sealing overall is a very cost effective measure with many houses having payback periods of well under ten years. All houses benefited significantly in terms of performance from this upgrade and it was one of the cheapest upgrades with an average cost of $685, based on commercial rates. In many cases, this upgrade could be undertaken by the householder more cheaply than this as a DIY project.
- On average this upgrade resulted in $136/yr of energy cost savings and 676 kg/yr of GHG savings. The average payback period was five years.
- Greatest GHG and cost savings were achieved in centrally conditioned houses but a number of space conditioned houses also achieved significant savings, particularly House 5, which had the highest recorded ACH rate in the study.
- Energy saved from draught sealing not only depends upon the net reduction in the ACH value achieved from draught sealing but also the volume of the house. Two houses may have the same ACH value but the house with the greater volume will have greater energy cost and GHG savings associated with the upgrade because a greater volume of air needs to be conditioned for the same ACH value. A better understanding of the differences in impact of draught sealing can be gained by examining the volume and the ACH value of individual houses presented in Table 13.
- The influence of house volume explains why Houses 2, 4, 6, 12 and 14 had high ACH values but low energy cost and GHG savings.
- House 11 is centrally conditioned but draught sealing did not deliver much benefit because it had the lowest recorded ACH rate of any house in the study.
- Modelled upgrades to some houses were more expensive due to the need to install dampers for evaporative air-conditioning systems and chimney dampers. As a result, while energy cost savings may have been significant, the payback period was longer, as shown with House 4.
- Common sources of air leakage identified included wall vents, doors, windows, unsealed exhaust fans, recessed downlights, skirting boards, open fire places with chimneys, manholes, and ducted evaporative air conditioners with no, or ineffective dampers. See Appendix D for the

[12] ACH at ambient air pressure is calculated by dividing ACH@50 by 20.

complete report on the air leakage tests and the main air leakage sources for individual houses.

Figure 2: Cost curve for draught sealing

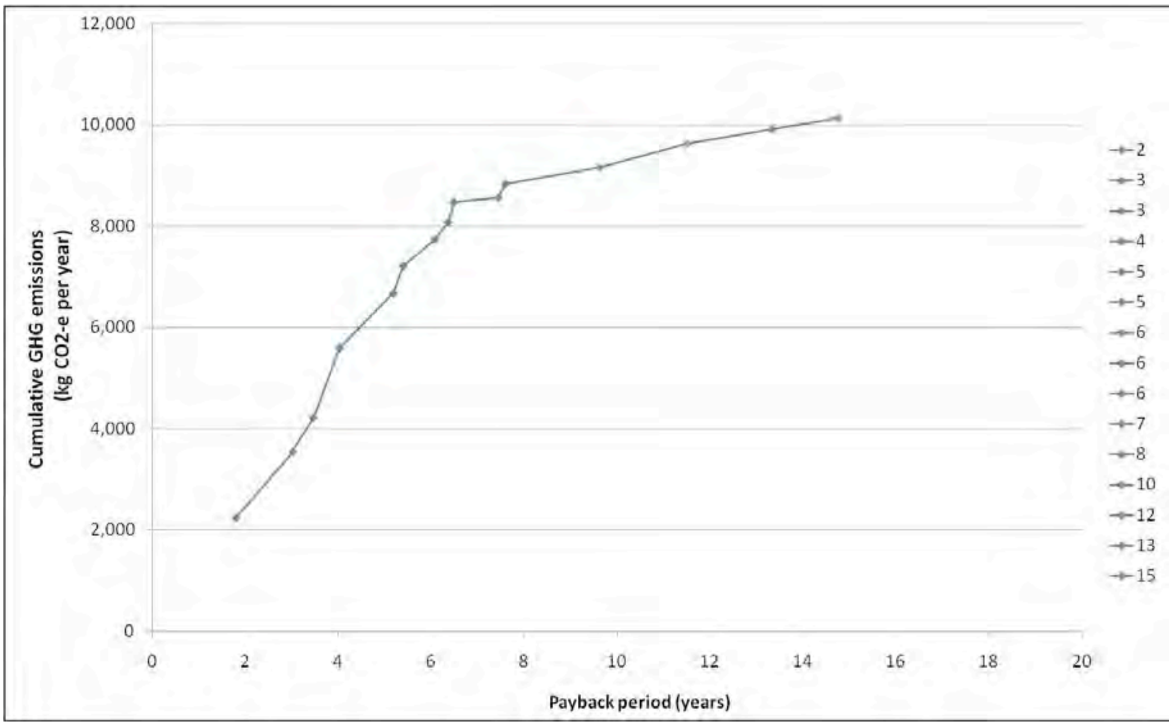


Table 13: Impacts of draught sealing ranked by payback period

House number	Measured ACH	Net reduction in ACH	Volume (m^3)	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 13* f	1.65	1.15	559	$795	$442	2,244	1.8
House 8* f	1.14	0.64	537	$776	$257	1,306	3.0
House 10*	1.68	1.18	276	$458	$132	673	3.5
House 3* f	1.71	1.21	454	$1,098	$272	1,381	4.0
House 1* a	1.16	0.66	420	$1,090	$210	1,069	5.2
House 5 f	2.67	2.17	256	$578	$107	543	5.4
House 7	1.43	0.93	373	$630	$104	526	6.1
House 9 f	0.87	0.37	480	$426	$67	341	6.4
House 11*	0.85	0.35	363	$505	$78	396	6.5
House 6	1.82	1.32	226	$456	$61	88	7.5
House 14	1.35	0.85	366	$404	$53	273	7.6
House 12	1.40	0.90	310	$620	$64	327	9.7
House 4a	2.00	1.50	235	$1,050	$91	465	11.5
House 15 f	0.98	0.48	458	$747	$56	286	13.3
House 2 f	1.09	0.59	273	$635	$43	219	14.7
Average	**1.45**	**0.95**	**372**	**$685**	**$136**	**676**	**5.0**

* = centrally heated house, f = fireplace seals installed, a = evaporative air conditioner damper installed

Upgrade 3: Underfloor insulation

The installation of underfloor insulation was modelled for four houses. The main points to emerge from Figure 3 and Table 14 are the following:

- Underfloor insulation did achieve significant cost and GHG savings, especially in centrally heated houses. On average this upgrade resulted in $215/yr of energy cost savings and 1,088 kg/yr of GHG savings.
- Centrally heated houses had payback periods of 7-10 years. This is relatively short and suggests that, where possible, houses with suspended timber floors should install underfloor insulation. These houses would also need to have good external shading on exposed east, west and north facing windows to ensure that the addition of extra insulation does not cause overheating in summer.
- House 4 had a payback of 14 years, due to it being space conditioned.

Figure 3: Cost curve for underfloor insulation

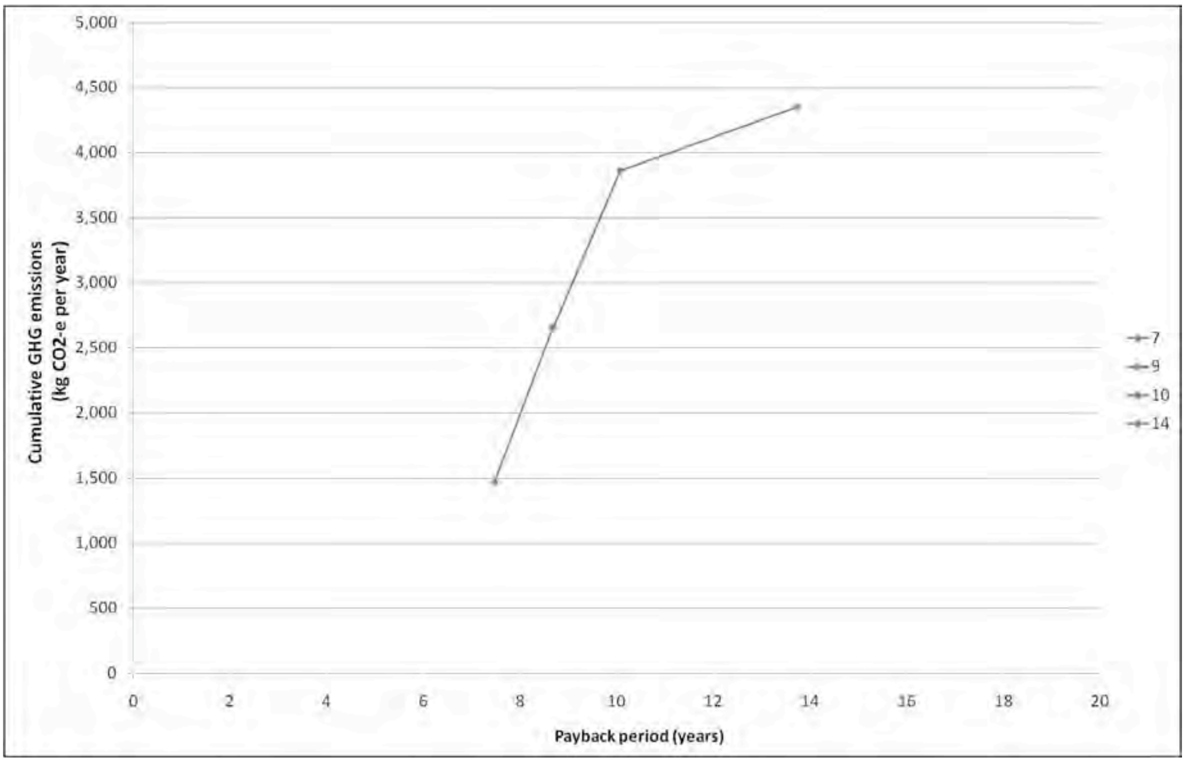


Table 14: Impacts of underfloor insulation ranked by payback period

House	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 8*	157m^2 of R1.5 floor insulation installed	$2,157	$289	1,467	7.5
House 11*	149.8m^2 of R1.5 floor insulation installed	$2,051	$236	1,188	8.7
House 1*	175m^2 of R1.5 floor insulation installed	$2,401	$238	1,207	10.1
House 4	97.3m^2 of R1.5 floor insulation installed	$1,332	$97	490	13.7
Average		**$1,985**	**$215**	**1,088**	**9.2**

* = centrally heated house

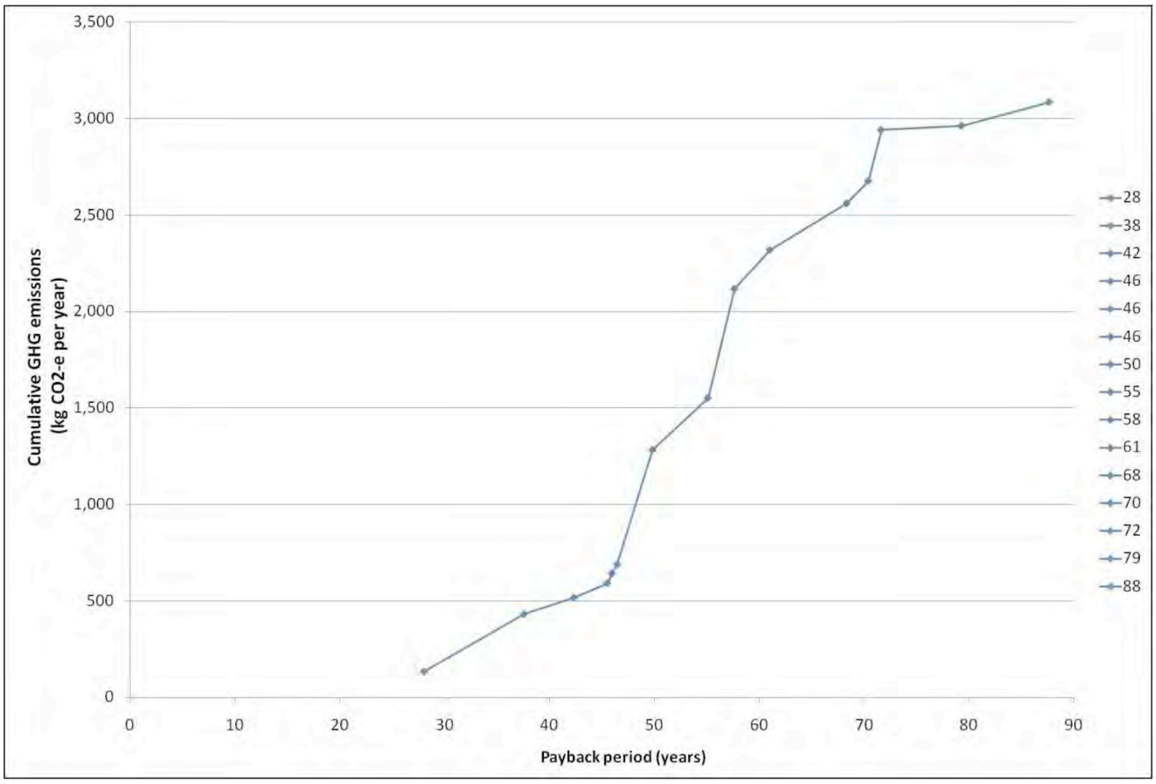
Upgrade 4: Drapes and pelmets

Drapes and pelmets were applied to all 15 houses in the study. The main points to emerge from Figure 4 and Table 15 are the following:

- On average this modelled upgrade resulted in $40/yr of energy cost savings and 206 kg/yr of GHG savings. The average payback across all 15 houses was 56 years. It is important to note that payback periods are based on commercial rates for manufacture and installation. A DIY approach could reduce costs and therefore the payback periods.
- Generally there was a relationship between the level of savings achieved and the number of drapes and pelmets installed.
- Payback periods varied depending upon the type of existing window treatments already installed. The version of FirstRate5 used for the analysis has different R-values associated with various window treatments. For example, venetian blinds have no associated R-value, while drapes and pelmets add R0.33 to a window, but curtains and pelmets only add R0.11. The result is that different combinations of window treatments lead to different R-values. Therefore, depending upon the treatments already installed, the benefit of installing drapes and pelmets varied. For example, House 6 already had a curtain and pelmet installed so the addition of a drape did not result in a significant saving.
- House 4 already had heavy drapes and only needed pelmets applied. FirstRate5 increases the added R-value associated with a drape by a factor of more than five once a pelmet is added. This means that performance of the windows in House 4 dramatically increased for a much lower cost than if both pelmets and drapes were required. This explains why this house has the shortest payback.
- The manner in which FirstRate5 models window treatments also explains why Houses 10, 12 and 14 have a relatively short payback period. These houses only had curtains and pelmets installed which has an

added R- value of 0.11. Installing drapes increased the added R-value to 0.33. The associated payback period was shorter because the upgrade cost was less, as only drapes were required rather than both drapes and pelmets.

Figure 4: Cost Curve for drapes and pelmets



House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 4	7.1m of pelmets installed	$748	$27	135	28
House 10*	19.7m^2 of drapes installed	$2,180	$58	295	38
House 7	4.2m^2 of drapes and 2.5m of pelmets installed	$737	$17	88	42
House 14	6m^2 of drapes installed	$659	$14	75	46
House 12	4.1m^2 of drapes installed	$456	$10	50	46
House 5	2.4m^2 of drapes and 1.5m of pelmets installed	$423	$9	46	46
House 13*	31.9m^2 of drapes and 21.9m of pelmets installed	$5,833	$117	594	50
House 8*	19.3m^2 of drapes and 7.5m of pelmets installed	$2,930	$53	270	55
House 1*	39.8m^2 of drapes and 19m of pelmets installed	$6,398	$111	565	58
House 15	15.5m^2 of drapes and 6.7m of pelmets installed	$2,429	$40	202	61
House 11*	23.6m^2 of drapes and 6m of pelmets installed	$3,248	$48	241	68
House 2	7.6m^2 of drapes and 7.3m of pelmets installed	$1,605	$23	116	70

House 3*	21.8m^2 of drapes and 12.6m of pelmets installed	$3,740	$52	265	72
House 6	3m^2 of drapes installed	$327	$4	21	79
House 9	14.2m^2 of drapes and 5.1m of pelmets installed	$2,105	$24	123	88
Average		**$2,255**	**$40**	**206**	**56**

Table 15: Impact of drapes and pelmets ranked by payback

* = centrally heated house

Upgrade 5: External awnings

External awnings were applied in the modelling to houses that had some form of air conditioning for summer cooling. While eight had air conditioners, only five needed external awnings as the other three already had adequately shaded windows.

The main points to emerge from Figure 5 and Table 16 are the following:

- The modelled upgrade resulted in an average annual energy cost saving of $2.68/yr and GHG saving of 17 kg/yr. The average cost of upgrade was $2,260.
- The average payback for this upgrade was 843 years. It is important to note that this is based on commercial costs for installing external awnings. A DIY approach could significantly reduce both the costs and payback period.
- The two houses with the shortest payback periods had a considerable amount of floor-to-ceiling glazing facing either north or west. Importantly, they also had reverse cycle air conditioning units which meant that energy required for cooling was much higher than houses using evaporative cooling systems.
- Houses 4 and 1 also had considerable amounts of unshaded glass but had evaporative cooling systems, which use considerably less energy than refrigerative air conditioners. This explains why their payback periods were so much longer.
- All windows at House 10 were already well shaded with the exception of one east facing window. The modelling shows that shading this window did not make a significant difference to cooling energy requirements.
- There has been some discussion that Accurate/FirstRate5 currently underestimates the amount of cooling energy required. If so, this would have an impact upon the payback period of external awnings. It is advised that the results for external awnings are re-examined if any changes are made to FirstRate5 cooling load calculations.

Figure 5: Cost curve for external awnings

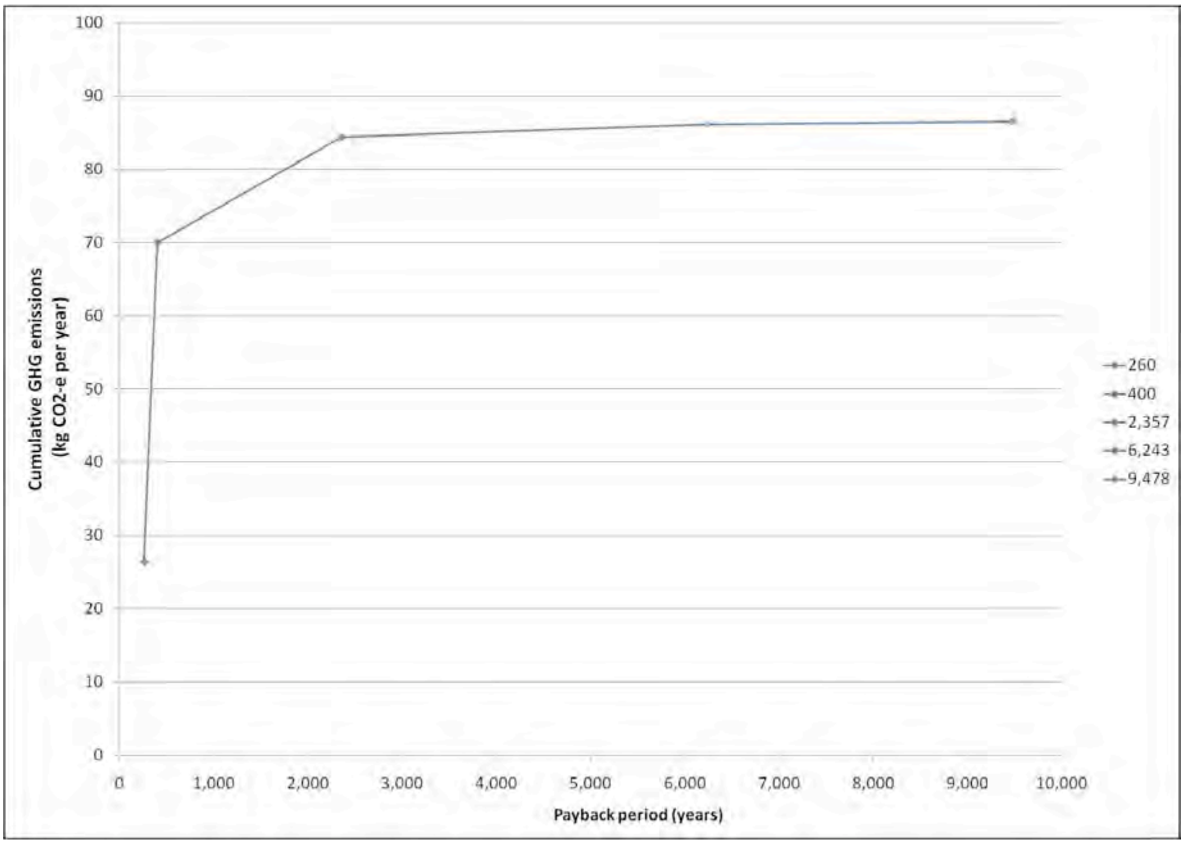


Table 16: Impacts of external awnings ranked by payback

House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 9	6.9m^2 of canvas awnings installed	$1,072	$4	26	260
House 15	17.5m^2 of canvas awnings installed	$2,702	$7	44	400
House 1*	34.1m^2 of canvas awnings installed	$5,270	$2	14	2,357
House 4	11.3m^2 of canvas awnings installed	$1,736	$0.3	2	6,243
House 10*	3.4m^2 of canvas awnings installed	$521	$0.1	0.4	9,478
Average		**$2,260**	**$3**	**17**	**843**

* = ducted evaporative cooling

Upgrade 6: Ceiling insulation (advanced)

Advanced ceiling insulation (i.e. insulation installed in flat roof construction) was modelled for six houses. The main points to emerge from Figure 6 and Table 17 are the following:

- The modelled upgrade resulted in an average annual energy cost saving of $68/yr and GHG saving of 347 kg/yr, with an average payback period of 6.9 years. The average cost of upgrade was $471.
- The longer payback period for advanced ceiling insulation is due to three of the houses having very small or no conditioned areas falling under flat roof areas. Three houses with a significant area of conditioned space with flat roofs had an average payback period of 4.4 years compared to 49 years for the three with very small or no conditioned areas with flat roofs. These results show that when a significant area of the flat roof area of a house is conditioned, the extra expense associated with advanced ceiling insulation does not considerably impact upon the payback period and financial viability of this upgrade.
- House 2 conditioned a smaller percentage of the floor area under the flat roof compared with Houses 8 and 9 and, as expected, had a longer payback period.
- The three houses with payback periods 26 years and above conditioned either a very small percentage of the floor area under flat roofs or none at all. Advanced insulation was applied to all flat roof areas connected to the main house regardless of whether the areas were conditioned or not, because it was decided during project design that insulation upgrades would be applied to the entire house regardless of the individual conditioning profiles (refer to the methodology section). As expected, payback periods increased as the area of conditioned floor under flat roofs decreased and as the flat roof area was further removed from the conditioned zones. In House 5, a very small area of the flat roof section of the house was conditioned. In House 7 the flat roof section was not conditioned but was directly next to the kitchen area, thus having an impact upon the energy required to condition this area. In House 14 the flat roof section of the house is separated from the conditioned area by two rooms, hence having a minimal impact upon the energy required for conditioning.
- While the payback was not as good for houses that did not significantly condition flat roof sections of the house, the installation of ceiling insulation would improve the thermal comfort in these areas. It should also be noted that cost of this modelled upgrade was on average only $471, a not unreasonable cost.

Figure 6: Cost curve for ceiling insulation (advanced)

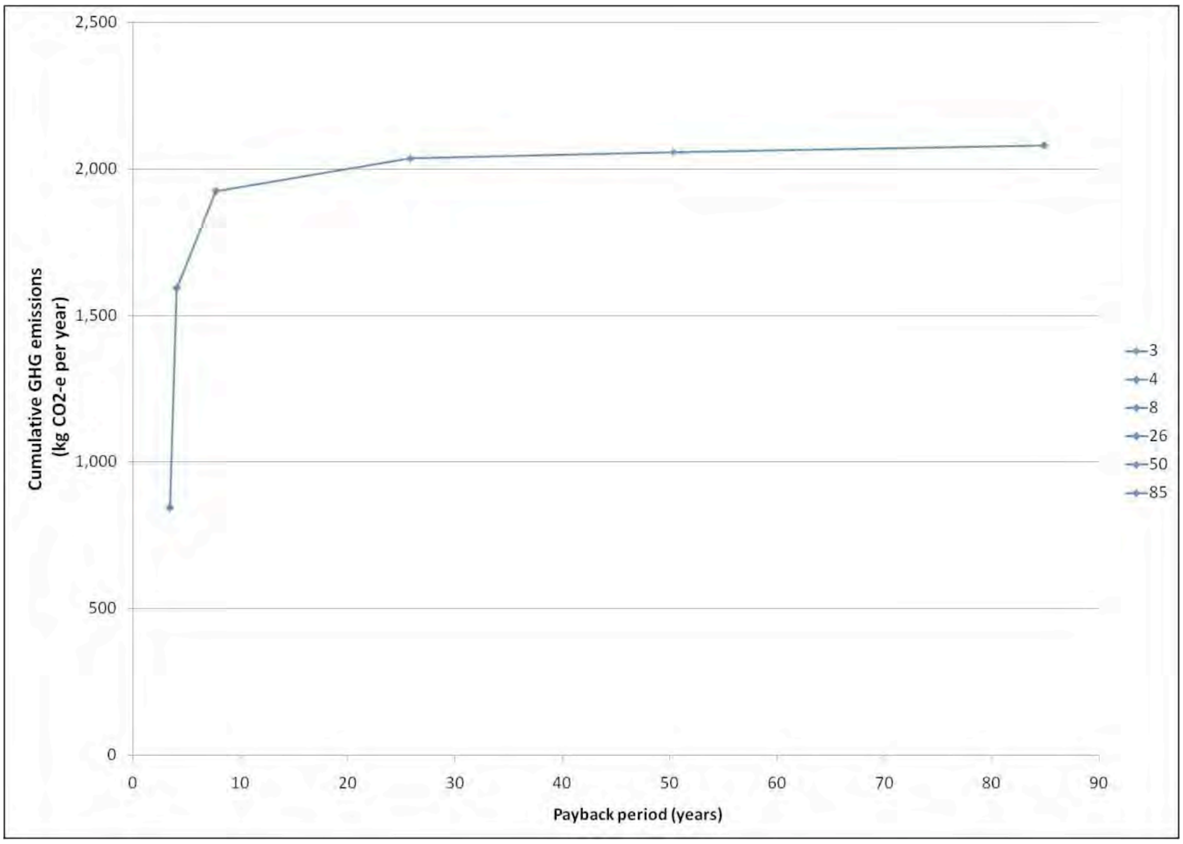


Table 17: Impacts of ceiling insulation (advanced) ranked by payback

House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 8*	25.1m^2 upgraded from no insulation to R2.5	$576	$167	846	3.5
House 9	25.7m^2 upgraded from no insulation to R2.5	$588	$145	747	4.2
House 2	22.1m^2 upgraded from no insulation to R2.5	$507	$66	333	7.7
House 5	24.7m^2 upgraded from no insulation to R2.5	$566	$22	111	26
House 7	9.3m^2 upgraded from no insulation to R2.5	$213	$4	21	50
House 14	16.4m^2 upgraded from no insulation to R2.5	$376	$4	23	85
Average		**$471**	**$68**	**347**	**6.9**

* = centrally heated house

Upgrade 7: Wall insulation

Wall insulation was applied to all 15 houses in the study. The main points to emerge from Figure 7 and Table 18 are the following:

- This modelled upgrade resulted in an average annual energy cost saving of $212/yr and GHG saving of 1,082 kg/yr, with a payback period of 11.5 years. The average cost of upgrade was $2,449.
- Wall insulation was a very effective measure achieving over 16 tonnes of GHG savings across the 15 houses. Further, it is a measure which is widely applicable to many existing houses, given that houses constructed prior to 1991 are unlikely to have any wall insulation. Houses with lightweight wall construction (e.g. brick veneer, weatherboard, etc) constructed since 1991 are likely to have some wall insulation, but it is unlikely in those with cavity brick walls built since this date, even under the current 5 Star standard.
- All houses with payback periods of 11 years or less were centrally conditioned, excepting Houses 9 and 2. These two had the largest area conditioned out of all space conditioned houses.
- A general trend to emerge is that payback periods for wall insulation increase as the percentage of conditioned floor area decreases. House 15 is an exception to this rule as more than 50% of its floor area is conditioned but it still has a payback period of 27 years, largely because the main living area has floor to ceiling glazing on one side and this limits the overall impact of wall insulation.

Figure 7: Cost curve for wall insulation

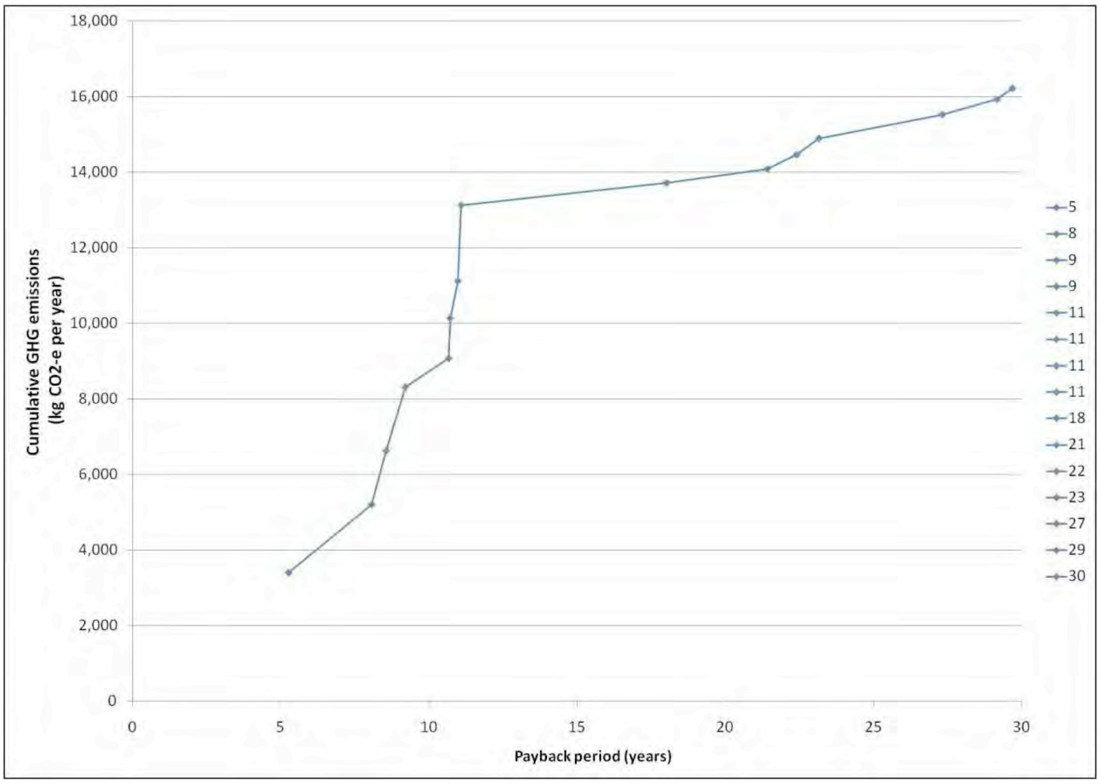


Table 18: Impacts of wall insulation ranked by payback periods

House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 8*	176.7m^2 of R2.5 wall insulation installed	$3,535	$671	3,407	5.3
House 3*	144.2m^2 of R1.5 wall insulation installed	$2,885	$357	1,812	8.1
House 11*	119m^2 of R1.5 wall insulation installed	$2,380	$278	1,415	8.7
House 9	150.1m^2 of R2.5 wall insulation installed	$3,002	$326	1,686	9.2
House 2	79.8m^2 of R2.5 wall insulation installed	$1,596	$150	759	10.6
House 1*	112m^2 of R1.5 wall insulation installed	$2,248	$210	1,068	10.7
House 10*	105.6m^2 of R1.5 wall insulation installed	$2,112	$192	977	11.0
House 13*	219.7m^2 of R1.5 wall insulation installed	$4,394	$396	2,011	11.8
House 12	104.4m^2 of R2.5 wall insulation installed	$2,087	$116	588	18.0
House 4	77.6m^2 of R1.5 wall insulation installed	$1,551	$72	369	21
House 7	83.4m^2 of R1.5 wall insulation installed	$1,667	$74	378	22
House 5	99.3m^2 of R2.5 wall insulation installed	$1,986	$86	435	23
House 15	168m^2 of R1.5 wall insulation installed	$3,360	$123	627	27
House 14	113m^2 of R2.5 wall insulation installed	$2,261	$78	401	29
House 6	83.6m^2 of R1.5 wall insulation installed	$1,673	$56	289	30
Average		**$2,449**	**$212**	**1,082**	**11.5**

* = centrally heated house

Upgrade 8: Double glazing

Double glazing was applied to all 15 houses in the study. The main points to emerge from Figure 8 and Table 19 are the following:

- The modelled upgrade resulted in an average annual energy cost saving of $27/yr and GHG saving of 140 kg/yr, and a payback of 373 years. The average cost of upgrade was $10,159.
- The upgrade saved a cumulative total of approximately 2 tonnes of GHG emissions across the 15 houses in this study.
- Centrally conditioned houses had much larger GHG and cost savings compared to space conditioned houses.

It is important to note that the cost and benefit figures presented in this analysis are for the removal of the existing single-glazed windows and their replacement with new double-glazed windows. Technologies are also available for the retrofit of an extra pane of glass, Perspex or film to an existing single-glazed window. The installation cost of these technologies is lower than full replacement of the window, and the thermal performance of the retrofitted window is likely to be lower (but this still is uncertain). The application of these technologies may well be more cost effective than full window replacement with double glazing.

It is also relevant to note that, due to the perceived long payback period for installing double-glazed windows, they were the last energy efficiency measure modelled, with curtains and boxed pelmets assumed to be installed prior to this. The application of double-glazing much earlier in the list of upgrades would result in a larger saving and therefore considerably lower payback time for this measure.

Double-glazed windows are still largely a niche product in Australia – unlike in Europe and the U.S.A. where they are the standard form of glazing – and currently command a premium price. The wider use of double glazing in Victoria would most probably reduce the unit cost of installing double-glazing and further improve the payback period.

Figure 8: Cost curve for double glazing

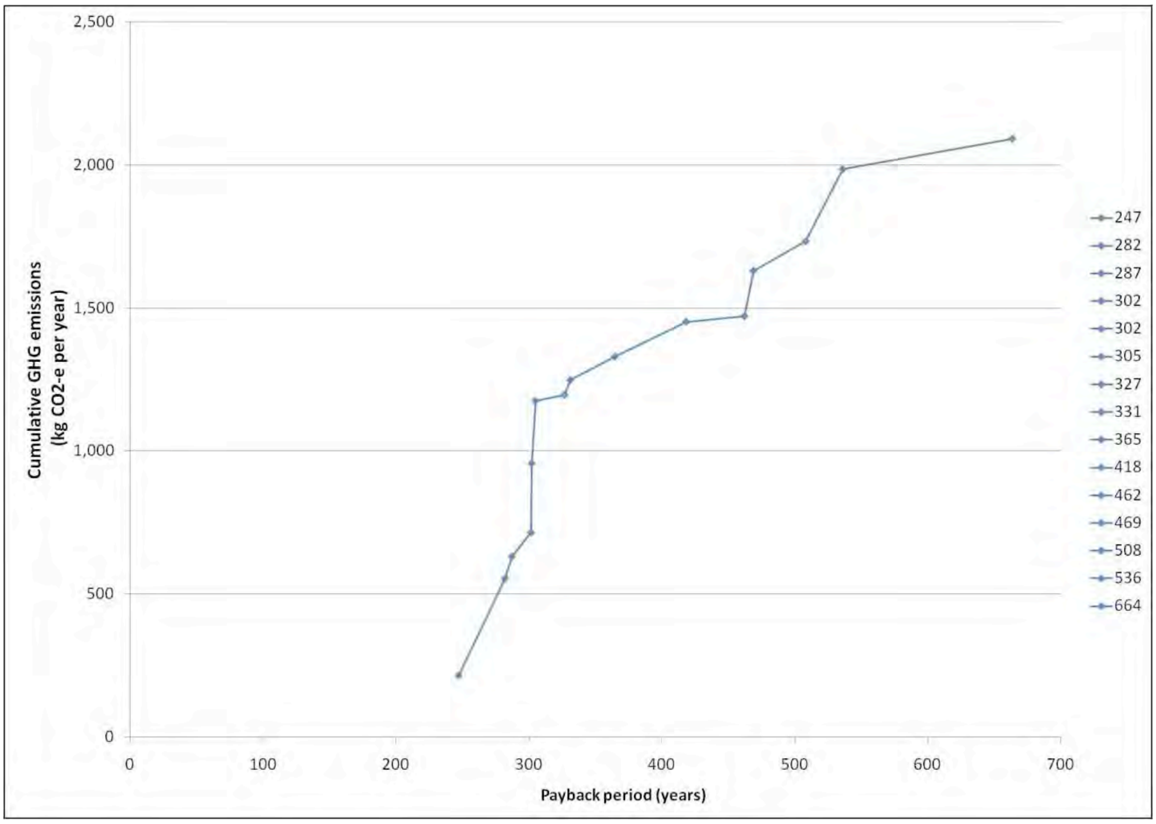


Table 19: Impacts for double glazing ranked by payback period

House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 11*	18m^2 of double glazing installed	$10,446	$42	217	247
House 13*	32.2m^2 of double glazing installed	$18,699	$66	337	282
House 14	7.4m^2 of double glazing installed	$4,309	$15	79	287
House 12	8.6m^2 of double glazing installed	$4,988	$17	84	302
House 10*	24.6m^2 of double glazing installed	$14,289	$47	242	302

House Number	Description	Cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 8*	22.5m^2 of double glazing installed	$13,100	$43	218	305
House 5	2.4m^2 of double glazing installed	$1,399	$4	22	327
House 7	5.7m^2 of double glazing installed	$3,312	$10	51	331
House 2	10.2m^2 of double glazing installed	$5,906	$16	82	365
House 4	17m^2 of double glazing installed	$9,880	$24	122	418
House 6	2.9m^2 of double glazing installed	$1,718	$4	20	462
House 3*	25.2m^2 of double glazing installed	$14,633	$31	158	469
House 9	17.3m^2 of double glazing installed	$10,073	$20	103	508
House 1*	45m^2 of double glazing installed	$26,288	$49	252	536
House 15	23m^2 of double glazing installed	$13,340	$20	106	664
Average		**$10,159**	**$27**	**140**	**373**

* = centrally heated house

4.2 Upgrades of appliances

4.2.1 Efficiency of existing appliances

Introduction

As discussed in the previous section, the effectiveness of a house in resisting inward and outward heat flow will greatly affect the energy required for space conditioning. However, the efficiency of fixed and non-fixed appliances and lighting in the home will also significantly impact on the overall energy consumption, especially large energy using appliances such as refrigerators and heating, cooling and hot water systems. This project provided the opportunity to assess in some detail appliances that were already in use, although this did not involve the end-use metering of these appliances to establish their actual in-use energy consumption. The tables in this section display the energy rating, estimated efficiency, estimated annual energy consumption, and age of the main appliances found in the 15 houses.

Heaters

In Table 20 the estimated annual energy use for heaters is based upon heating requirements modelled using FirstRate5. The total heating load from FirstRate5 was taken after the application of the basic building shell upgrade package and the estimated conversion efficiency of the existing heaters was used to calculate the annual energy demand.

The estimated annual energy use for Houses 1, 8, 11 and 13 is very high and an initial analysis of the household gas billing data indicates that for most houses the modelled energy consumption for space heating is somewhat higher than what is consumed in reality. It is suggested that further research be undertaken to understand why this is the case and to develop a more accurate methodology for estimating actual heating energy use, but this work was not within the scope of the pilot study. With this in mind it was decided that for this study that the modelled energy consumption will be used to complete the impact analysis.

In Table 20 an asterisk in the efficiency column indicates that the efficiency is an average of two heaters. In these cases there are two ages and energy ratings also listed. An average energy rating is not calculated as it is not possible to compare energy ratings across gas central heaters, gas space heaters and reverse cycle air conditioners. The average energy rating for each technology type is instead listed below.

There was considerable variation in the type of heating in the houses surveyed. Six homes had central heating while the rest relied on space heating. One house relied on a reverse cycle air conditioner and the rest used gas heating. Three houses had more than one space heater. The results from Table 20 show:

- The average energy rating for gas central heaters was 3.3 stars.
- The average energy rating for gas space (room) heaters was 2.8 stars.
- The one reverse cycle air conditioner in use had an energy rating of 4.1 stars.
- Estimated conversion efficiency of the gas heaters (not including duct losses) ranged from 65 - 91%, with an average of 73%. The overall average for the 15 houses listed in Table 20 is higher than this because of the inclusion of the reverse cycle air conditioner.
- Once duct losses were taken into account the average conversion efficiency of the six gas central heaters dropped to 54%.
- Nine of the heaters were 17 years old or more and were quite inefficient.

Table 20: Existing heaters

House number	Heater type/s	Energy rating	Estimated conversion efficiency	Assumed duct losses	Estimated energy use (MJ/yr)	Age (Yrs)
1	Gas central	2.5	65%	24%	101,655	9
2	Gas space-1 wall furnace/1 convection	2.2/4.3	*73%	N/A	47,966	10/10
3	Gas central	4.8	87%	20%	87,864	2
4	Gas space-two wall furnaces	2.2/2.2	*65%	N/A	33,055	30/30
5	Gas space-radiant	2.5	71%	N/A	31,749	25
6	Reverse cycle air conditioner	4.1	283%	N/A	4,799	8
7	Gas space-	2.5	71%	N/A	39,451	25

House number	Heater type/s	Energy rating	Estimated conversion efficiency	Assumed duct losses	Estimated energy use (MJ/yr)	Age (Yrs)
	radiant					
8	Gas central	2.5	65%	32%	186,213	17
9	Gas space-1 convection/1 wall furnace	4.3/2.2	*71%	N/A	82,459	8/30
10	Gas central	5.1	91%	20%	61,958	4
11	Gas central	2.5	65%	35%	115,087	20
12	Gas space-radiant	2.5	71%	N/A	45,678	19
13	Gas central	2.5	65%	27%	168,418	20
14	Gas space-radiant	1.7	65%	N/A	38,130	19
15	Gas space-convection	4.2	82%	N/A	43,547	10
Average		**N/A**	**86%**	**26%**	**72,535**	**16**

* = efficiency is the average of two heaters

Air conditioners

The efficiency of refrigerative air conditioners was reduced to take into account degradation in performance over time. For this project it was assumed that these units have no degradation in performance for the first five years, but that their efficiency degrades by 1% per annum after this point. The air conditioner efficiencies shown in the table above have been adjusted to take the age into account. Evaporative air conditioners were assumed to be very efficient already with an effective conversion efficiency of 1300%, and no degradation in performance was modelled.

The estimated annual energy use is based upon the cooling requirements of the houses modelled using FirstRate5. The total cooling load was taken after the application of the basic upgrade package and the efficiency of the existing air conditioners were used to calculate the annual energy demand.

The results from Table 21 show:

- Only eight of the 15 houses had operating air conditioners.
- Two air conditioners were evaporative systems, three were spilt systems and three were window/wall mounted box units.
- The age of the units ranged from 1 to 25 years.
- Refrigerative air conditioners had an estimated average energy efficiency ratio (EER) of 235%.
- The energy rating of the refrigerative air conditioners ranged from 2 to 4.5 stars, with an average of 2.8 stars.

Table 21: Existing air conditioners

House number	Air conditioner type	Estimated conversion efficiency	Energy rating	Estimated energy use (MJ/yr)	Age (Yrs)
1	Evaporative	1300%	N/A	476	5
4	Evaporative	1300%	N/A	269	1
6	AC wall box (reverse cycle)	283%	4.1	276	8
9	AC split (reverse cycle)	308%	4.5	1,021	1
10	AC wall box (cooling only)	184%	2	312	25
11	AC split (cooling only)	207%	2	647	15
14	AC wall box (cooling only)	198%	2	1,104	19
15	AC split (reverse cycle)	230%	2	696	6
Average		**501%**	**2.8**	**600**	**10**

Hot water systems

The annual energy use for hot water systems was calculated using an estimated average consumption of 150 litres of hot water per day. The results from Table 22 show:

- Most hot water systems were gas storage.
- The energy rating of the gas water heaters ranged from 2 to 5.1 stars with the average rating being 3.5 stars.
- Estimated annual gas usage for water heating ranged from 6.3 GJ to 25.7 GJ.
- One gas boosted solar hot water system was in use.
- The ages of hot water systems varied from 1 year to 30 years, with the average being 11 years.

Table 22: Existing hot water systems

House	HWS type	Brand	Energy Rating	Estimated energy use (MJ/yr)	Estimated age (Yrs)
House 1	Gas HWS storage	Rheem	3.2	19,906	6
House 2	Gas HWS storage	Rheem	3.2	20,069	15
House 3	Gas HWS storage	Rheem Glass	3.3	19,816	10
House 4	Gas HWS storage	Vulcan	3.9	18,659	4
House 5	Gas HWS storage	Rheem	2.0	22,251	17
House 6	Gas HWS storage	Hardie dux	3.2	19,906	12
House 7	Gas instantaneous	Valliant	3.0	19,777	30
House 8	Gas HWS storage	Vulcan	3.2	19,960	13
House 9	Gas HWS storage	Rheem	3.2	19,906	10
House 10	Gas instantaneous	Rinnai	5.1	15,525	3
House 11	Solar, gas boosted	Solarhart	N/A	6,331	7
House 12	Gas HWS storage	Rheem	2.0	22,251	13
House 13	Gas HWS storage	Aquamax	5.0	16,778	N/A

House	HWS type	Brand	Energy Rating	Estimated energy use (MJ/yr)	Estimated age (Yrs)
House 14	Electric storage	Rheem	N/A	14,035	12
House 15	Gas HWS storage	Aquamax	5.0	16,778	1
Average			**3.5**	**18,295**	**11**

Refrigerators

The comparative energy consumption figures (estimated annual energy use in kWh/yr) from the energy rating label of the fridges were reduced by 15% to adjust for Melbourne's climate and the adjusted figure is listed in Table 23. It was also assumed that after five years there would be a 1.5% increase in energy consumption per year due to degradation.

A review of the results from Table 23 show:

- Two door refrigerators varied from 2 to 5 stars, with the average being 3.5 stars.
- Annual energy consumption varied from 272 - 792 kWh/yr.
- The majority of refrigerators were aged 10 years or less.

In addition, House 2 had a chest freezer, but of an unknown brand so its efficiency could not be assessed. One bar refrigerator was also in use at House 13.

Table 23: Existing refrigerators

House	Type	Brand	Energy rating	Estimated energy use (kWh/yr)	Age (Yrs)
House 1	2 door refrigerator	Fisher & Paykel	4.5	432	5
House 2	1 door refrigerator	Fisher & Paykel	5.5	295	6
House 3	2 door refrigerator	LG	2	618	7
House 4	2 door refrigerator	Fisher & Paykel	3.5	496	2
House 5	2 door refrigerator	LG	4	370	5
House 6	2 door refrigerator	Samsung	3.5	469	9
House 7	2 door refrigerator	Westinghouse	4	410	5
House 8	2 door refrigerator	Fisher & Paykel	3.5	479	3
House 9	2 door refrigerator	Westinghouse	4	396	5
House 10	2 door refrigerator	Kelvinator	3.5	454	7
House 11	2 door refrigerator	Westinghouse	2.5	648	8
House 12	2 door refrigerator	Electrolux	5	345	1
House 13	2 door refrigerator	Kelvinator	3.5	454	7
House 13	1 door bar refrigerator	Westinghouse	1.5	272	10
House 14	2 door refrigerator	Bosch	3	582	10
House 15	2 door refrigerator	Fisher & Paykel	2	792	18
Average			**3.5**	**470**	**7**

Clothes washers

The calculations for clothes washers were based upon the following assumptions:

- average five wash cycles per week, which reflects current average Victorian usage
- 60 % of washes used the cold water cycle, with the remainder on a warm wash cycle, and
- 131 MJ/yr of electricity used for spinning and pumping.

The gas required to heat hot water was calculated using the efficiencies of hot water systems installed to replace existing hot water systems as part of the hot water upgrade. This was done because the payback period for replacing hot water systems was much shorter than that of replacing clothes washers, so it was assumed that hot water systems would be replaced before clothes washers. In Houses 4, 10, 13 and 15 the upgraded hot water system was a gas boosted solar hot water system, which explains why annual gas consumption for water heating is low. The complete list of the type of replacement hot water systems modelled at each house can be found in Table 30.

The results from Table 24 show:

- Clothes washers in Houses 8, 11, 14 and 15 had a cold water only connection and hence heated water internally with an electric element. Thus there was no associated gas consumption.
- Four houses had top loaders and the rest had front loaders – at 73%, the penetration of front loaders for this sample of houses is somewhat above the average penetration from front loading machines.
- Half of the clothes washers were less than five years old.
- Star ratings ranged from 2 to 4.5 stars and the average was 3.5 stars. The high average star rating reflects the high penetration of front loading machines.
- Estimated gas usage, to heat the hot water the clothes washers used, ranged from 81 MJ to 602 MJ/yr.

Table 24: Existing clothes washers

House	Type	Brand	Energy rating	Estimated gas use (MJ/yr)	Estimated electricity use (MJ/yr)	Age (Yrs)
House 1	Front loader	Ariston	3	299	131	7
House 2	Front loader	LG	4.5	201	131	4
House 3	Top loader	Simpson	2	499	131	5
*House 4	Front loader	LG	4	81	131	2
House 5	Top loader	Hoover	N/A	602	131	16
House 6	Top loader	Fisher&Paykel	N/A	479	131	15

House	Type	Brand	Energy rating	Estimated gas use (MJ/yr)	Estimated electricity use (MJ/yr)	Age (Yrs)
House 7	Front loader	Ariston	3	377	131	1
House 8	Front loader	Miele	3.5	0	292	3
House 9	Front loader	Simpson	3	334	131	5
*House 10	Front loader	Whirlpool	3	133	131	1
House 11	Front loader	Asko	4.5	0	271	5
House 12	Front loader	LG	4	137	131	5
*House 13	Top loader	Fisher&Paykel	N/A	160	131	12
House 14	Front loader	Bosch	4	0	294	3
*House 15	Front loader	Westinghouse	4	0	315	6
Average			**3.5**	**300**	**174**	**6**

* = gas boosted solar hot water system

Dishwashers

The annual electricity use figures (kWh/yr) displayed in the Table 25 have been adjusted to reflect an average of 3.7 uses per week, the current Victorian average.

The dishwasher results show:

- Nine of the 15 houses had dishwashers.
- Two thirds of the dishwashers were less than five years old.
- Star ratings ranged from 2.5 to 4.0 stars and the average was 3.1 stars.
- Estimated electricity usage ranged from 119-200 kWh/yr, or by 40%.

Table 25: Existing dishwashers

House	Brand	Energy rating	Estimated electricity use (kWh/yr)	Age (Yrs)
House 1	Bosch	2.5	187	7
House 2	Bosch	4.0	119	2
House 9	Asko	2.5	177	4
House 10	Electrolux	3.5	123	1
House 11	Miele	3.0	171	2
House 12	Electrolux	3.5	123	3
House 13	AEG	2.5	166	10
House 14	Bosch	3.5	141	2
House 15	Asko	2.5	200	10
Average		**3.1**	**156**	**5**

Computers and televisions

Computers and televisions (TVs) can add significantly to the energy consumption of a household and there is considerable variation in their energy consumption. However, computers are not currently energy rated and, at the time this study was undertaken, energy labelling for TVs had not commenced[13], meaning that it was not possible to assess the energy efficiency of existing TVs.

The energy audits identified that:

- Eight houses had the older technology cathode ray tube (CRT) televisions.
- Four homes had liquid crystal display (LCD) televisions.
- Two homes had Plasma televisions.

For the homes with the CRT and LCD televisions, little or no energy savings would be made by upgrading them to alternative televisions, although the recent introduction to the market of a range of light-emitting diode (LED) backlit LCD TVs may generate reasonable savings. Replacement of the two plasma televisions with high efficiency LCD TVs would probably generate worthwhile savings, although, as these TVs are not that old, the payback periods for upgrading before the end of their useful life would be relatively long. TV upgrades are examined in more detail in the next section.

Regarding computers, the energy audits found 12 of the 15 homes had computers; all but one were personal computers (PCs) with relatively efficient LCD monitors, or laptops with integrated LCD monitors. The exception was an iMac computer which has the computer and the CRT monitor integrated as one unit.

As newer desktop computers invariably use more energy than older computers, mainly due to the impact of their enhanced graphics cards, there is no opportunity to save energy by upgrading the computer processing unit. For laptops, there is no significant difference in the energy requirements of older laptops and newer machines. The only possible area for energy saving is upgrading CRT monitors to LCD monitors, but this could not be done for the single CRT monitor as it is not a stand-alone monitor. Consequently there are no potential energy savings from upgrading computers in these houses.

[13] Mandatory energy labelling of TVs commenced in Australia in October 2009, making it possible to assess the energy performance of new TVs. Energy labelling for computers and computer monitors is currently under consideration.

4.2.2 Impact of appliance upgrades

Introduction

This section examines the modelled impact of upgrading the existing appliances described in the previous section to high efficiency appliances. In this section, tables list both the full upgrade cost and associated payback period, and the age adjusted upgrade cost and associated payback. The way in which these have adjusted figures have been calculated is described in the methodology section.

Cost curves were constructed for the different appliance upgrades to provide a better understanding of the cost effectiveness and impact of the modelled upgrades. To develop the costs curves, individual measures were first ranked by payback period. These payback points were then mapped against the cumulative GHG savings, starting with the upgrade with the shortest payback period. These curves are displayed below and clearly show the extent of variation in the feasibility and effectiveness of the different upgrade actions. Age adjusted upgrade costs and payback periods were used when compiling cost curves for appliance upgrades as it was felt that this would give the most accurate impression of the cost effectiveness of these upgrades in comparison to the building shell upgrades.

The analysis of the each type of appliance upgrade will include the following information:

- list of assumptions used when modelling the appliance upgrade
- detailed table setting out the impact of the appliance upgrade ranked by adjusted payback, and
- cost curve to show effectiveness and impact of modelled upgrade.

Heaters

The assumptions used when modelling the replacement of existing heaters were as follows:

- All gas heaters were replaced with the same type of heater with the exception of gas wall furnaces, which were replaced with gas convection heaters because a high efficiency wall furnace could not be found.
- Gas central heater ducts were not upgraded as a visual inspection suggested that all were in reasonably good condition.
- The reverse cycle window/wall box air conditioner installed at House 6 was replaced with a high efficiency gas convection heater because the house already had gas connected for the stove. It was also assumed that upgrading to efficient gas heating would lead to greater GHG savings and similar energy cost savings as an efficient reverse cycle air conditioner upgrade.
- Installation costs were based upon a range of factors, such as type of flue required, whether an electrician would be needed, and if any minor

works were required to patch up walls etc. after the removal of the old heater

- Upgrades were undertaken in the modelling at all houses, with the exceptions of Houses 3 and 10 as they already had relatively efficient gas central heaters.

The upgrade cost for each house is listed in Table 26. The results from the heater upgrades are also set out in Table 26 and Figure 9. The main findings are the following:

- The heater upgrades resulted in an average annual energy cost saving of $188/yr and GHG saving of 980 kg/yr, with an *adjusted* payback period of 3.1 years.
- Upgrades undertaken at houses with gas central heating resulted in very large savings, especially in the case of Houses 8 and 13. Both of these had inefficient heaters; House 13 also had the largest floor area and House 8 the least efficient building shell of any house in the study. Heater upgrades at the four houses with central heating resulted in an average annual cost saving of $438/yr and GHG saving of 2,222 kg/yr, with an *adjusted* payback of 1.4 years.
- Heater upgrades undertaken at the nine houses with space heating resulted in an average annual cost saving of $77/yr, GHG saving of 427 kg/yr and an *adjusted* payback of 7.5 years.
- All upgrades had an *adjusted* payback of seven years or less with the exception of three houses. Those three either needed two heaters upgraded and so had a higher upgrade cost, or already had a reasonably efficient heater installed.

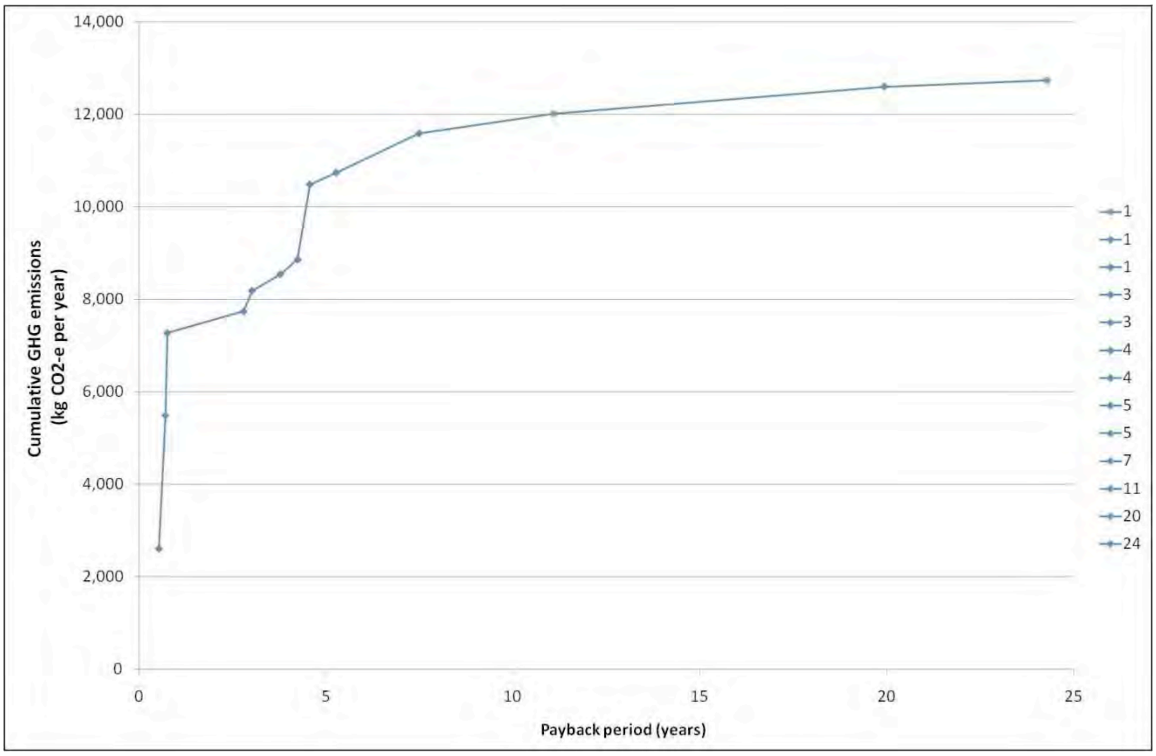
The implication is that it makes sense to upgrade heaters in many of the houses. This upgrade has the potential to deliver significant GHG savings and, if the adjusted capital cost is taken into account, the payback period for replacement is mostly seven years or less.

Table 26: Impact and payback of heater upgrades ranked by payback period

House	Age of existing system/s (Yrs)	Heater conversion efficiency upgrade	Estimated cost of upgrade ($)	Adjusted cost of upgrade ($)	Estimated energy savings– (MJ/yr)	Estimated energy cost savings ($/yr)	Estimated GHG savings (kg/yr)	Payback (years)	Adjusted payback (years)
House 13*	20	65% to 91%	$2,715	$272	46,676	$513	2,606	5.3	0.5
House 8*	17	65% to 91%	$2,650	$398	51,607	$568	2,881	4.7	0.7
House 11*	20	65% to 91%	$2,650	$265	31,896	$351	1,781	7.6	0.8
House 4	30	65% to 87%	$2,569	$257	8,359	$92	467	28	2.8
House 14	19	65% to 83%	$2,660	$266	8,021	$88	448	30	3.0
House 12	19	71% to 83%	$2,660	$266	6,406	$70	358	38	3.8
House 7	25	71% to 83%	$2,660	$266	5,704	$63	318	42	4.2
House 1*	9	65% to 91%	$2,650	$1,458	29,044	$319	1,622	8.3	4.6
House 5	25	71% to 83%	$2,660	$266	4,590	$50	256	53	5.3
House 9	8 &30	71% to 87%	$4,809	$1,249	15,165	$167	847	29	7.5
House 2	15 &10	73% to 87%	$5,071	$941	7,719	$85	431	60	11
House 6	8	263% to 87%	$2,837	$1,091	-10,826	$55	586	52	20
House 15	10	82% to 87%	$2,269	$648	2,428	$27	136	85	24
House 3*	2	No upgrade	$0	$0	0	$0	0	N/A	N/A
House 10*	4	No upgrade	$0	$0	0	$0	0	N/A	N/A
Average	**16**		**$2,989**	**$588**	**15,907**	**$188**	**980**	**15.9**	**3.1**

*** = centrally heated house**

Figure 9: Cost curve for heater upgrades



Air conditioners

The assumptions used when modelling air conditioner upgrades were as follows:

- Evaporative air conditioners were not upgraded as they were considered already quite efficient[14].
- In all houses except House 6, existing split and window/wall box refrigerative air conditioners were upgraded to a 5 star cooling-only refrigerative air conditioner with an output of 7.1 kW, for a cost of $1,849.
- The existing window/wall box refrigerative air conditioner at House 6 was upgraded to a $999 6 star reverse cycle air conditioner with an output of 2.6 kW because the current unit only had an output of 2.4 kW. This was significantly smaller than those installed at the other five houses.
- Installation costs depended on individual circumstances at each house.
- Upgrades were undertaken at all six houses that had a refrigerative air conditioner installed.

The total cost of installation modelled for each house is listed below in Table 27.

[14] Some companies now have 'inverter' model evaporative coolers on the market, which could provide savings relative to conventional evaporative coolers. However, given the relatively low cooling requirement in Melbourne the savings are likely to be small and the paybacks quite long.

The results from the air conditioner upgrades are also set out in Table 27 and Figure 10. The main findings are:

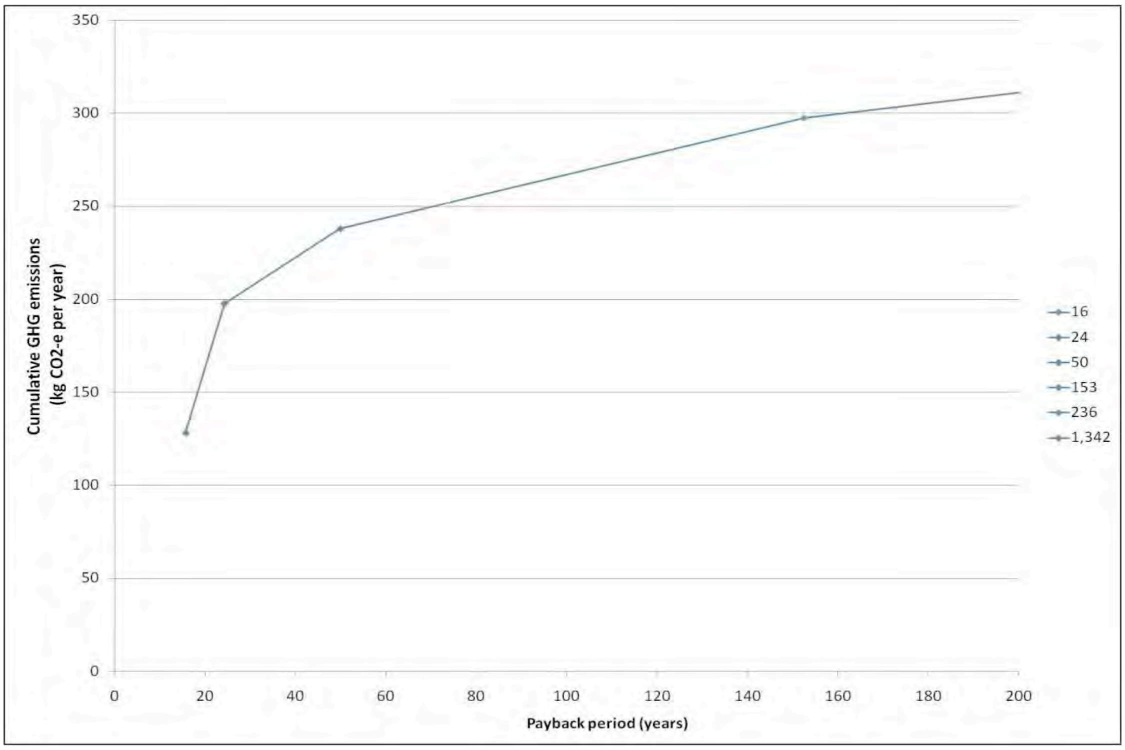
- The upgrade resulted in an average annual energy cost saving of $9/yr and a GHG saving of 56 kg/yr, with an *adjusted* payback period of 108 years.
- Houses 10, 11 and 14 had units that were 15 years or older and were assumed to be performing quite poorly due to degradation in performance over time. These units had the shortest payback periods, with an average of 24 years.
- The three houses with adjusted paybacks of 153 years and above all had units that were relatively new and were still reasonably efficient.

The implication is that, in some houses, it makes sense to upgrade old and inefficient air conditioners, especially when the adjusted cost is taken into account (e.g. when existing units are at or close to the end of their useful life). Overall however, the financial, GHG and energy savings are quite low from upgrading air conditioners. This partly reflects the relatively mild summers in Melbourne, but could also be a result of FirstRate5 under-estimating the total cooling load for houses. The weather data files used in FirstRate5 are based on older weather data, while it is generally agreed that summers are getting hotter – more days in excess of 30^{o}C and an increasing number of days of extreme heat when temperatures exceed 35^{o}C.

Table 27: Impacts and paybacks of air conditioner upgrades ranked by payback

House number	Age of existing unit (Yrs)	Efficiency upgrade	Estimated cost of upgrade ($)	Adjusted cost of upgrade ($)	Estimated energy savings (MJ/yr)	Estimated energy cost savings ($/yr)	Estimated GHG savings (kg/yr)	Payback (years)	Adjusted payback (years)
House 14	19	198% to 320%	$3,129	$313	422	$20	128	157	15.7
House 11	15	207% to 320%	$2,629	$263	228	$11	69	244	24
House 10	25	184% to 320%	$3,129	$313	133	$6	40	499	50
House 15	6	230% to 320%	$2,629	$1,416	196	$9	60	283	153
House 6	1	283% to 396%	$2,279	$877	79	$4	24	614	236
House 9	8	308% to 320%	$2,629	$2,427	38	$2	12	1,454	1,342
Average	**12**		**$2,737**	**$935**	**183**	**$9**	**56**	**317**	**108**

Figure 10: Cost curve for air conditioner upgrades



The cost curve above only shows the results of units with a payback period shorter than 200 years as the full range between the highest and lowest paybacks is too large.

Hot water systems

There were two upgrade scenarios analysed in regard to hot water systems (HWS). Firstly, the impact of replacing existing systems with high efficiency gas storage or gas instantaneous systems was analysed. Secondly, the impact of replacing HWS with gas boosted solar hot water was analysed. Both are examined below.

Efficient gas hot water systems

The assumptions used when modelling the replacement of existing HWS with efficient gas HWS were as follows:

- Gas storage was replaced by more efficient gas storage, with the new system being a 5 star 135 litre HWS using 16,778 MJ/yr, based on an average of 150 litres of hot water used per day.
- Gas instantaneous systems upgrades were not considered for houses with gas storage HWS currently installed as there is a considerable cost associated with upgrading the gas line to allow for the installation of an instantaneous system.

- The gas instantaneous system in House 10 was replaced by a more efficient gas instantaneous system, with the new system being a 5.5 star system using 14,800 MJ/yr, based on an average of 150 litres of hot water used per day.
- A gas instantaneous system was not installed in House 7 (where the system currently installed was estimated to be 30 years old) as a gas plumber advised that the cost to upgrade the gas line to allow for the installation of a modern instantaneous system would be considerable. Instead a high efficiency gas storage system was installed.
- The electric storage system in House 14 was replaced with a 5 star gas storage system as there was natural gas already supplied to the property. Gas instantaneous was not considered as the cost to upgrade the gas lines to allow for the installation was considerable.
- The existing HWS was only replaced if the new system was more efficient.

Table 28: Impacts and payback of replacing hot water systems with efficient gas systems ranked by payback periods

House	Existing HWS	Age of existing HWS (Yrs)	Energy rating of existing HWS	Upgrade cost ($)	Adjusted upgrade cost ($)	Estimated energy savings (MJ/yr)	Estimated energy cost saving ($/yr)	Estimated GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 14	Electric storage	12	N/A	$2,029	$203	-2,743	$127	3,328	16	2.0
House 5	Gas HWS storage	17	2	$1,277	$128	5,474	$60	306	21	2.1
House 12	Gas HWS storage	13	2	$1,277	$128	5,474	$60	306	21	2.1
House 2	Gas HWS storage	15	3.2	$1,277	$128	3,291	$36	184	35	3.5
House 8	Gas HWS storage	13	3.2	$1,277	$128	3,182	$35	178	36	3.6
House 6	Gas HWS storage	12	3.2	$1,277	$128	3,128	$34	175	37	3.7
House 7	Gas instantaneous	30	3	$1,277	$128	2,999	$33	167	39	3.9
House 9	Gas HWS storage	10	3.2	$1,277	$213	3,128	$34	175	37	6.2
House 3	Gas HWS storage	10	3.3	$1,277	$213	3,038	$33	170	38	6.4
House 1	Gas HWS storage	6	3.2	$1,277	$639	3,128	$34	175	37	18.6
House 4	Gas HWS storage	4	3.9	$1,277	$851	1,881	$21	105	62	41
House 10	Gas instantaneous	3	5.1	$1,577	$1,183	700	$13	73	125	94
House 11	Solar, gas boosted	7	N/A	$0	$0	0	$0	0	NA	NA
House 13	Gas HWS storage	5	5	$0	$0	0	$0	0	NA	NA
House 15	Gas HWS storage	1	5	$0	$0	0	$0	0	NA	NA
Average		**11**	**3.5**	**$1,365**	**$339**	**2,723**	**$43**	**445**	**31**	**7.9**

Table 28 shows that 12 existing HWS could be upgraded to high efficiency gas systems. The main results are the following:

- The replacement of gas storage systems in ten houses resulted in average annual energy costs savings of $39/yr and average GHG savings of 197 kg/yr, with an average *adjusted* payback period of 7.1 years.
- The instantaneous HWS replaced in House 10 resulted in an annual energy cost saving of $13/yr and a GHG saving 73kg/yr, with an *adjusted* payback period of 94 years. The existing system was already quite efficient.
- The instantaneous HWS replaced in House 7 with an efficient gas storage system resulted in an annual energy cost saving of $33/yr and a GHG saving 167kg/yr, with an *adjusted* payback period of 4 years. The existing system was the oldest system found and this resulted in a low adjusted payback period.
- The replacement of the electric storage HWS by a 5 star gas storage system resulted in an annual energy cost saving of $127/yr and GHG saving of 3,328 kg/yr, with an *adjusted* payback period of two years.
- The average *adjusted* payback across all gas HWS was 7.9 years.

The implication is that it would be sensible to replace many of the currently installed HWSs with efficient gas HWSs. This is especially the case for systems that are nearing the end of their life or are off-peak electric storage systems.

Gas boosted solar hot water system

The assumptions used when modelling the replacement of existing HWS with gas boosted solar HWS are as follows:

- All HWS are replaced with a gas boosted solar HWS with the exception of House 11 which already has such a system installed.
- Solar HWS systems would consist of a 3 star gas storage system and flat plate solar collectors. An average solar gain of 70% per year was chosen for the analysis.
- 65 kWh/yr of electricity would be used for pumping.
- Estimated monies from the sale of Renewable Energy Certificates and Victorian Energy Efficiency Certificates, and state and federal government rebates was deducted from the total cost of installation to arrive at the full upgrade cost.
- Adjusted costs were calculated according to the method set out in the methodology section. A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water

heater (SWH) upgrade due to the significant difference between a SWH and a high efficiency gas water heater.

Table 29: Impacts and payback of replacing hot water systems with gas boosted solar hot water ranked by payback period

House	Existing HWS	Age of existing HWS (Yrs)	Energy rating of existing HWS	Upgrade cost ($)	Adjusted upgrade cost ($)	Estimated energy savings (MJ/yr)	Estimated energy cost saving ($/yr)	Estimated GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 14	Electric storage	12	N/A	$3,809	$1,780	7,704	$234	3,854	16	7.6
House 5	Gas HWS storage	17	2	$3,673	$2,396	15,920	$167	902	22	14.4
House 12	Gas HWS storage	13	2	$3,673	$2,396	15,920	$167	902	22	14.4
House 2	Gas HWS storage	15	3.2	$3,673	$2,396	13,738	$143	780	26	16.8
House 8	Gas HWS storage	13	3.2	$3,673	$2,396	13,629	$141	774	26	16.9
House 6	Gas HWS storage	12	3.2	$3,673	$2,396	13,574	$141	771	26	17.0
House 7	Gas instantaneous	30	3	$3,673	$2,396	13,445	$139	693	26	17.2
House 9	Gas HWS storage	10	3.2	$3,673	$2,609	13,574	$141	771	26	18.5
House 3	Gas HWS storage	10	3.3	$3,673	$2,609	13,484	$140	766	26	18.7
House 1	Gas HWS storage	6	3.2	$3,673	$3,035	13,574	$141	771	26	22
House 4	Gas HWS storage	4	3.9	$3,673	$3,247	12,328	$127	701	29	26
House 13	Gas HWS storage	5	5	$3,673	$3,141	10,446	$106	596	35	30
House 10	Gas instantaneous	3	5.1	$3,673	$3,279	9,193	$103	526	36	32
House 15	Gas HWS storage	1	5	$3,673	$3,567	10,446	$106	596	35	34
House 11	Solar, gas boosted	7	N/A	$0	$0	0	$0	0	NA	NA
Average		**11**	**3.5**	**$3,683**	**$2,689**	**12,641**	**$143**	**957**	**26**	**18.8**

Table 29 shows that 14 existing HWS could be upgraded to gas boosted solar HWS. The main results from the solar hot water upgrade are the following:

- The replacement of gas storage and gas instantaneous systems in 13 houses resulted in average annual energy costs saving of $136/yr and average GHG savings of 735kg/yr, with an average *adjusted* payback period of 20.3 years.
- The replacement of the electric storage HWS by a gas boosted solar HWS resulted in an annual energy cost saving of $234/yr and GHG saving of 3,854 kg/yr, with an *adjusted* payback period of 7.6 years.
- The average *adjusted* payback across the 15 houses was 18.8 years.

The implication is that the method used to calculate the adjusted upgrade cost and payback for the gas boosted solar HWS upgrade generally did not result in adjusted paybacks equivalent or shorter than the paybacks calculated for the high efficiency gas HWS upgrade. Houses 4, 10, 13 and 15 were exceptions to this rule. The solar HWS upgrade had a shorter payback in these four houses because the existing HWSs were already efficient and relatively new.

Cost curve for hot water system upgrades

Compiling the cost curve for hot water system upgrade involved choosing the upgrade with the shortest adjusted payback for each house. Table 30 sets out the hot water system upgrade chosen for each house.

In the case of Houses 4, 10, 13 and 15 the modelled upgrade with the shortest payback was the gas boosted solar HWS upgrade. In all other houses the high efficiency gas HWS upgrade resulted in a shorter payback. It can be seen from Figure 11 that all gas HWS upgrades, with the exception of the upgrade at House 1, had adjusted paybacks of six years or less. The houses with payback periods of 19 years and above either received the solar HWS upgrades or had a relatively new existing gas HWS upgraded to a 5 star gas storage HWS. The solar HWS upgrade delivered a significant level of GHG and energy cost savings but the extra cost of the system meant that this upgrade had a much longer payback period.

Figure 11: Cost curve for hot water upgrades

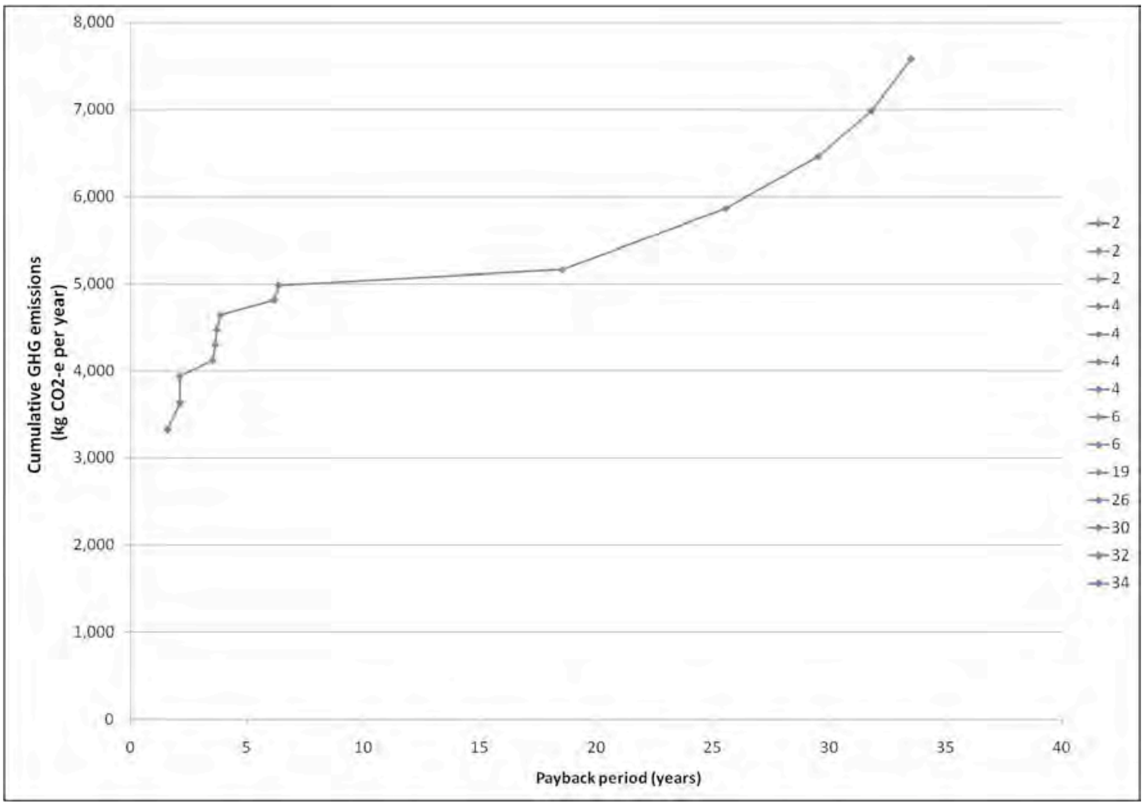


Table 30: Impacts of hot water system upgrades ranked by payback

House Number	Type of HWS upgrade	Energy rating of existing HWS	Age of existing HWS (Yrs)	Cost of upgrade ($)	Estimated energy cost savings ($/yr)	Estimated GHG savings (kg/yr)	Adjusted payback (years)
House 14	Gas HWS	N/A	12	$203	$127	3,328	2.0
House 12	Gas HWS	2	13	$128	$60	306	2.1
House 5	Gas HWS	2	17	$128	$60	306	2.1
House 2	Gas HWS	3.2	15	$128	$36	184	3.5
House 8	Gas HWS	3.2	13	$128	$35	178	3.6
House 6	Gas HWS	3.2	12	$128	$34	175	3.7
House 7	Gas HWS	3	30	$128	$33	167	3.9
House 9	Gas HWS	3.2	10	$213	$34	175	6.2
House 3	Gas HWS	3.3	10	$213	$33	170	6.4
House 1	Gas HWS	3.2	6	$639	$34	175	18.6
House 4	Solar HWS	3.9	4	$3,247	$127	701	26
House 13	Solar HWS	5	5	$3,141	$106	596	30
House 10	Solar HWS	5.1	3	$3,279	$103	526	32

House Number	Type of HWS upgrade	Energy rating of existing HWS	Age of existing HWS (Yrs)	Cost of upgrade ($)	Estimated energy cost savings ($/yr)	Estimated GHG savings (kg/yr)	Adjusted payback (years)
House 15	Solar HWS	5	1	$3,567	$106	596	34
Average		**3.5**	**11**	**$1,090**	**$67**	**542**	**16.2**

Refrigerators

The assumptions used when modelling the replacement of existing refrigerators were as follows:

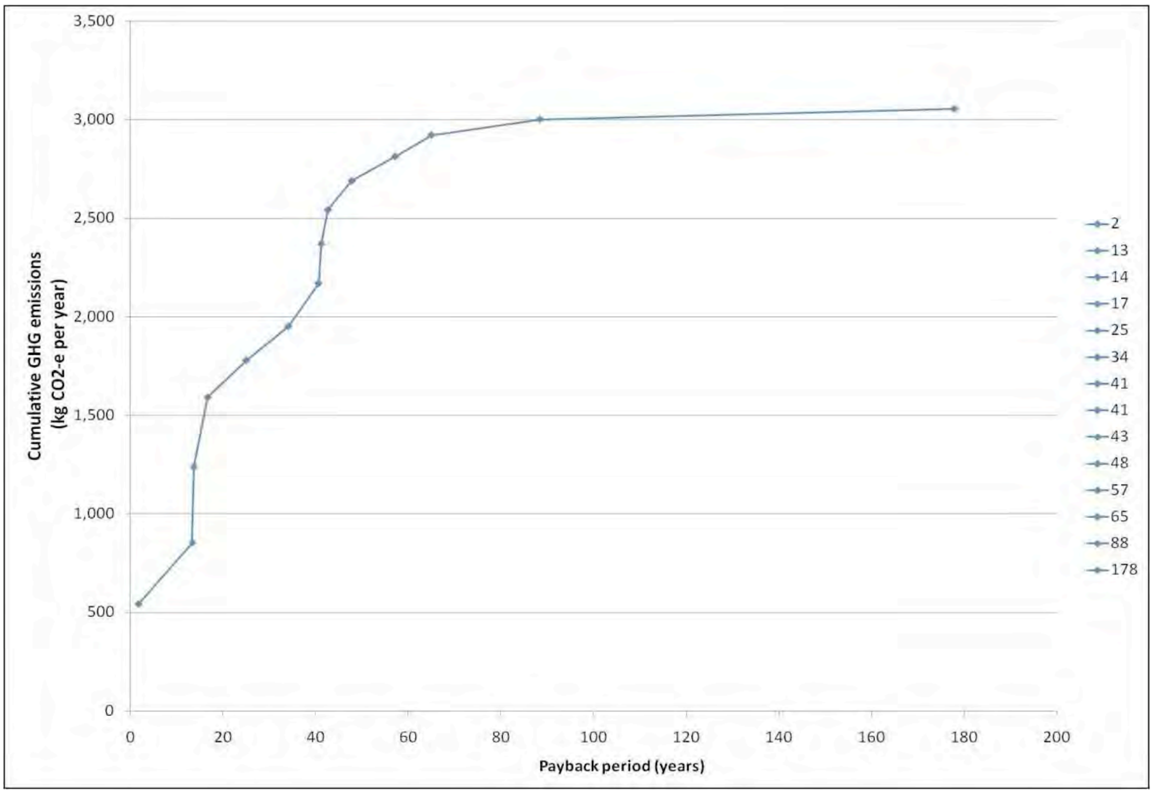
- All comparative energy consumption figures (kWh/yr) from the energy rating labels were reduced by 15% to account for Melbourne's climate.
- Energy consumption of existing refrigerators older than 5 years was increased by 1.5 % for every year in age they exceeded 5 years as a result of assumed degradation.
- All two door refrigerators, found in all but one house, were replaced with a high efficiency, 5 star, 420 litre two door refrigerator. This refrigerator was chosen as it was the closest two door 5 star refrigerator to the sales weighted average of 370 litres. The replacement refrigerator used 297 kWh/yr once adjusted for the Melbourne climate.
- The replacement cost was $1,557.
- Refrigerators were only replaced when the replacement was more energy efficient than the existing refrigerator.
- A high-efficiency one door refrigerator and chest freezer at one home were not replaced as the refrigerator was already efficient and no information could be found on the freezer.
- An additional bar refrigerator in one home was not replaced as the proposed replacement, though having a higher star rating, was larger and used approximately the same energy as the existing appliance.

Table 31: Impacts and payback of replacing refrigerators ranked by payback

House number	Age of existing refrigerator (Yrs)	Energy rating of existing refrigerator	Estimated energy savings (kWh/yr)	Estimated energy cost saving ($/yr)	GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 15	18	2	496	$84	542	18	1.8
House 14	10	3	285	$49	312	33	13.4
House 11	8	2.5	352	$60	385	26	13.8
House 3	7	2	321	$55	352	28	16.9
House 6	9	3.5	172	$29	188	53	25
House 10	7	3.5	158	$27	173	58	34

House number	Age of existing refrigerator (Yrs)	Energy rating of existing refrigerator	Estimated energy savings (kWh/yr)	Estimated energy cost saving ($/yr)	GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 4	2	3.5	199	$34	218	46	41
House 8	3	3.5	183	$31	200	50	41
House 13	7	3.5	158	$27	173	73	43
House 1	5	4.5	135	$23	148	68	48
House 7	5	4	113	$19	124	81	57
House 9	5	4	99	$17	109	92	65
House 5	5	4	73	$12	80	125	88
House 12	1	5	48	$8	53	189	178
House 2	6	5.5	0	$0	0	N/A	N/A
Average	**7**	**3.6**	**199**	**$34**	**218**	**47**	**29**

Figure 12: Cost curve for refrigerators



The results above show:

- Upgraded refrigerators could create energy and greenhouse savings in 14 of the 15 houses.
- The average annual energy savings were 199 kWh/yr and $34/yr in energy costs, with 218 kg/yr in GHG savings.
- Average *adjusted* payback period was 29 years but much shorter in cases where the refrigerator was much older or had a low star rating.

- The scope for energy savings was reduced as many of the refrigerators were already reasonably efficient, averaging 3.5 stars – this is somewhat higher than average for Victorian housing stock.

The implication is that replacing the refrigerators in these homes would lead to energy and greenhouse savings but overall relatively small energy cost savings. It makes sense to replace old refrigerators nearing the end of their life with new high efficiency models as the adjusted payback period is quite short. In situations where the refrigerator is relatively new or already quite efficient it makes sense to wait until its end of the life before buying a new high efficiency model.

Clothes washers

The assumptions used when modelling the replacement of existing clothes washers were as follows:

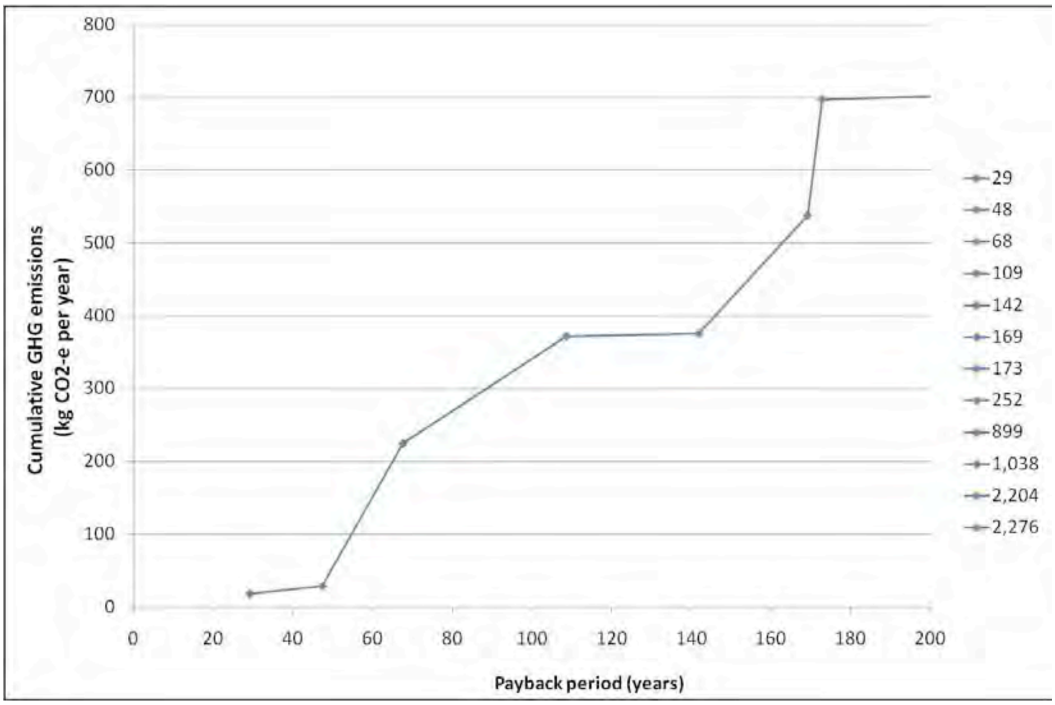
- All clothes washers were replaced by a high efficiency, 4 star, 7 kg capacity front loading washer with a hot and cold water connection. This capacity is slightly bigger than the sales weighted average but a suitable model with hot/cold connection smaller than this could not be found. The choice of a front loader with a hot/cold connection was important to ensure that any heated water was undertaken by the external gas/solar water heater, rather than heated internally with an electric element.
- The replacement clothes washer cost $1,034.
- Clothes washers were only replaced when the replacement was more energy efficient than the existing washer.
- The energy savings from the washer replacement was based on the amount of hot water saved, as it was assumed that the energy required for spinning and pumping was essentially the same for all machines. In practice this would vary, but the energy savings are likely to be very small.
- The washer was assumed to be used five times weekly, with 60% of washes on a cold wash cycle and the remainder on a warm wash cycle.
- The gas required to heat hot water was calculated using the efficiencies of hot water systems installed to replace existing hot water systems. This was done because the payback period for replacing hot water systems was much shorter than that of replacing clothes washers, so it was assumed that hot water systems would be replaced before clothes washers. The complete list of the type of replacement hot water systems installed at each house can be found in Table 30.
- The clothes washers in Houses 5, 6 and 13 could be found in the historical appliance spreadsheet supplied by Sustainability Victoria but there was no energy rating recorded, most probably because of the age of the units.

Table 32: Impacts and payback of replacing clothes washers ranked by payback period

House	Age of existing unit (Yrs)	Energy rating of existing unit	Estimated gas savings (MJ/yr)	Estimated electricity savings (MJ/yr)	Energy cost saving ($/yr)	GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 5*	16	N/A	321	0	$3.53	18	293	29
House 6*	15	N/A	198	0	$2.18	11	475	48
House 15	6	4	-94	184	$7.63	196	135	68
House 11	5	5	-94	140	$5.55	147	186	109
House 13*	12	N/A	66	0	$0.73	4	1,419	142
House 14	3	4	-281	163	$4.58	162	226	169
House 8	3	4	-281	160	$4.48	160	231	173
House 3*	5	2	218	0	$2.39	12	432	252
House 7	1	3	96	0	$1.05	5	981	899
House 9	5	3	53	0	$0.58	3	1,780	1,038
House 10	1	3	39	0	$0.43	2	2,404	2,204
House 1	7	3	17	0	$0.19	1	5,463	2,276
House 2	4	5	0	0	$0.00	0	N/A	N/A
House 4	2	4	0	0	$0.00	0	N/A	N/A
House 12	5	4	0	0	$0.00	0	N/A	N/A
Average	**6**	**3.5**	**21**	**162**	**$3**	**60**	**372**	**195**

* = top loader

Figure 13: Cost curve for clothes washer upgrades



The cost curve above only shows the results of clothes washers with a payback period shorter than 200 years as the full range between the highest and lowest paybacks is too large.

The results above show:

- Upgrading clothes washers in 12 of the 15 houses created energy and GHG savings.
- Clothes washers with a payback period of 252 years or less were either old top loaders or ones that internally heat water with an electric element.
- Four clothes washers that heat water internally produced much higher GHG savings than systems that are connected to gas hot water due to the associated electricity usage.
- Upgrading the seven clothes washers with the shortest payback periods resulted in 97% of the GHG savings.
- It was not sensible to consider upgrading in houses where the adjusted payback was in the thousands of years.
- Average gas savings were small at 21 MJ/yr, with average electricity saving at 162 MJ/yr.
- Average annual energy cost savings were $3/yr, with 60 kg/yr GHG savings.
- The average adjusted payback period for clothes washers was 195 years.
- Water cost savings were also available, especially when switching from a top loader to a water/energy efficient front loader, and would likely be larger than the energy cost savings, therefore reducing the overall payback period.
- The scope for efficiency savings was reduced as many of the clothes washers were already reasonably efficient, averaging 3.5 stars.

The implication is that replacing the clothes washers in these homes would lead to only a small energy and GHG savings, and almost no energy cost savings. The replacement of the clothes washers could not be justified on financial grounds or on energy savings alone, as the payback periods all vastly exceed the operating life of the washers. The results support the position that, where possible, it is better to avoid clothes washers that heat water internally.

Dishwashers

The assumptions used when modelling the replacement of existing dishwashers were as follows:

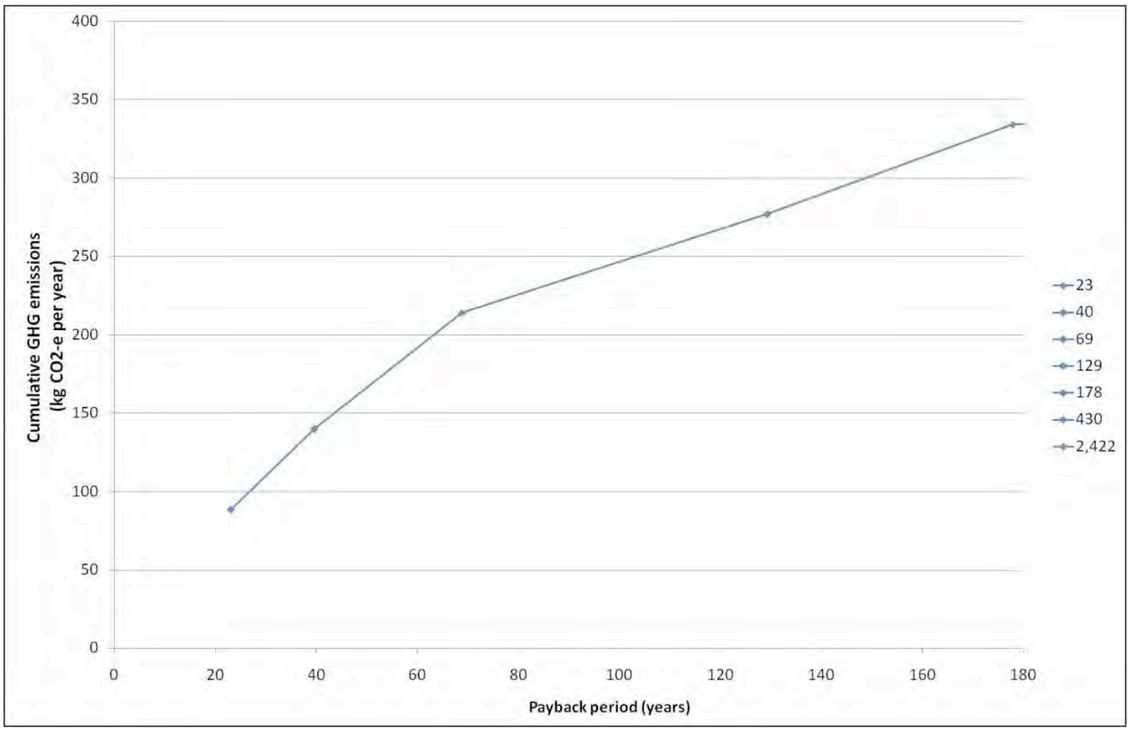
- Dishwashers were used on average 3.7 times per week, reflecting the Victorian average

- All were replaced by a high efficiency, 4 star, 14 setting capacity dishwashers
- Replacement dishwashers cost $1,899
- Dishwashers were only replaced when the replacement was more energy efficient than the existing washer.

Table 33: Impacts and payback of replacing dishwashers ranked by payback

House	Age of existing unit (Yrs)	Energy rating of existing unit	Estimated energy savings (kWh/yr)	Estimated energy cost saving ($/yr)	GHG saving (kg/yr)	Payback (years)	Adjusted payback (years)
House 15	10	2.5	81	$14	88	138	23
House 13	10	2.5	47	$8	51	237	40
House 1	7	2.5	68	$12	74	165	69
House 9	4	2.5	58	$10	63	194	129
House 11	2	3	52	$9	57	213	178
House 14	2	3.5	22	$4	24	515	430
House 10	1	3.5	4	$1	5	2,642	2,422
House 2	2	4	0	$0	0	N/A	N/A
House 12	3	3.5	0	$0	0	N/A	N/A
Average	**5**	**3.1**	**47**	**$8**	**52**	**236**	**135**

Figure 14: Cost curve for dishwasher upgrades



The cost curve above only shows the results for dishwashers with a payback shorter than 180 years as the full range between the highest and lowest paybacks is too large.

The results above show:

- Upgrading dishwashers in seven of the nine houses would create energy and greenhouse savings.
- Older dishwashers had a shorter payback period as they tended to be lower efficiency units, but also due to the manner in which adjusted payback was calculated.
- Average annual savings were reasonably small at 47 kWh/yr, $8/yr in energy costs and 52 kg/yr in GHG emissions.
- The average *adjusted* payback period was 135 years.
- Annual water savings of around 500 litres would also add around $1 to the cost savings of the appliance upgrade, and slightly reduce the payback period.
- Scope for efficiency savings was reduced as many of the dishwashers were already reasonably efficient, averaging 3.1 stars.

The implication is that replacing the dishwashers in these homes would lead to a small energy, energy cost and GHG savings. The replacement of the dishwashers could not be justified on financial grounds, as the payback periods all vastly exceed the operating life of the washers. The general finding is that when the appliance reaches the end of its operating life it should be upgraded with a high efficiency model.

Lighting

The assumptions used when modelling the lighting upgrades were as follows:

- Inefficient incandescent lamps will no longer be available due to the Commonwealth Government's import ban introduced in February 2009, followed by the implementation of minimum energy performance standards (MEPS) for incandescent lamps in November 2009. Thus, for this analysis it was assumed that any incandescent lighting would be the more efficient 240 volt halogen lamps, which comply with MEPS and use around 30% less energy. This reduces the scope of the savings compared to the old style incandescent lamps. Mains voltage halogen lamps (28W, 42W, 53W and 72W) are now available on the market as direct replacements for inefficient incandescent lamps which are no longer available.
- Lamps were assumed to be used for 2.2 hours per day in living areas and 1 hour per day in non-living areas.

- The additional life of the CFL versus incandescent or halogen lamps was not factored in. The use of longer life CFL lamps means that lamps are replaced less often and can result in further operational savings.
- Incandescent lamps (assumed to be 240 volt halogen lamps) and low voltage halogen downlights were replaced by appropriate compact fluorescent lamps (CFL).
- Non-dimmable incandescent lamps were replaced with CFLs, with the cost as that of the new CFL globe - $5.
- Dimmable incandescent lights were replaced with a dimmable CFL, with the cost as that of the new CFL globe - $30.
- Non-dimmable halogen lights were replaced with a CFL lamp and a new fitting, with the cost for the new CFL globe, fitting and labour - $38.
- Dimmable halogen lamps were replaced with a dimmable CFL lamp and fitting, with the cost for the globe, fitting and labour at $63.

Table 34 sets out the lamps that could be upgraded at each house. In three houses no upgrades were required as the existing lighting was already efficient.

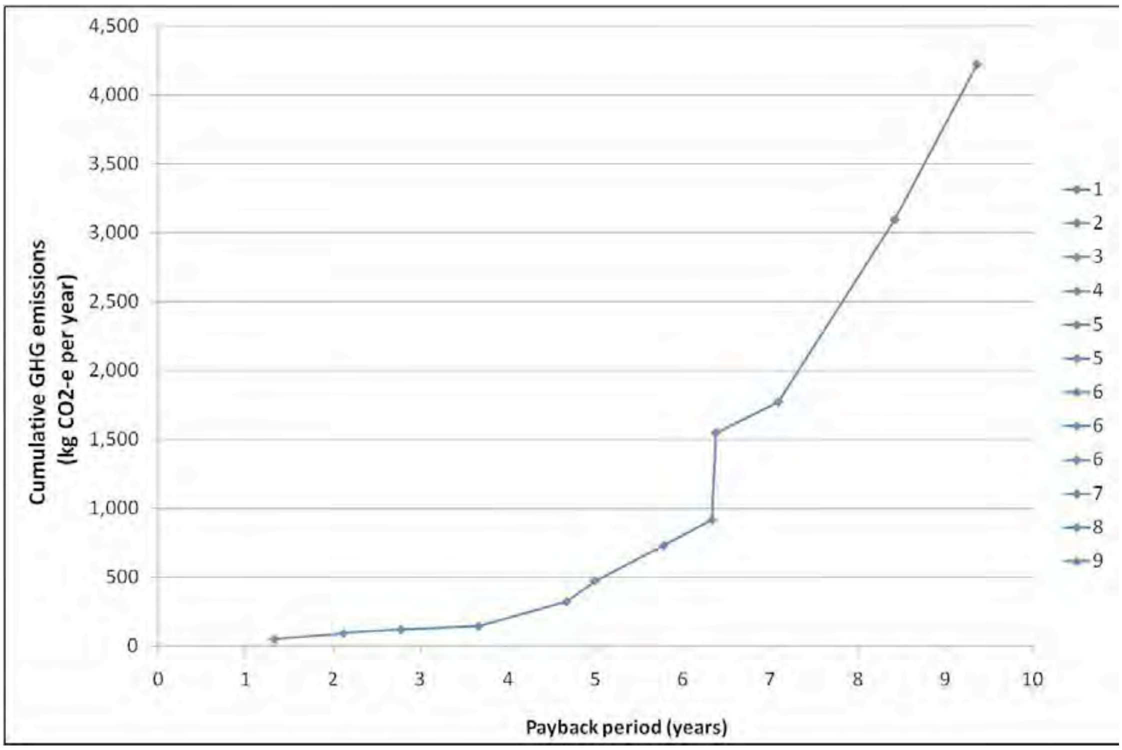
Table 34: Potential lighting upgrades

House	Incandescent	Dimmable incandescent	Low voltage halogen downlights	Dimmable halogens	Total
House 1	6	0	9	4	19
House 2	2	0	0	0	2
House 3	0	0	0	0	0
House 4	5	3	0	0	8
House 5	0	0	0	0	0
House 6	0	0	0	0	0
House 7	3	0	3	0	6
House 8	14	0	3	0	17
House 9	1	0	6	0	7
House 10	2	0	0	0	2
House 11	0	0	10	20	30
House 12	0	2	5	0	7
House 13	10	0	31	8	49
House 14	3	0	0	0	3
House 15	3	0	0	0	3
Average	**3.3**	**0.3**	**4.5**	**2.1**	**10.2**

Table 35: Impacts and payback of lighting upgrades ranked by payback period

House	CFLs installed	Installation cost	Total energy saved (kWh/yr)	Energy cost saving ($/yr)	GHG savings (kg/yr)	Payback (years)
House 2	2	$10	44	$8	49	1.3
House 15	3	$15	42	$7	46	2.1
House 10	2	$10	21	$4	23	2.8
House 14	3	$15	24	$4	26	3.7
House 7	6	$129	162	$28	178	4.7
House 4	8	$115	135	$23	148	5.0
House 9	7	$233	237	$40	259	5.8
House 8	17	$184	171	$29	187	6.3
House 1	19	$624	576	$98	630	6.4
House 12	7	$250	207	$35	227	7.1
House 13	49	$1,732	1,210	$206	1,323	8.4
House 11	30	$1,640	1,030	$175	1,127	9.4
House 3	0	$0	0	$0	0	N/A
House 5	0	$0	0	$0	0	N/A
House 6	0	$0	0	$0	0	N/A
Average	**10.2**	**$330**	**257**	**$43.7**	**281**	**7.6**

Figure 15: Cost curve for lighting upgrades



The results above show:

- It was cost effective to replace incandescent lighting (even the more efficient 240 volt halogen lamps) and low voltage halogen downlights in all homes.
- The upgrade on average resulted in an annual energy saving of 257 kWh/yr, an energy cost saving of $43.7/yr, and a GHG saving of 281 kg/yr. The average payback was 7.6 years.
- Nearly 80% of GHG savings came from houses where a significant number of low voltage halogen downlights were upgraded to CFLs. The steep climb in the cost curve from the six year payback point is largely driven by this type of lighting replacement.
- Longer payback periods were invariably related to the replacement of relatively expensive low voltage halogen downlights and their fittings.

The implication of the results is that replacing incandescent lighting and low voltage halogen downlights in these homes is cost effective and would lead to significant energy, energy cost and GHG savings. The replacement of the low voltage halogens downlights may also have additional energy saving benefits relating to a reduced cooling load in summer.

Televisions

The two 50 inch plasma TVs found in Houses 4 and 7 could be upgraded to 42 inch 5.5 star LED backlit LCD TVs. For the two plasma televisions identified, their present energy use and potential energy and GHG emission savings from the upgrade are presented in the table below. This analysis assumed the televisions were used 2,600 hours annually (EES, 2008) and the replacement would cost $3,000. An adjusted capital cost has not been calculated for televisions based on age. LCD televisions with LED backlighting have only just been introduced to the market in Australia, and their cost would be expected to reduce significantly over the next few years, making the replacement of plasma TVs more cost effective. Technologies under development such as organic light-emitting diode (OLED) and laser TV promise even lower energy consumption.

Table 36: Plasma television energy consumption and upgrade impacts

House number	Brand of existing television	Estimated energy consumption for plasma (kWh/yr)	Estimated energy consumption for 5.5* LCD (kWh/yr)	Energy savings (kWh/yr)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
House 4	Samsung	669	231	438	$75	479	40
House 7	LG	801	231	570	$97	624	31

The results indicate that a reasonable energy cost and GHG savings are possible through replacing the plasma televisions. However, the paybacks are still rather long and would be longer than the life of the appliance. The implication is that upgrading to a high efficiency appliance is best left to when televisions are replaced. The introduction of the energy rating program for televisions will make choosing energy efficient televisions much easier in the future. A cost curve was not produced for the television upgrade.

4.3 Combined cost curve for all houses

A combined cost curve was created for the 15 houses in this pilot study, taking into account all individual building shell and appliance upgrades modelled. This was undertaken in order to understand the variability across the different building shell and appliance upgrades, and to give an indication of the amount of greenhouse abatement which could be achieved at different payback points across this small stock of houses. Adjusted payback periods were used for the appliance upgrades, as it was felt this gave a fairer comparison between the appliance upgrades and the building shell upgrades. Table 37 and Figures 16 and 17 display the results. The cost curve only shows the results for upgrades with a payback period shorter than 50 years as the range between the shortest and longest payback period is too large.

Figure 16: Combined cost curve for all houses

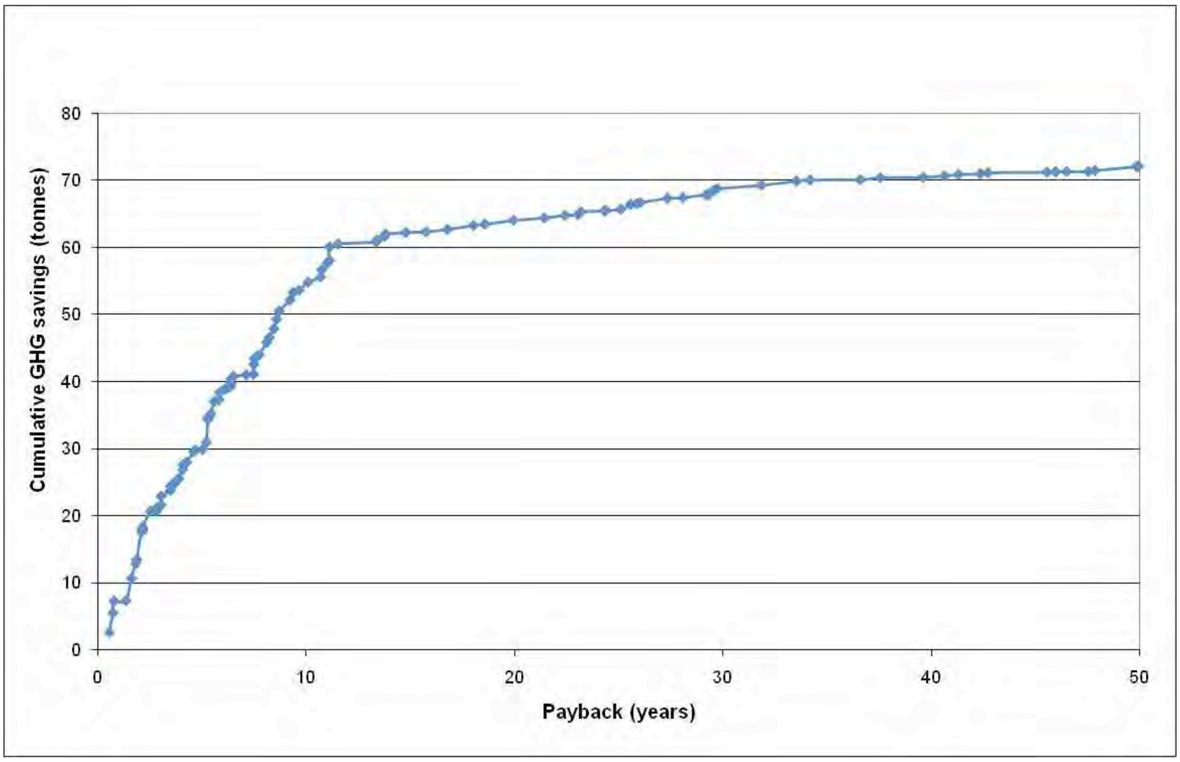


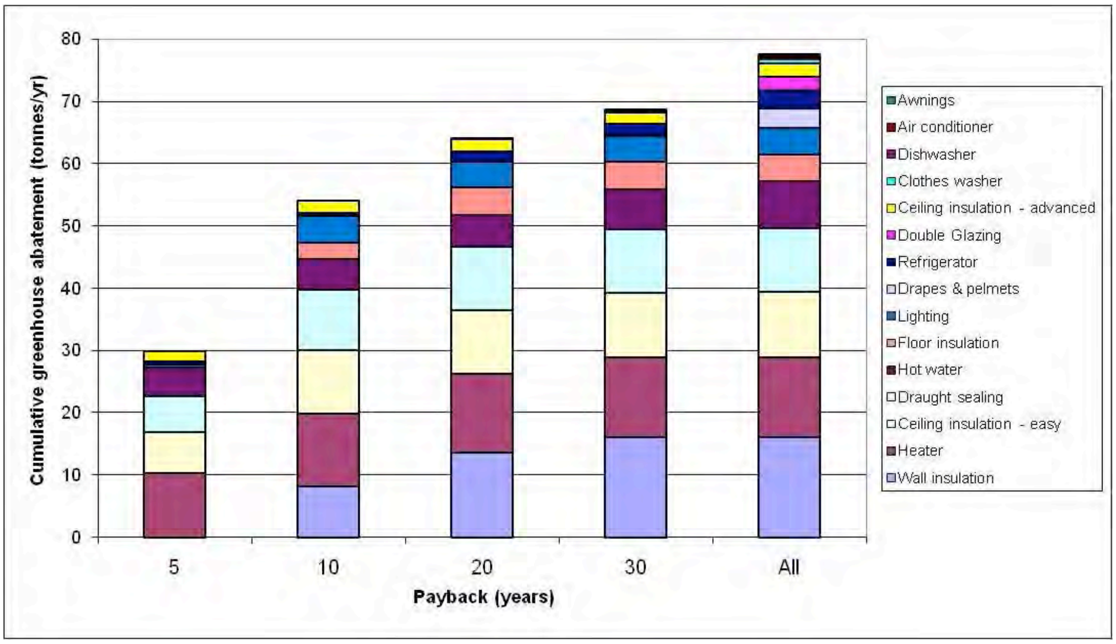
Table 37 displays the following information:

- the total number of upgrades that fall within the different of payback ranges examined
- the number of individual upgrades that fall within the different payback ranges, and
- the total amount of GHG emissions resulting from upgrades within the different payback ranges and the percentage this constitutes of the overall GHG savings achieved.

Table 37: Contribution of individual upgrades to cumulative GHG savings

	Upgrades with paybacks between 0-5 years	Upgrades with paybacks between 0-10 years	Upgrades with paybacks between 0-20 years	Upgrades with paybacks between 0-30 years	All upgrades
GHG savings (tonnes CO_{2-e})	30	54	64	69	78
Percent of total GHG savings	38%	69%	83%	89%	100%
Number of upgrades	29	58	75	91	161
Air conditioner upgrade	-	-	1	2	6
Refrigerator upgrade	1	1	4	5	14
Lighting	5	12	12	12	12
Hot water system upgrade	7	9	10	12	14
Clothes washer upgrade	-	-	-	1	12
Dishwasher upgrade	-	-	-	1	7
Heater upgrade	8	10	12	13	13
Draught sealing	4	12	15	15	15
Wall insulation	-	4	9	15	15
Drapes and pelmets	-	-	-	1	15
Double glazed windows	-	-	-	-	15
External window treatment	-	-	-	-	5
Ceiling insulation - advanced	2	3	3	4	6
Ceiling insulation - easy (bare ceiling)	2	5	5	5	5
Ceiling insulation - easy (top-up)	-	-	-	1	3
Underfloor insulation	-	2	4	4	4

Figure 17: Contribution of Energy Efficiency Measures to Greenhouse Abatement



The results from Table 37 and Figures 16 and 17 show that:

- Nearly 70% of GHG savings could be achieved by implementing measures with a payback period of 10 years or less. The upgrades with a 10 year or less payback mainly consisted of draught sealing, wall insulation, underfloor insulation, ceiling insulation (where applied to bare ceilings and areas that are significantly conditioned), and heater, hot water system and lighting upgrades.
- For measures with a payback period of 20 years of less, the largest amount of GHG abatement across the 15 houses is delivered by wall insulation, followed by heater upgrades, ceiling insulation, draught sealing, hot water upgrade, floor insulation and lighting upgrades.
- The majority of non-fixed appliance upgrades had payback periods of 20 years or longer.
- Double glazing and external window treatments were the only upgrade types where the payback periods for all upgrades fell into the 30 years or greater category.
- There is a potential to save a total of nearly 78 tonnes of GHG emissions if all 161 upgrades were implemented across the 15 houses, or an average of 5.2 tonnes per house.

5. Recommendations and next steps

5.1 Building shell upgrades

Wall, ceiling and floor insulation and draught sealing created the vast majority of savings across the 15 houses. It is recommended that in any future study all of these upgrades are treated as basic upgrades and that the advanced upgrade categories are reserved for double glazing and internal and external window treatments.

It would be valuable to investigate cheaper alternatives than replacing single glazed windows with new double glazed units. For example, it is possible to retrofit additional panes of glass to single glazed windows using a desiccant strip as a spacer at a lower cost per square metre than installing new double glazed window units, and some commercially available products allow this. This process is particularly simple for fixed windows. It may be worthwhile, during the energy audit, to assess the feasibility of this style of window upgrade (e.g. recording if the depth of existing window frame/s allowed for this retrofit possibility), and to also test customer acceptance of this type of upgrade compared to a new double-glazed window. Even if only certain windows (i.e. fixed windows or windows of a certain size) could be retrofitted in this manner it would be interesting to model in FirstRate5 how a limited window upgrade would impact upon the performance of the house.

It is recommended that further on-ground research is undertaken to develop a better understanding of the impact and effectiveness of comprehensive draught sealing and the installation of blow-in granulated rockwool wall insulation.

It was assumed for this project that houses could be reduced to an air leakage rate of 0.5 ACH at ambient air pressure. The contractor who undertook the air leakage testing advised that generally it is feasible to achieve this level in most houses, but this assumption was not tested as it fell outside the scope of the project. It would be useful to undertake some 'before and after' testing of the 15 houses that participated in this study to see if this level of reduction can be achieved in practice. It would also be interesting to progressively test houses as the draught sealing upgrade was applied to the houses to gauge the impact that different draught sealing measures have upon air leakage (e.g. weather-stripping windows and doors, filling in wall vents, caulking skirting boards).

It would be instructive to determine how effectively blow-in wall granulated rockwool insulates walls. This could be tested using thermal cameras and other devices such as inspection cameras. Since the presence of gaps significantly reduces the performance of insulation, it is important to determine how this upgrade performs in reality. Also, installers quoted approximately $20 per square metre to install blow-in wall insulation and it would be informative to find out how accurate this figure is and how it differs across construction types.

5.2 Appliance upgrades and impact analysis

Non-fixed appliance upgrades tended to have significantly longer payback periods than for fixed appliances, even when an adjusted capital cost methodology was employed. A more sophisticated analysis may develop from building a stronger link to existing desktop analysis on appliance use and household surveys about consumer motivations for appliance upgrades.

Household audits still provide an important role in documenting actual appliance types, age and usage. In field data is still needed to verify assumptions on appliance conditions and energy consumption.

The analysis of heaters, hot water systems and lighting showed that significant GHG and energy cost savings can be achieved by undertaking upgrades. It would worthwhile to continue further analysis.

5.3 On-ground data collection

On the whole the on-ground data collection process worked well. It would have been possible to schedule the air leakage test, the energy audit and the architectural measure-up all at the same time if the architect MEFL used for this project was available at the same time as the other assessors. The overall time needed to assess each house was approximately 2 to 2.5 hours to complete all data collection. If all houses are in a close proximity, three houses can be assessed per day.

In some cases it would be easier for the architect to indicate some existing building shell conditions on the floor plan (e.g. the extent of ceiling insulation or construction characteristics) rather than have the energy auditor describing this information in the Excel spreadsheet energy audit tool.

The age of appliances turned out to be a very useful when undertaking the cost benefit analysis. The age allowed for more accurate matching of models when there were multiple entries found in the historical appliance energy rating spreadsheets supplied by Sustainability Victoria. It also allowed the efficiency of appliances to be estimated when relevant model details could not be found. It is recommended that the gathering of the age of appliances be formalised in the energy audit process so that householders are surveyed to obtain an additional estimate of the age of appliances. Gathering such information might best take place when booking households for the assessments. This information could then be checked on-site by the energy auditor.

Taking photographs of appliances and their nameplates was useful and allowed for accurate appliance matching. It is recommended this practice is continued.

MEFL worked closely with the architect to ensure that all relevant data required to complete a FirstRate5 assessment was collected. Standard data gathering templates and window, room and site schedules were developed to streamline the process. However, even with these resources there were some misunderstandings and mistakes that surfaced a number of times and further training was necessary. Many of these mistakes centred on differences between terminologies used by FirstRate5 energy assessors and architects. Examples of commonly confused terms included the head height of windows, eave offset and projection, and sub-floor ventilation types. It should be remembered that most architects do not have a working knowledge of FirstRate5 and it is essential that they should receive adequate training before they start collecting information for a FirstRate5 assessment. The data collection sheets developed by MEFL could be further refined and a brief manual developed to streamline the architectural measure-up process further. The most effective way to collect the data would be to use a PDA or laptop so the data could be entered directly into an Excel spreadsheet. This would allow for preset choices to be built into the worksheet. In addition, having all the data in Excel format would also streamline the costing of window upgrades for the analysis as working off hard copies was time consuming.

The architect simply drew a floor plan for each house and used breakout boxes to indicate construction details that could not be easily indicated on plan. This approach used in conjunction with the window, room and site schedules worked very effectively and for the majority of houses there is no need for elevations and sections to be drawn.

5.4 FirstRate5 modelling

It would be a valuable exercise to re-apply the building upgrades in a different order to determine how this would impact upon the impact upon house energy ratings and energy intensity. Double glazing would be more cost effective if applied before drapes and pelmets. While drapes and pelmets can have an energy saving impact approaching that of double glazing, the actual energy savings depend partly on behaviour, as they will only be realised if the drapes are drawn when heating is operating and there is no sun entering through windows. The impact of double glazing is largely independent of human behaviour. This further analysis could be undertaken with data gathered in this project.

There has been some recognition that that Accurate/FirstRate5 may underestimate the cooling load for houses. It is possible that Accurate/FirstRate5 may be updated in the near future to give a more realistic estimate of cooling requirements and it would be wise to re-examine the impact of external shading on this study after this upgrade has taken place.

This project involved trialling an approach to include the air leakage results from the blower door test in the FirstRate5 modelling. The contractor used to undertake the air leakage tests is currently working with a range of stakeholders to see how air leakage can be better incorporated into current housing energy rating software programs. The approach used for this project definitely revealed that comprehensive draught sealing was a very effective action in most houses and incorporating the air leakage test results into the FirstRate5 models was a positive step.

As part of this study energy bill data (electricity and gas) was collected from most of the households participating in the study. A preliminary analysis of this gas data indicates that the modelled heating energy consumption (base heating energy use from FirstRate5 divided by the appliance efficiency) was generally higher than gas consumption for heating estimated from the energy bills. This would mean that the energy and greenhouse savings estimated for the building shell and heater upgrades would be higher than can be achieved in practice, and the paybacks longer. It is recommended that further detailed work be undertaken to determine the reason for this and to develop a modelling methodology which can more accurately estimate actual heating energy use. Issues to explore are:

- The impact of the assumed occupancy profile compared to the actual occupancy profile.
- Whether or not there is a difference in the accuracy of the estimate between central and space conditioned homes.
- The impact of the areas of the house chosen as conditioned zones, especially for space conditioned homes – the assumption that hallways were also conditioned may be partially responsible.
- The impact of the actual winter conditions when the energy use data was collected compared to the weather files used in FirstRate5 - there is some evidence to suggest that winters have become warmer than is assumed in FirstRate5.
- The impact of the assumed thermostat settings used in FirstRate5.
- The impact of appliance efficiency estimates, especially assumed ductwork losses.

5.6 Undertaking a larger study

The methods used in the project were successful and it would be very feasible to roll this project out on a larger scale after refining the data collection methods and the exact nature of upgrades to be considered.

With a wider rollout it would be sensible to start testing the actual impact and effectiveness of different upgrades on houses. It would be possible to do 'on the spot' assessments of the effectiveness of insulation measures using a thermal camera and of draught sealing using the fan pressurisation test. Collection of actual energy usage data before and after the upgrades would also provide valuable information on the ultimate effectiveness of the upgrades in achieving energy and greenhouse savings. This on-ground testing would be most valuable for the development of government policies, such as the mandatory disclosure of residential building energy performance and the development of rebates and incentives to increase the uptake of residential energy efficiency upgrades.

6. References

EES 2008, *Energy Use in the Australian Residential Sector 1986-2020*, prepared for the Department of the Environment, Water, Heritage and the Arts by Energy Efficiency Strategies, 2008.

GWA 2005, *Guide to Preparing Regulatory Impact Statements for the National Appliance and Equipment Energy Efficiency Program (NAEEEP)*, George Wilkenfeld and Associates, May 2005.

Roy Morgan Research 2008, *Victorian Utility Consumption Household Survey 2007*, prepared for the Department of Human Services by Roy Morgan Research, April 2008.

Appendix A: FirstRate5 modelling methodology

FirstRate5 thermal modelling approach

FirstRate5 is a thermal modelling software program that can be used to model the thermal efficiency of a house, estimate the energy required to heat or cool conditioned zones to maintain pre-determined thermal comfort conditions, and determine its star rating under the National House Energy Rating Scheme (NatHERS). When house design, construction and site details are input into FirstRate5 the different areas of the house (e.g. kitchen, living area, bedrooms etc.) are defined as discrete zones that are individually set as conditioned or non-conditioned zones. This means that in FirstRate5 it is possible to model different heating and cooling profiles for a house (i.e. space conditioned or centrally conditioned) in addition to the standard zoning protocol that must be followed to generate an energy rating.

In addition to assessing the thermal efficiency of the houses' building shells, the focus of this project was to estimate the actual energy used for conditioning houses to allow a cost benefit analysis of upgrades to be completed. This meant that only zones that had fixed heaters, central heating outlets, evaporative cooling outlets, or air-conditioning systems were set as conditioned zones in FirstRate5 when calculating heating and cooling energy requirements. Hallways were also conditioned as it was assumed that doors leading into these areas are often left open.

In the case of space conditioned[15] houses, the zones that were set as "conditioned" when determining energy requirements for the cost benefit analysis needed to be altered in order to determine the star rating. This was necessary because in order to determine the star rating in FirstRate5 a standard zoning protocol must be followed in regard to the zones of a house that are conditioned, corresponding closely to a centrally conditioned house. This approach is taken in order to ensure that all houses are compared in a standard manner regardless of individual conditioning profiles and that all main zones of a house are tested for thermal efficiency.

The individual house reports (contained in Appendix C), include a floor plan showing the different zones that were set as "conditioned" in star rating mode and the actual conditioning mode. Zones set as "conditioned" in the actual conditioning mode are coloured blue. Zones set as "conditioned" in star rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in star rating mode and actual conditioning mode are the same.

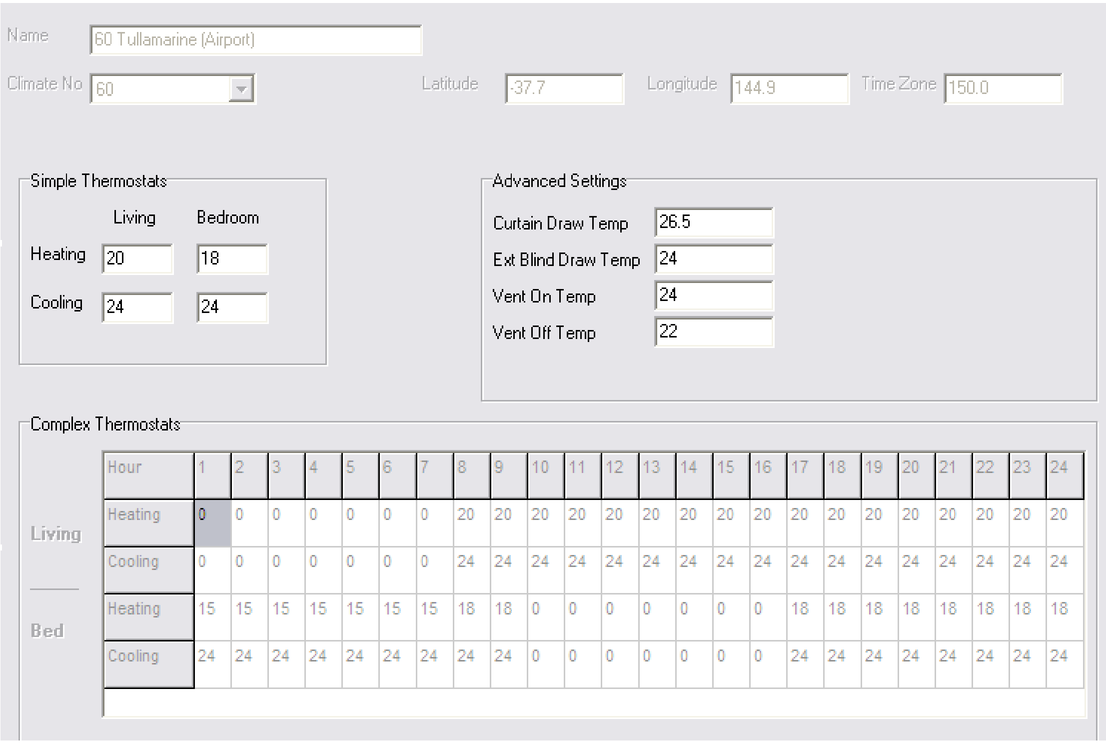
At the request of Sustainability Victoria AccuBatch was used to run scratch files saved from each FirstRate5 simulation with altered thermostat and occupancy settings to reflect a 'Home All Day' scenario and an 'Away During Work' scenario.

[15] "Space conditioning" refers to a heater or cooler which conditions a room of defined open plan area, as opposed to a central or "whole house" heating/cooling system.

This was done to more accurately simulate the real usage patterns households. The FirstRate5 results used for the cost benefit analysis assumed a weighted occupancy profile for the 15 houses, based on 55% of households being occupied in line with the 'Home All Day' scenario and 45% being occupied in line with the 'Away During Work' scenario. All AccuBatch runs were undertaken in Climate Zone 60 (Tullamarine Airport).

Figures A1, A2 and A3 below are screen shots taken from AccuBatch and they show the different AccuBatch settings used for this project. Figure A1 shows the default settings for Climate Zone 60 used when generating star ratings. Figures A2 and A3 show the setting used for the 'Home All Day' and 'Away During Work' scenarios. Changes were only made to the default thermostat settings and hours of operation.

Figure A1: AccuBatch climate zone 60 default settings



	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Living	Heating	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Cooling	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Bed	Heating	15	15	15	15	15	15	15	18	18	0	0	0	0	0	0	0	18	18	18	18	18	18	18	18
	Cooling	24	24	24	24	24	24	24	24	24	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24

Figure A2: Settings used for 'Home All Day' scenario

Name: Tulla_AllDay_SV2009update

Climate No: 60 | Latitude: -37.7 | Longitude: 144.9 | Time Zone: 150.0

Simple Thermostats

	Living	Bedroom
Heating	20	20
Cooling	24	24

Advanced Settings

Curtain Draw Temp	26.5
Ext Blind Draw Temp	24
Vent On Temp	24
Vent Off Temp	22

Complex Thermostats

	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Living	Heating	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Cooling	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Bed	Heating	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Cooling	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24

Figure A3: Settings used for 'Away During Work' scenario

Name: Tulla_M&E_SV2009update

Climate No: 60 | Latitude: -37.7 | Longitude: 144.9 | Time Zone: 150.0

Simple Thermostats

	Living	Bedroom
Heating	20	20
Cooling	24	24

Advanced Settings

Curtain Draw Temp	26.5
Ext Blind Draw Temp	24
Vent On Temp	24
Vent Off Temp	22

Complex Thermostats

	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Living	Heating	0	0	0	0	0	0	20	20	20	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20
	Cooling	0	0	0	0	0	0	24	24	24	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24
Bed	Heating	0	0	0	0	0	0	20	20	20	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20
	Cooling	0	0	0	0	0	0	24	24	24	0	0	0	0	0	0	0	24	24	24	24	24	24	24	24

Incorporating results from air leakage tests

The air leakage rate determined by the fan pressurisation method was incorporated into the FirstRate5 models for each house through the use of proxies for the measured air leakage. Undertaking this required modelling additional ‘proxy’ leakage sites with known air change impacts and taking account of inherent air leakages modelled by the software. The proxy role in FirstRate5 was best filled by the addition of sealed or unsealed exhaust fans.

At a room volume of $100m^3$ the impact of an unsealed exhaust fan is 0.216 air changes per hour (ACH) and the impact of a sealed exhaust fan is 0.036 ACH. Exhaust fans were chosen to be used as they only have a stack (static) air leakage impact and no wind driven impact, thus simplifying the overall approach.

The AccuRate model allocates each zone a static (stack) leakage rate in ACH and a wind driven value. The total ACH for any zone is calculated at each time step as ACH = A + B x V, where V is the wind speed in m/s at that time step.

The value assigned to each zone is dependent on several factors including window area, number of doors etc. Sealing windows and doors reduces leakage but does not make it zero. As such, there is no simple way to define the base air leakage rate of a house.

For the purposes of this study, Sustainability Victoria proposed to use a base rate of 0.2 ACH, which is the equivalent total air change rate of a particular house that has no additional leakage sites and all windows and doors are weather-stripped. This value is an indicative value, and if recalculated would vary between houses. However, it was determined that this value would be suitable for the current project.

The approach used to implement this method was the following:

1) Determine the existing air leakage of the home at ambient air pressure in ACH as provided by Air Barrier Technology.

2) Deduct the inherent base air change rate that the software has (0.2) from the existing ACH to come up with the Target ACH.

   Target ACH = Existing ACH - 0.2

3) Multiply the Target ACH value by house volume/100 (A). The house volume should include all habitable rooms.

4) Divide (A) by 0.216 to determine the number of unsealed exhaust fans required (or divide by 0.036 for sealed exhaust fans).

5) Add the number of exhaust fans to the rooms, spreading the numbers around as much as possible favouring larger living spaces.

When undertaking the modelling it was essential to not add any other air leakage sites into the FirstRate5 models and to ensure that all door and windows were weather-stripped. This is important as this procedure uses the exhaust fans as a proxy for the actual measured leakage rate. Adding in other sites (e.g. wall vents or real exhaust fans) adds additional air leakage sources that are not present in the house.

To work out the number of exhaust fans that should be present in the house after the air leakage rate has been reduced to 0.5 ACH the procedure above was followed with 0.5 ACH used as the existing air leakage of the house. To model the impact of draught sealing on the house the appropriate number of exhaust fans were deducted from the FirstRate5 model to reduce air leakage to 0.5 ACH at ambient air pressure.

Below is a worked example of the above method:

House floor area = 200m^2

Wall height = 2.4m

Total volume = 200 x 2.4 = 480 m^3

Existing ACH = 0.5 (determined by fan pressurisation test)

Target ACH= 0.5 - 0.2 = 0.3

Target ACH x (Vol/100) = 0.3 x 480/100 =1.44

1.44/0.216 = 6.7 = 7 unsealed exhaust fans

Undertaking the FirstRate5 modelling

The floor plans drawn after the architectural measure-ups were inputted into FirstRate5 and all relevant building design characteristics were entered to create files that represented the houses in their current condition.

The following procedure was followed to complete the FirstRate5 analysis:

- Modify the zoning of FirstRate5 files to reflect the actual conditioning profile of the houses in order to model actual energy required for space conditioning.
- Determine the current level energy efficiency.
- Apply upgrade one through to eight set out in Table 1.
- Save the scratch file and FirstRate5 file after each upgrade.
- Reopen FirstRate5 files and save them as new files.
- Modify the zoning of newly saved FirstRate5 files to comply with standard star rating protocols.

- Run each new FirstRate5 and record the star rating improvement after the application of each upgrade.
- Save the scratch file and the FirstRate5 file after the star ratings are determined.

Using AccuBatch, the scratch files generated when the houses were in actual conditioning profile were run through the 'Home All Day' and the 'Away During Work' scenarios (i.e. Figure 2 & 3) and the results were then weighted (55% 'Home All Day' and 45% 'Away During Work') to come up with the final heating and cooling load. These final figures were then used to calculate the energy, financial and greenhouse gas savings for each building shell upgrade.

The results generated when the house was in standard star rating mode were only used to determine the star rating of the house after each upgrade. The star rating results were not analysed as they are about the theoretical energy efficiency potential (i.e. star rating) rather than the actual energy used for conditioning a house.

Appendix B: Costs of building shell upgrades and high efficiency appliances

Table B1: Cost of high efficiency appliances and installation

Appliance type	Brand	Model	Appliance cost ($)	Installation cost ($)	Energy rating	Comments
Gas central heater - external	Brivis	HE20E	$1,950	$700	5.1	Standard installation cost quoted by Origin Energy.
Gas central heater - internal	Brivis	HE20I	$2,015	$700	5.1	Standard installation cost quoted by Origin Energy.
Gas space heater - radiant	Rinnai	Ultima II REH 311FT (B)	$2,115	$545	4.3	The installation cost is based upon the flue being installed in an old chimney and the heater being hard wired by an electrician. This was the only type of installation required for this project.
Gas space heater - convection	Braemar	SH25	$1,379	$793-$1055	4.8	The installation cost depends upon what type of flue is installed and if the heater needs to be hard wired by an electrician. If a wall furnace is removed there is an additional cost of $300 on top of the installation cost listed for a handy man to patch up the wall after the removal of the existing wall furnace.
Split system reverse cycle air conditioner	Fujitsu	ASTA09LCC	$999	$780 or $1,280	6.0	$780 is the installation cost when an existing split system reverse cycle air conditioner is being replaced. $1,280 is the installation cost for replacing a wall/window mounted box air-conditioner.

Appliance type	Brand	Model	Appliance cost ($)	Installation cost ($)	Energy rating	Comments
Split system air conditioner (cooling only)	Fujitsu	ASTA24JCC	$1,849	$780 or $1,280	5.0	$780 is the installation cost when an existing split system reverse cycle air conditioner is being replaced. $1,280 is the installation cost for replacing a wall/window mounted box air-conditioner.
Gas storage hot water heater	AquaMAX	AquaMAX 135	$899	$378 or $1,130	5.0	$378 is the installation cost when an existing gas storage system is being replaced. $1,130 is the installation cost where an existing electric storage system is being replaced.
Continuous flow gas water heater	Bosch	Bosch Highflow 26e	$1,199	$378	5.5	The installation cost is for replacing an existing continuous flow gas water heater.

Appliance type	Brand	Model	Appliance cost ($)	Installation cost ($)	Energy rating	Comments
Gas boosted solar hot water heater	N/A	N/A	$4,409	$1,500 or $2,500	3.0	There was no particular brand or model chosen for the gas boosted solar hot water heater. An average appliance cost was taken from a wide range of flat plate systems listed on the Sustainability Victoria website. It was assumed that a 3.0 star gas storage system would be installed as the gas booster. $1,500 is the installation cost for replacing an existing gas storage water heater. $2,500 is the installation cost for replacing an existing electric water heater. It was estimated that the total rebates and money from the sale of renewable energy and energy efficiency certificates for replacing a gas storage water heater would be $2,236 and $3,100 for replacing an electric storage water heater.
Dishwasher	Bosch	SMS63M08AU	$1,749	$150	4.0	Installation cost is for a handy man to install the dishwasher and to remove the old unit.
Refrigerator	Electrolux	ETM4200SC	$1,557	N/A	5.0	N/A
Clothes washer	LG	WD11020D	$1,034	N/A	4.0	N/A
Television	LG	42LH90QD	$3,000	N/A	5.5	N/A

Table B2: Costs used to calculate building shell upgrades

Upgrade	Description	Cost ($/m2)	Source
Ceiling insulation (easy)	Glasswool batt R1.5	$7.36	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
	Glasswool batt R2.0	$9.58	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
	Glasswool batt R2.5	$10.90	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
	Glasswool batt R3.0	$11.57	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
	Glasswool batt R3.5	$12.96	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
Underfloor insulation	Glasswool batt R1.5	$13.69	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
Drapes and pelmets	Basic pelmet	$105.46	Phone survey of curtain shops
	Basic heavy drape	$110.46	Phone survey of curtain shops
External window treatment	Canvas awning	$154.34	Phone survey of blind shops
Ceiling insulation (advanced)	Glasswool batt R2.5	$10.90	Cordell Housing Building Cost Guide - JUL/AUG/SEP 2009
	Extra labour charges for installing insulation in flat roofs	$12.00	Phone survey of insulation companies
Wall insulation	Blow-in granulated rockwool	$20.00	Phone survey of insulation companies
Double glazed windows	Double glazed windows with aluminium frame	$580.00	ArchiCentre Cost Guide - Autumn 2009

Appendix C: Individual house reports

Individual report for House 1

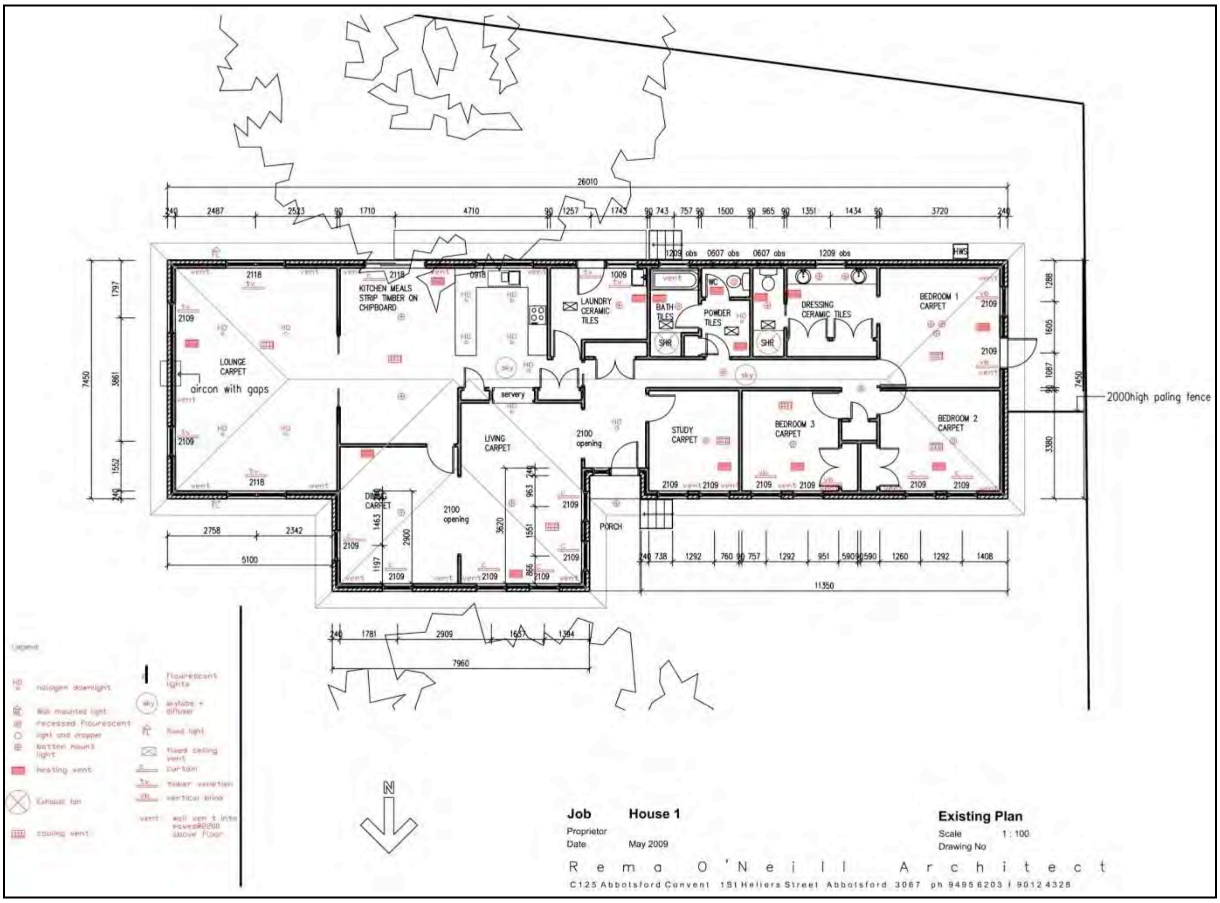
Description

Table 1 provides a basic description of House 1, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 1 with north indicated.

Table1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick veneer • Suspended timber floor
Age	1970s
Floor area (m2)	175.3
Existing star rating	1.5
Main type of heating	Gas central heating
Main type of cooling	Evaporative cooling
Percentage of total floor area conditioned	100%
Existing insulation and air leakage status	• R0.5 ceiling insulation • 1.16 ACH

Figure 1: Floor plan of House 1



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 1 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode

Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 1 it is possible to achieve a 5.3 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.5	N/A
Upgrade 1: Ceiling insulation (easy)	*Yes	175m^2 topped up from R0.5 to R3.5	2.2	$2,029
Upgrade 2: Draught proofing	Yes	Reduced from 1.16 ACH to 0.5 ACH	2.7	$1,090
Upgrade 3: Underfloor insulation	Yes	175m^2 of R1.5 floor insulation installed	3.2	$2,401
Upgrade 4: Drapes and pelmets	Yes	39.8m^2 of drapes and 19m of pelmets installed	3.7	$6,398
Upgrade 5: External awnings	Yes	34.1m^2 of canvas awnings installed	3.7	$5,270
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	112m^2 of R1.5 wall insulation installed	4.9	$2,248
Upgrade 8: Double glazed windows	Yes	45m^2 of double glazing installed	5.3	$26,288

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades (listed in Table 2) are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation	$2,029	$365	1,865	6
Draught sealing	$1,090	$210	1,069	5
Underfloor insulation	$2,401	$238	1,207	10
Drapes & pelmets	$6,398	$111	565	58
External window treatment	$5,270	$2	14	2,357
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$2,248	$210	1,068	11
Double glazing windows	$26,288	$49	252	536

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 1 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem	Yes - 6 year old 3.2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Fisher & Paykel	Yes - 5 year old 4.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Ariston	Yes - 7 year old 3 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Bosch	Yes - 7 year old 2.5 star dishwasher upgraded to 4 star dishwasher

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Heater	Gas central heater	Braemar	Yes - 9 year old 65% efficient heater upgraded to 91% efficient heater
Air conditioner	Evaporative	N/A	No – Evaporative AC not upgraded
Lighting	N/A	N/A	Yes - 6 incandescent lamps and 13 low voltage halogen down-lights replaced with 19 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,906	3,128	$639	$34	175	19
Refrigerator (kWh)	432	135	$1,099	$23	148	48
Clothes washer (MJ)*	299	17	$431	$0.19	1	2,276
Dishwasher (kWh)	187	68	$791	$12	74	69
Lighting (kWh)	Not estimated	576	$624	$98	630	6
Heater upgrade (MJ)	101,655	29,044	$1,458	$319	1,622	5
Air conditioner upgrade (MJ)	476	0	$0	$0	0	N/A

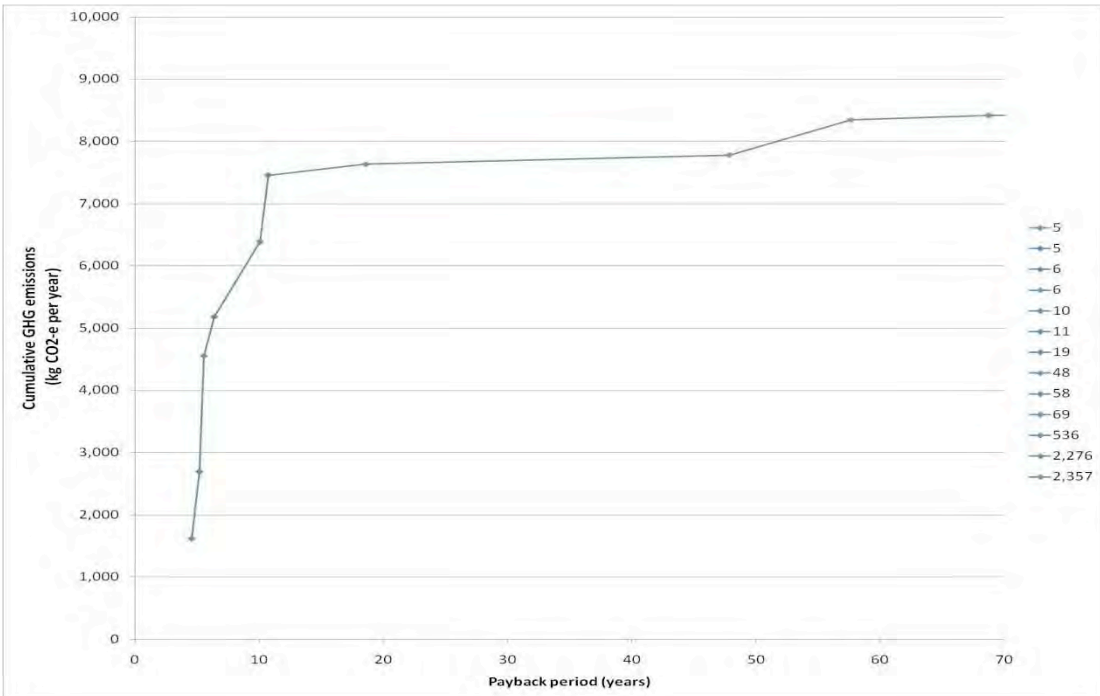
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 1 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 1



The cost curve above only shows the results of upgrades with a payback lower than 70 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Heater upgrade	Yes - 9 year old 65% efficient heater upgraded to 91% efficient heater	$1,458	$319	1,622	5
Draught sealing	Reduced from 1.16 ACH to 0.5 ACH	$1,090	$210	1,069	5
Ceiling insulation	175m^2 topped up from R0.5 to R3.5	$2,029	$365	1,865	6
Lighting	Yes - 6 incandescent lamps and 13 low voltage halogen down-lights replaced with 19 CFLs	$624	$98	630	6
Underfloor insulation	175m^2 of R1.5 floor insulation installed	$2,401	$238	1,207	10
Wall insulation	112m^2 of R1.5 wall insulation installed	$2,248	$210	1,068	11
Hot water system	Yes - 6 year old 3.2 star HWS upgraded to 5 star gas storage HWS	$639	$34	175	19
Refrigerator	Yes - 5 year old 4.5 star refrigerator upgraded to 5 star refrigerator	$1,099	$23	148	48
Drapes & pelmets	39.8m^2 of drapes and 19m of pelmets installed	$6,398	$111	565	58
Dishwasher	Yes - 7 year old 2.5 star dishwasher upgraded to 4 star dishwasher	$791	$12	74	69
Double glazed windows	45m^2 of double glazing installed	$26,288	$49	252	536
Clothes washer	Yes - 7 year old 3 star clothes washer upgraded to 4 star clothes washer	$431	$0	1	2,276

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
External window treatment	34.1m^2 of canvas awnings installed	$5,270	$2	14	2,357

Summary and discussion

The cost curve analysis reveals that almost 88% of the total greenhouse gas savings can be achieved by implementing the seven upgrades with the shortest payback periods. The top seven upgrades in order of shortest to longest payback are:

- heater upgrade
- draught sealing
- ceiling insulation
- lighting upgrade
- underfloor insulation
- wall insulation
- gas HWS upgrade

These actions are estimated to result in nearly eight tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The installation of double glazing and internal and external window treatments also have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 2

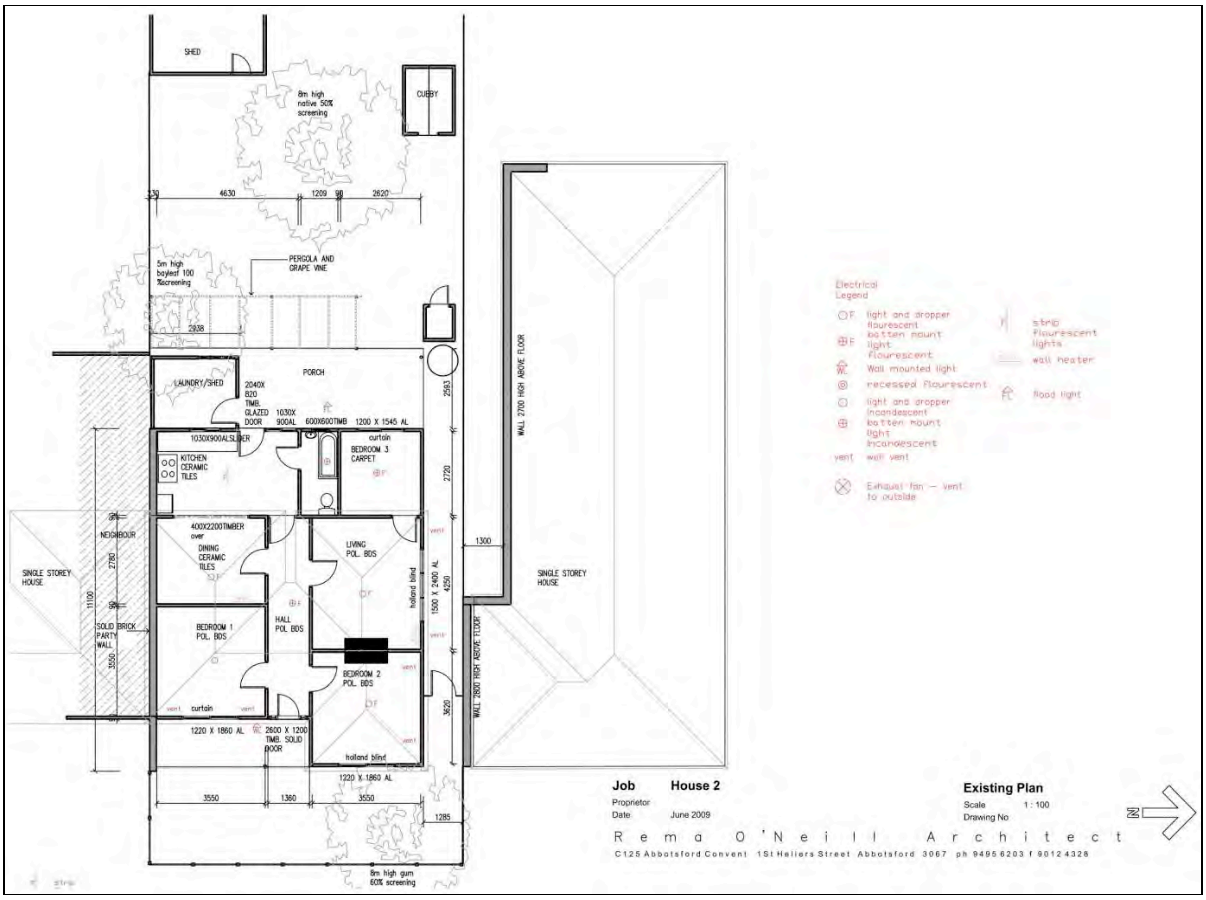
Description

Table 1 provides a basic description of House 2, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 2 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Semi-detached • Weatherboard • Suspended timber floor
Age	1910s
Floor area (m2)	88.7
Existing star rating	1.5
Main type of heating	Gas space heating
Main type of cooling	N/A
Percentage of total floor area conditioned	67%
Existing insulation and air leakage status	• R2.0 ceiling insulation except in flat roof • 1.09 ACH

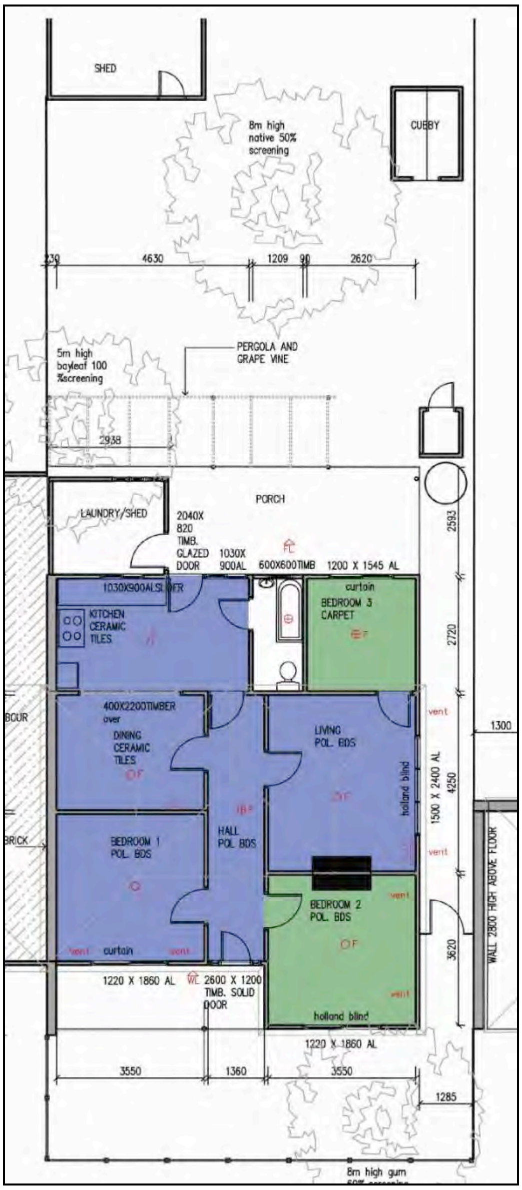
Figure 1: Floor plan of House 2



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 2 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 2 it is possible to achieve a 4.1 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.5	N/A
Upgrade 1: Ceiling insulation (easy)	*Yes	59m^2 topped up from R2.0 to R3.5	1.5	$437
Upgrade 2: Draught proofing	Yes	Reduced from 1.09 ACH to 0.5 ACH	1.8	$635
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	11.7m^2 of drapes and 10.7m of pelmets installed	2	$2,419
Upgrade 5: External awnings	Yes	11.7m^2 of canvas awnings installed	2	$1,806
Upgrade 6: Ceiling insulation (advanced)	Yes	22.1m^2 upgraded from no insulation to R2.5	2.5	$507
Upgrade 7: Wall insulation	Yes	79.8m^2 of R2.5 wall insulation installed	3.8	$1,596
Upgrade 8: Double glazed windows	Yes	14.3m^2 of double glazing installed	4.1	$8,294

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 2 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	*Yes	59m^2 topped up from R2.0 to R3.5	$437
Upgrade 2: Draught proofing	Yes	Reduced from 1.09 ACH to 0.5 ACH	$635

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	7.6m^2 of drapes and 7.3m of pelmets installed	$1,605
Upgrade 5: External awnings	No	No air-conditioner so no external awnings installed	N/A
Upgrade 6: Ceiling insulation (hard)	Yes	22.1m^2 upgraded from no insulation to R2.5	$507
Upgrade 7: Wall insulation	Yes	79.8m^2 of R2.5 wall insulation installed	$1,596
Upgrade 8: Double glazed windows	Yes	10.2m^2 of double glazing installed	$5,906

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$437	$12	61	37
Draught sealing	$635	$43	219	15
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$1,605	$23	116	70
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$507	$66	333	8
Wall insulation	$1,596	$150	759	11
Double glazed windows	$5,906	$16	82	365

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 2 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem	Yes - 15 year old 3.2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	1 door fridge	Fisher & Paykel	No - 6 year old 5.5 star refrigerator
Clothes washer	Front loader	LG	No - 4 year old 4.5 star clothes washer
Dishwasher	N/A	Bosch	No - 2 year old 4 star dishwasher
Heater	Gas space-1 wall furnace/1 convection	Convair/Rinnai	Yes – Two 10 year old 73% efficient heaters upgraded to 87% efficient heaters
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	Yes - 2 incandescent lamps replaced with 2 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	20,069	3,291	$128	$36	184	4
Refrigerator (kWh)	295	0	$0	$0	0	N/A
Clothes washer (MJ)*	201	0	$0	$0	0	N/A
Dishwasher (kWh)	119	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	44	$10	$8	49	1
Heater upgrade (MJ)	47,966	7,719	$941	$85	431	11
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

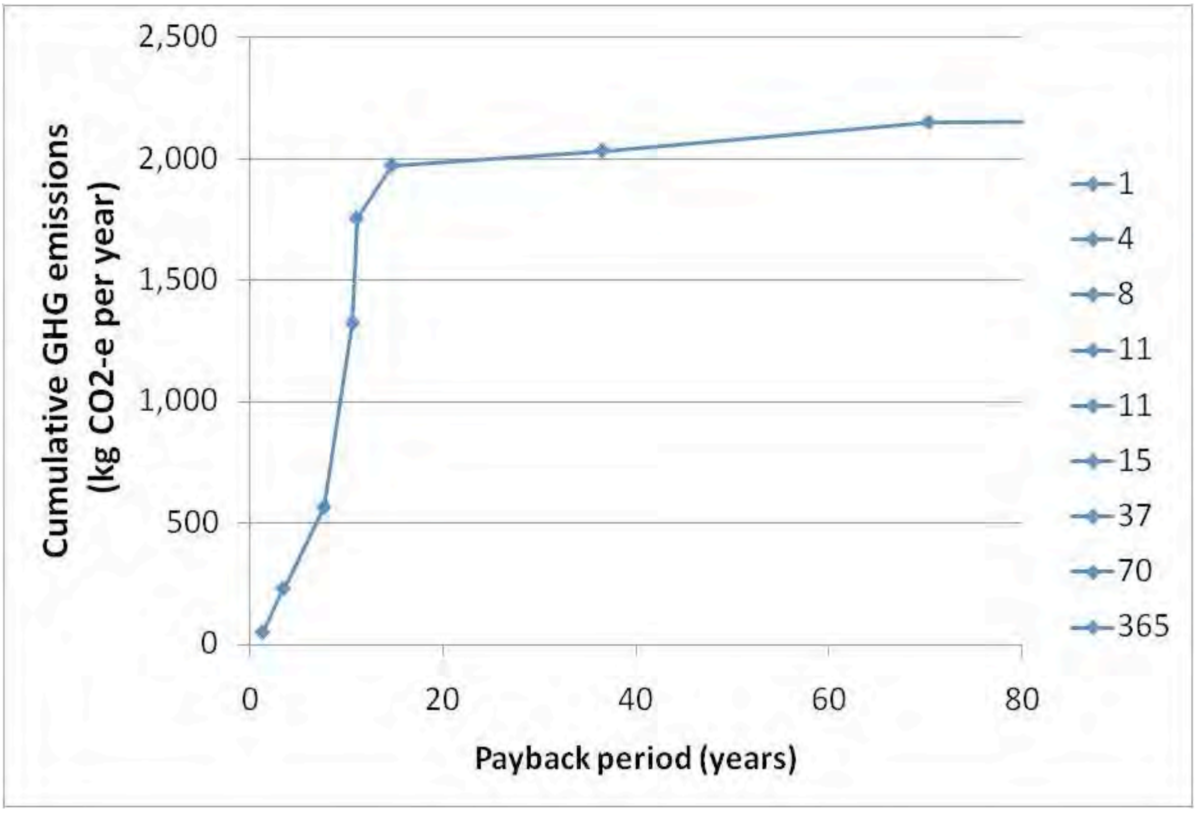
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 2 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 2



The cost curve above only shows the results of upgrades with a payback lower than 80 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Lighting	Yes - 2 incandescent lamps replaced with 2 CFLs	$10	$8	49	1
Hot water system	Yes - 15 year old 3.2 star HWS upgraded to 5 star gas storage HWS	$128	$36	184	4
Ceiling insulation (advanced)	22.1m^2 upgraded from no insulation to R2.5	$507	$66	333	8
Wall insulation	79.8m^2 of R2.5 wall insulation installed	$1,596	$150	759	11
Heater upgrade	Yes - Two 10 year old 73% efficient heaters upgraded to 87% efficient heaters	$941	$85	431	11
Draught sealing	Reduced from 1.09 ACH to 0.5 ACH	$635	$43	219	15
Ceiling insulation	59m^2 topped up from R2.0 to R3.5	$437	$12	61	37
Drapes & pelmets	7.6m^2 of drapes and 7.3m of pelmets installed	$1,605	$23	116	70
Double glazed windows	10.2m^2 of double glazing installed	$5,906	$16	82	365

Summary and discussion

The cost curve analysis reveals that almost 88% of the total greenhouse gas savings can be achieved by implementing the six upgrades with the shortest payback periods. The top six upgrades in order of shortest to longest payback are:

- lighting
- hot water system
- ceiling insulation (advanced)
- wall insulation
- heater upgrade

- draught sealing

These actions are estimated to result in nearly two tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 3

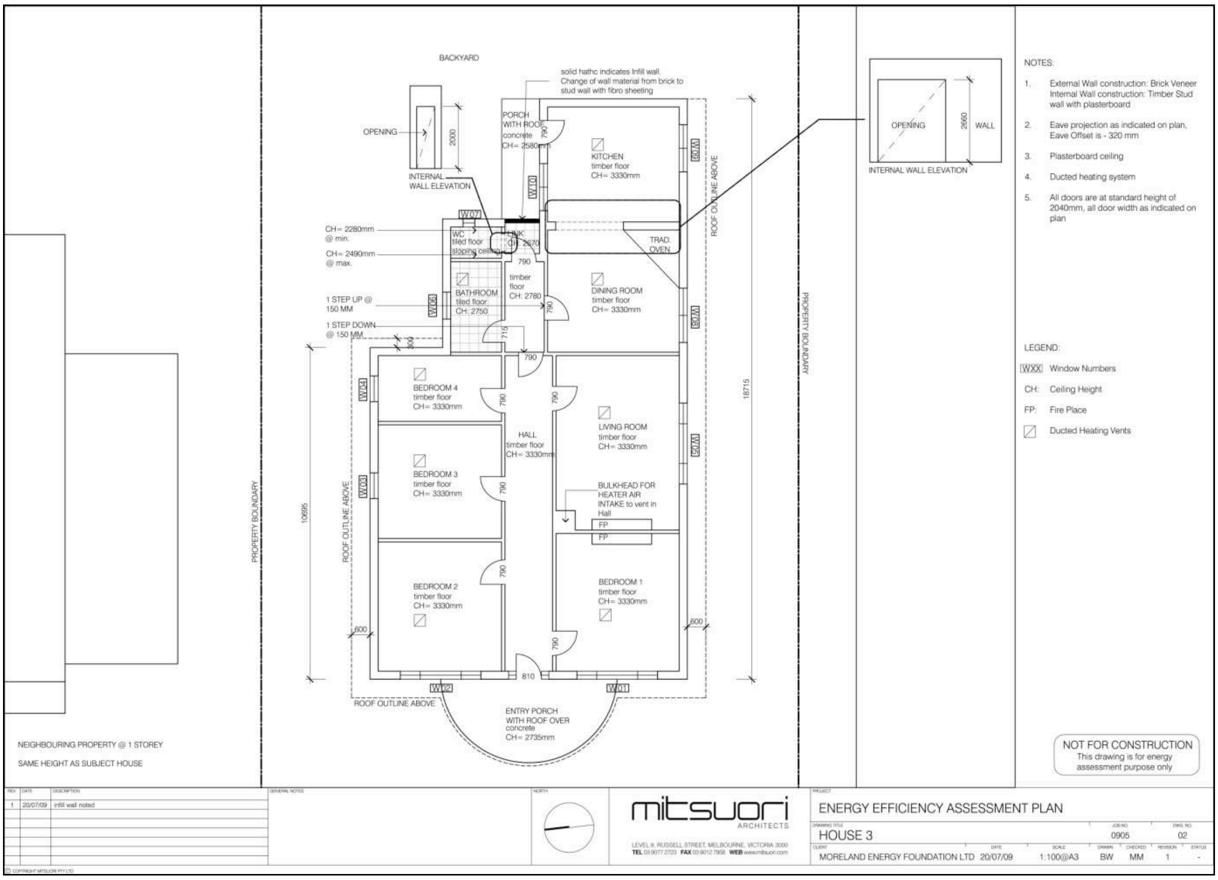
Description

Table 1 provides a basic description of House 3, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 3 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick veneer • Suspended timber floor
Age	1950s
Floor area (m2)	139
Existing star rating	0
Main type of heating	Gas central heating
Main type of cooling	N/A
Percentage of total floor area conditioned	98%
Existing insulation and air leakage status	• No ceiling insulation • 1.71 ACH

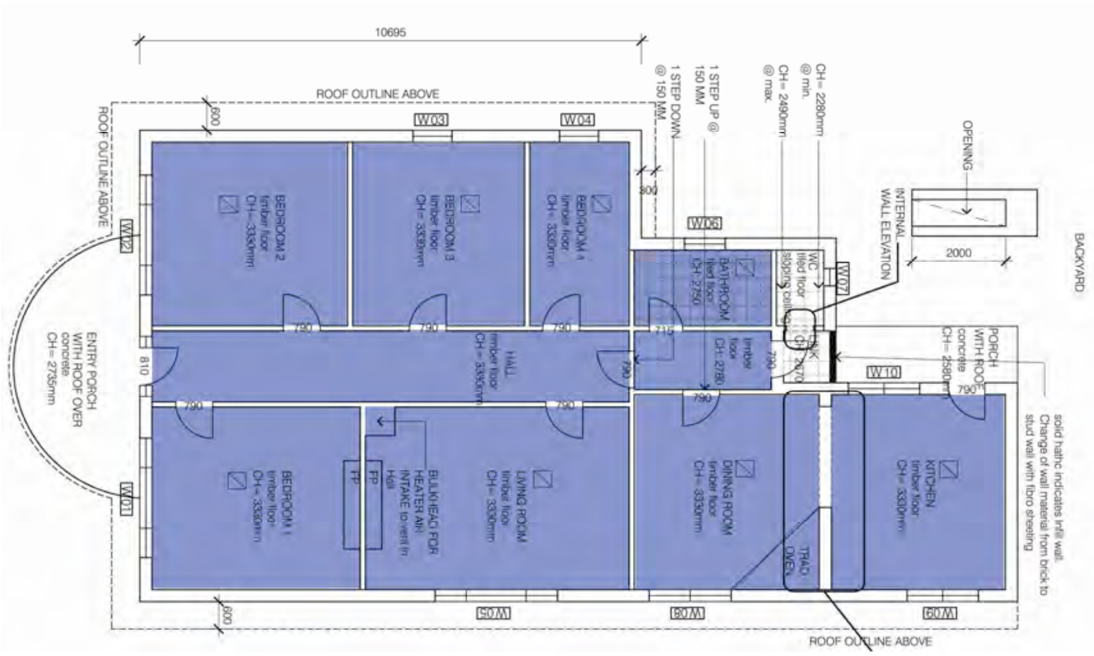
Figure 1: Floor plan of House 3



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 3 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 3 it is possible to achieve a 4.4 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	0	N/A
Upgrade 1: Ceiling insulation (easy)	Yes	90m^2 upgraded from no insulation to R3.5	1.6	$1,166
Upgrade 2: Draught proofing	Yes	Reduced from 1.71 ACH to 0.5 ACH	2.4	$1,098
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	21.8m^2 of drapes and 12.6m of pelmets installed	2.5	$3,740
Upgrade 5: External awnings	Yes	No air-conditioner so no external awnings installed	2.5	$596

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	144.2m^2 of R1.5 wall insulation installed	4.2	$2,885
Upgrade 8: Double glazed windows	Yes	25.2m^2 of double glazing installed	4.4	$14,633

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 2 are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$1,166	$466	2,366	3
Draught sealing	$1,098	$272	1,381	4
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$3,740	$52	265	72
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$2,885	$357	1,812	8
Double glazed windows	$14,633	$31	158	469

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 3 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem Glass	Yes - 10 year old 3.3 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	LG	Yes - 7 year old 2 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Top loader	Simpson	Yes - 5 year old 2 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	N/A	N/A
Heater	Gas central	Braemar	No - 2 year old 87% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	No

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,816	3,038	$213	$33	170	6
Refrigerator (kWh)	618	321	$916	$55	352	17
Clothes washer (MJ)*	499	218	$603	$2	12	252
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	0	0	$0	$0	0	N/A
Heater upgrade (MJ)	87,864	0	$0	$0	0	N/A
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

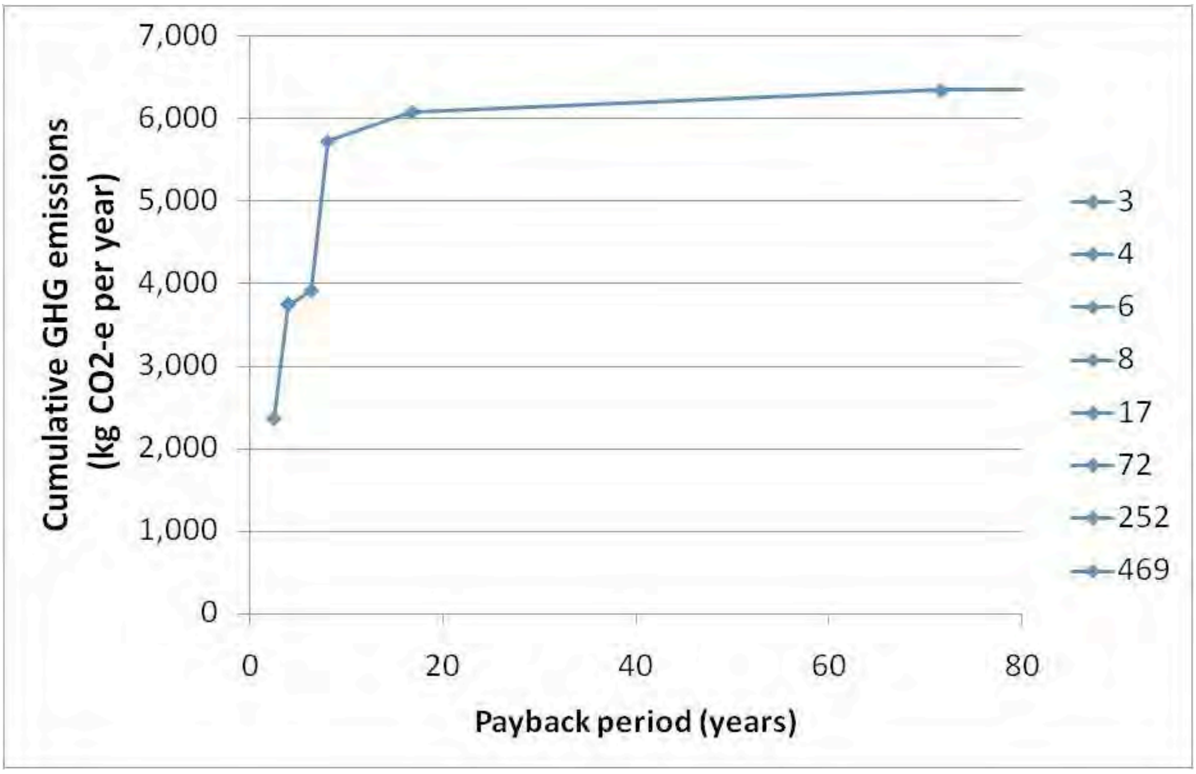
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 3 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 3



The cost curve above only shows the results of upgrades with a payback lower than 80 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Ceiling insulation	90m² upgraded from no insulation to R3.5	$1,166	$466	2,366	3
Draught sealing	Reduced from 1.71 ACH to 0.5 ACH	$1,098	$272	1,381	4
Hot water system	Yes - 10 year old 3.3 star HWS upgraded to 5 star gas storage HWS	$213	$33	170	6
Wall insulation	144.2m² of R1.5 wall insulation installed	$2,885	$357	1,812	8
Refrigerator	Yes - 7 year old 2 star refrigerator upgraded to 5 star refrigerator	$916	$55	352	17
Drapes & pelmets	21.8m² of drapes and 12.6m of pelmets installed	$3,740	$52	265	72
Clothes washer	Yes - 5 year old 2 star clothes washer upgraded to 4 star clothes washer	$603	$2	12	252
Double glazed windows	25.2m² of double glazing installed	$14,633	$31	158	469

Summary and discussion

The cost curve analysis reveals that almost 88% of the total greenhouse gas savings can be achieved by implementing the four upgrades with the shortest payback periods. The top four upgrades in order of shortest to longest payback are:

- ceiling insulation
- draught sealing
- hot water system
- wall insulation

These actions are estimated to result in nearly six tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 4

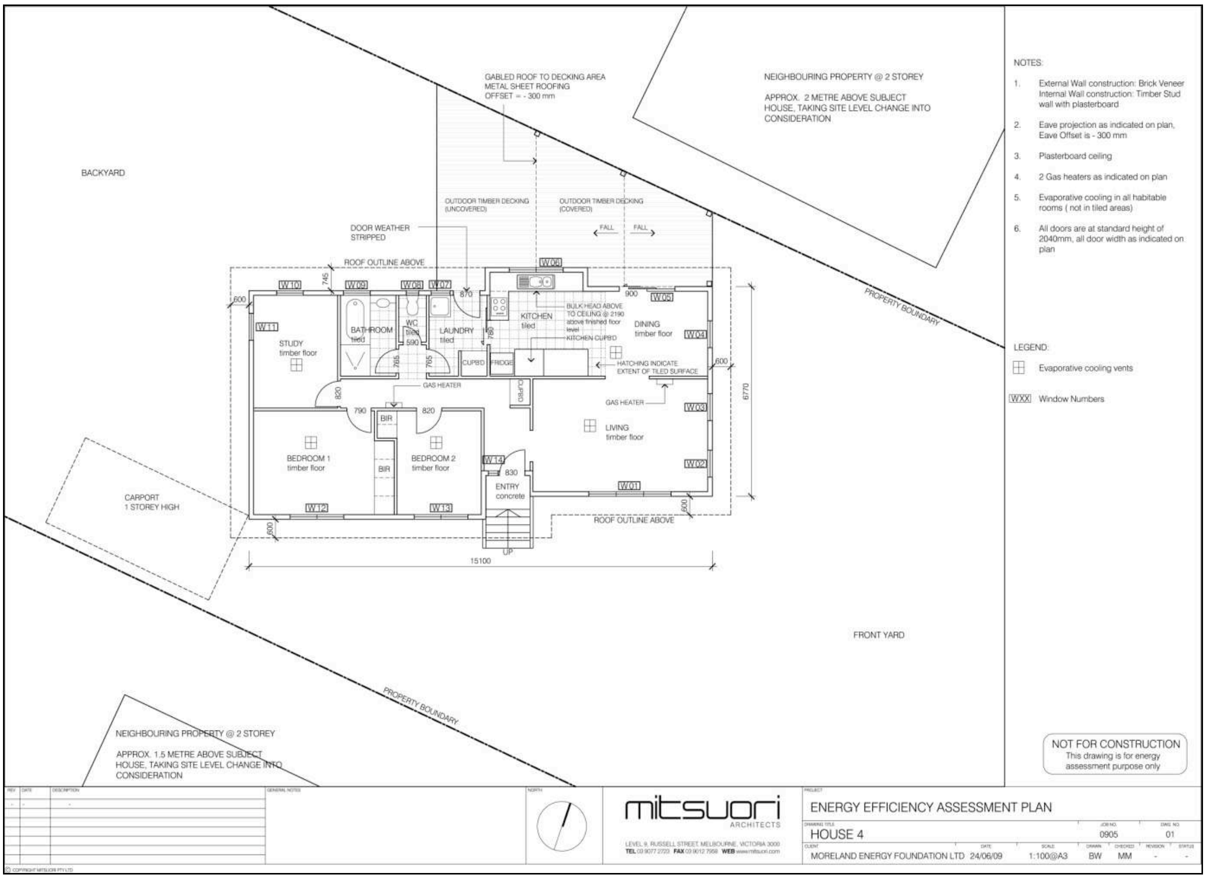
Description

Table 1 provides a basic description of House 4, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 4 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick veneer • Suspended timber floor
Age	1970s
Floor area (m2)	97.3
Existing star rating	1.6
Main type of heating	Gas space heating
Main type of cooling	Evaporative cooling
Percentage of total floor area conditioned	52%
Existing insulation and air leakage status	• R1.5 ceiling insulation • 2.00 ACH

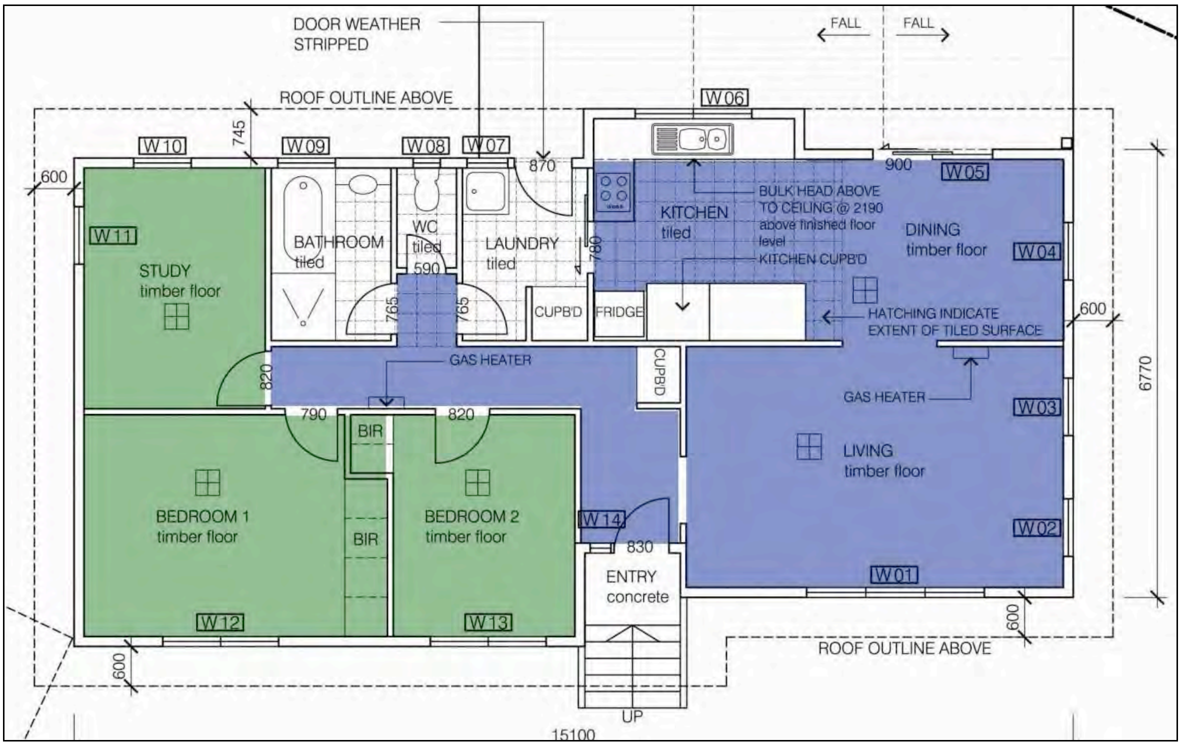
Figure 1: Floor plan of House 4



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 4 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 4 it is possible to achieve a 4.9 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.6	N/A
Upgrade 1: Ceiling insulation (easy)	*Yes	97.3m^2 topped up from R1.5 to R3.5	1.7	$932
Upgrade 2: Draught proofing	Yes	Reduced from 2.00 ACH to 0.5 ACH	2.4	$1,050
Upgrade 3: Underfloor insulation	Yes	97.3m^2 of R1.5 floor insulation installed	2.8	$1,332
Upgrade 4: Drapes and pelmets	Yes	12.3m of pelmets installed	3.1	$1,300
Upgrade 5: External awnings	Yes	13.1m^2 of canvas awnings installed	3.1	$2,017

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	77.6m^2 of R1.5 wall insulation installed	4.4	$1,551
Upgrade 8: Double glazed windows	Yes	28m^2 of double glazing installed	4.9	$16,263

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 4 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	*Yes	97.3m^2 topped up from R1.5 to R3.5	$932
Upgrade 2: Draught proofing	Yes	Reduced from 2.00 ACH to 0.5 ACH	$1,050
Upgrade 3: Underfloor insulation	Yes	97.3m^2 of R1.5 floor insulation installed	$1,332
Upgrade 4: Drapes and pelmets	Yes	7.1m of pelmets installed	$748
Upgrade 5: External awnings	Yes	11.3m^2 of canvas awnings installed	$1,736
Upgrade 6: Ceiling insulation (hard)	No	No hard to access ceiling space	N/A
Upgrade 7: Wall insulation	Yes	77.6m^2 of R1.5 wall insulation installed	$1,551
Upgrade 8: Double glazed windows	Yes	17m^2 of double glazing installed	$9,880

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$932	$17	86	56
Draught sealing	$1,050	$91	465	12
Underfloor insulation	$1,332	$97	490	14
Drapes & pelmets	$748	$27	135	28
External window treatment	$1,736	$0	2	6,243
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$1,551	$72	369	21
Double glazed windows	$9,880	$24	122	418

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 4 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Vulcan	Yes - 4 year old 3.9 star HWS upgraded to solar HWS
Refrigerator	2 door fridge	Fisher & Paykel	Yes - 2 year old 3.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	LG	No - 2 year old 4 star clothes washer
Dishwasher	N/A	N/A	N/A
Heater	Gas space-two wall furnaces	Braemar/Vulcan	Yes - 30 year old 65% efficient heater upgraded to 87% efficient heater
Air conditioner	Evaporative	N/A	No – Evaporative AC not upgraded
Lighting	N/A	N/A	Yes - 8 incandescent lamps replaced with 8 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	18,659	12,328	$3,247	$127	701	26
Refrigerator (kWh)	496	199	$1,374	$34	218	41
Clothes washer (MJ)*	81	0	$0	$0	0	N/A
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	135	$115	$23	148	5
Heater upgrade (MJ)	33,055	8,359	$257	$92	467	3
Air conditioner upgrade (MJ)	269	0	$0	$0	0	N/A

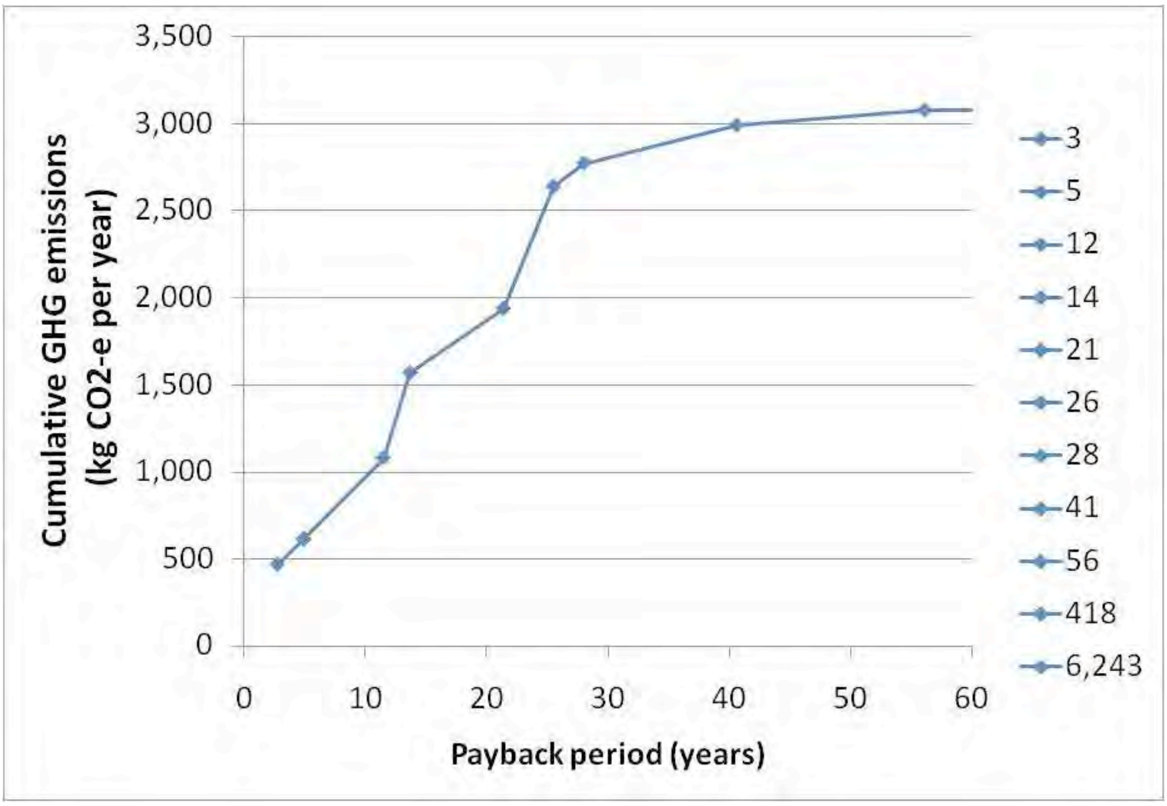
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 4 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 4



The cost curve above only shows the results of upgrades with a payback lower than 60 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Heater upgrade	Yes - 30 year old 65% efficient heater upgraded to 87% efficient heater	$257	$92	467	3
Lighting	Yes - 8 incandescent lamps replaced with 8 CFLs	$115	$23	148	5
Draught sealing	Reduced from 2.00 ACH to 0.5 ACH	$1,050	$91	465	12
Underfloor insulation	97.3m^2 of R1.5 floor insulation installed	$1,332	$97	490	14
Wall insulation	77.6m^2 of R1.5 wall insulation installed	$1,551	$72	369	21
Hot water system	Yes - 4 year old 3.9 star HWS upgraded to solar HWS	$3,247	$127	701	26
Drapes & pelmets	7.1m of pelmets installed	$748	$27	135	28
Refrigerator	Yes - 2 year old 3.5 star refrigerator upgraded to 5 star refrigerator	$1,374	$34	218	41
Ceiling insulation	97.3m^2 topped up from R1.5 to R3.5	$932	$17	86	56
Double glazed windows	17m^2 of double glazing installed	$9,880	$24	122	418
External window treatment	11.3m^2 of canvas awnings installed	$1,736	$0.28	2	6,243

Summary and discussion

The cost curve analysis reveals that almost 60% of the total greenhouse gas savings can be achieved by implementing the five upgrades with the shortest payback periods. The top five upgrades in order of shortest to longest payback are:

- heater upgrade
- lighting
- draught sealing
- underfloor insulation
- wall insulation

These actions are estimated to result in nearly two tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The installation of double glazing and internal and external window treatments also have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 5

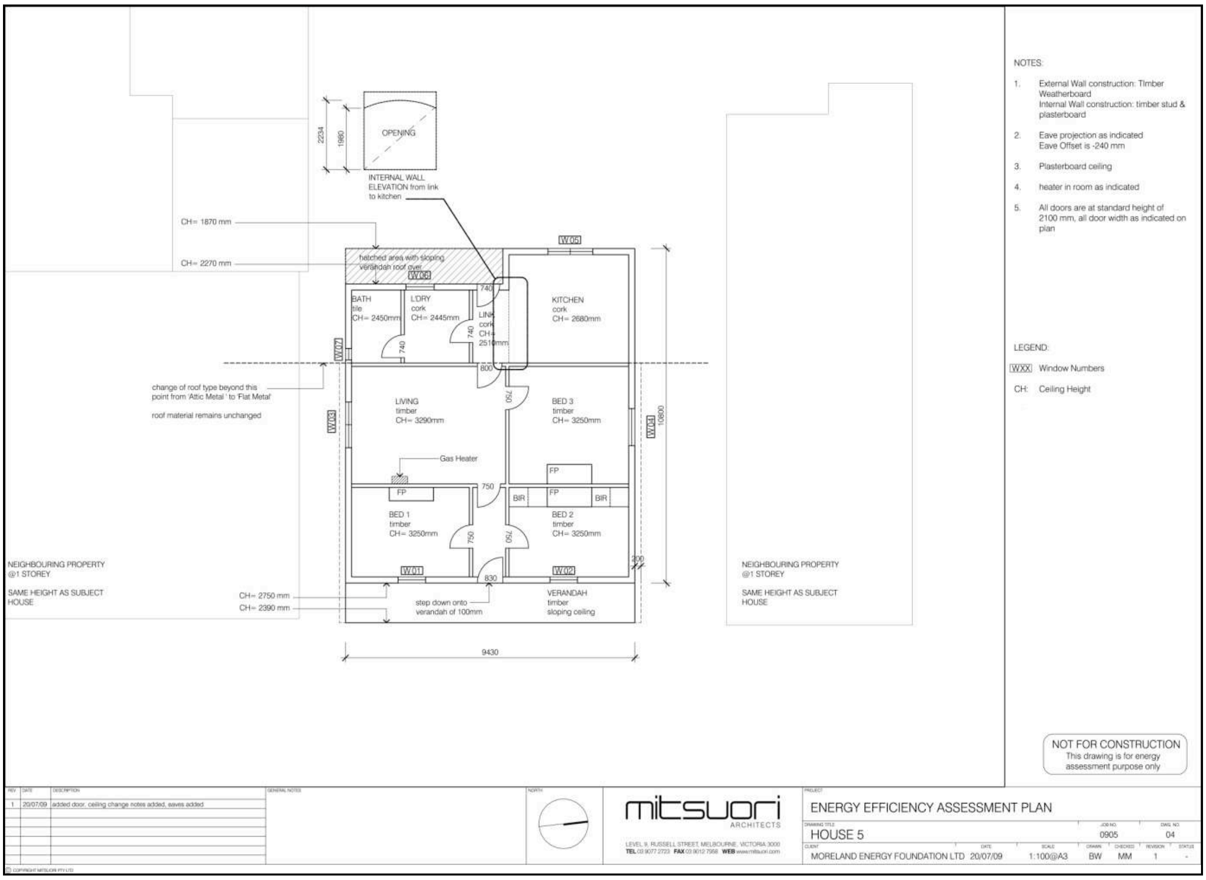
Description

Table 1 provides a basic description of House 5, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 5 with north indicated.

Table1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Weatherboard • Suspended timber floor
Age	1950s
Floor area (m2)	83.8
Existing star rating	0.8
Main type of heating	Gas space heating
Main type of cooling	N/A
Percentage of total floor area conditioned	29%
Existing insulation and air leakage status	• R3.0 ceiling insulation except in flat roof • 2.67 ACH

Figure 1: Floor plan of House 5



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 5 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode

Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 5 it is possible to achieve a 3.9 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	0.8	N/A
Upgrade 1: Ceiling insulation (easy)	No	R3.0 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 2.67 ACH to 0.5 ACH	1.5	$578

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	7.1m^2 of drapes and 4.5m of pelmets installed	1.6	$1,251
Upgrade 5: External awnings	Yes	4.7m^2 of canvas awnings installed	1.6	$719
Upgrade 6: Ceiling insulation (advanced)	Yes	24.7m^2 upgraded from no insulation to R2.5	2.2	$566
Upgrade 7: Wall insulation	Yes	99.3m^2 of R2.5 wall insulation installed	3.8	$1,986
Upgrade 8: Double glazed windows	Yes	8.5m^2 of double glazing installed	3.9	$4,947

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 5 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	No	R3.0 already installed	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 2.67 ACH to 0.5 ACH	$578
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	2.4m^2 of drapes and 1.5m of pelmets installed	$423
Upgrade 5: External awnings	No	No air-conditioner so no external awnings installed	N/A
Upgrade 6: Ceiling insulation (hard)	Yes	24.7m^2 upgraded from no insulation to R2.5	$566

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 7: Wall insulation	Yes	99.3m^2 of R2.5 wall insulation installed	$1,986
Upgrade 8: Double glazed windows	Yes	2.4m^2 of double glazing installed	$1,399

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$578	$107	543	5
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$423	$9	46	46
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$566	$22	111	26
Wall insulation	$1,986	$86	435	23
Double glazed windows	$1,399	$4	22	327

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 5 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem	Yes - 17 year old 2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	LG	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Clothes washer	Top loader	Hoover	Yes - 16 year old clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	N/A	N/A
Heater	Gas space-radiant	Vulcan	Yes - 25 year old 71% efficient heater upgraded to 83% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	No

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	22,251	5,474	$128	$60	306	2
Refrigerator (kWh)	370	73	$1,099	$12	80	88
Clothes washer (MJ)*	602	321	$103	$4	18	29
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	0	$0	$0	0	N/A
Heater upgrade (MJ)	31,749	4,590	$266	$50	256	5
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

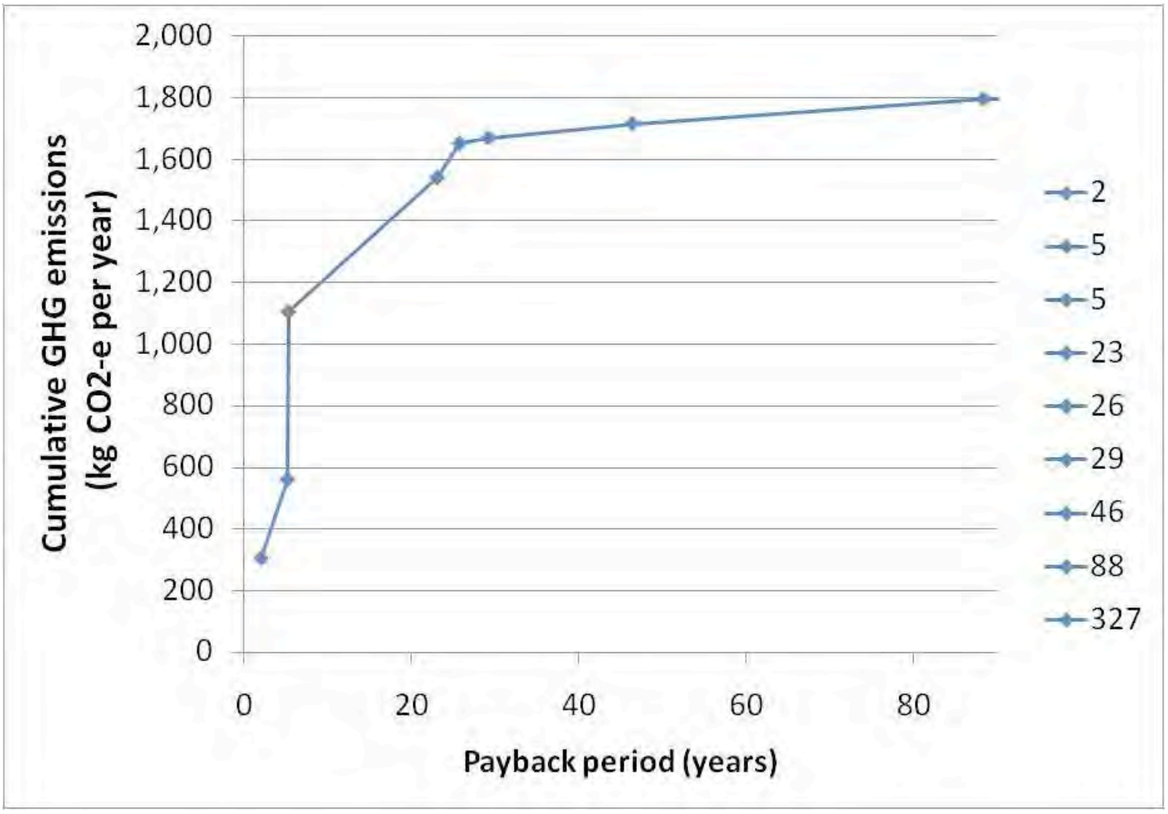
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 5 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 5



The cost curve above only shows the results of upgrades with a payback lower than 90 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Hot water system	Yes - 17 year old 2 star HWS upgraded to 5 star gas storage HWS	$128	$60	306	2
Heater upgrade	Yes - 25 year old 71% efficient heater upgraded to 83% efficient heater	$266	$50	256	5
Draught sealing	Reduced from 2.67 ACH to 0.5 ACH	$578	$107	543	5
Wall insulation	99.3m^2 of R2.5 wall insulation installed	$1,986	$86	435	23
Ceiling insulation (advanced)	24.7m^2 upgraded from no insulation to R2.5	$566	$22	111	26
Clothes washer	Yes - 16 year old clothes washer upgraded to 4 star clothes washer	$103	$4	18	29
Drapes & pelmets	2.4m^2 of drapes and 1.5m of pelmets installed	$423	$9	46	46
Refrigerator	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator	$1,099	$12	80	88
Double glazed windows	2.4m^2 of double glazing installed	$1,399	$4	22	327
Lighting	No	$0	$0	0	N/A
Underfloor insulation	Sub-floor not accessible	$0	$0	0	N/A
Ceiling insulation	R3.0 already installed	$0	$0	0	N/A
External window treatment	No unshaded windows in conditioned zones	$0	$0	0	N/A
Dishwasher	N/A	$0	$0	0	N/A
Air conditioner upgrade	N/A	$0	$0	0	N/A

Summary and discussion

The cost curve analysis reveals that almost 85% of the total greenhouse gas savings can be achieved by implementing the four upgrades with the shortest payback periods. The top four upgrades in order of shortest to longest payback are:

- hot water system
- heater upgrade
- draught sealing
- wall insulation

These actions are estimated to result in over one and a half tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 6

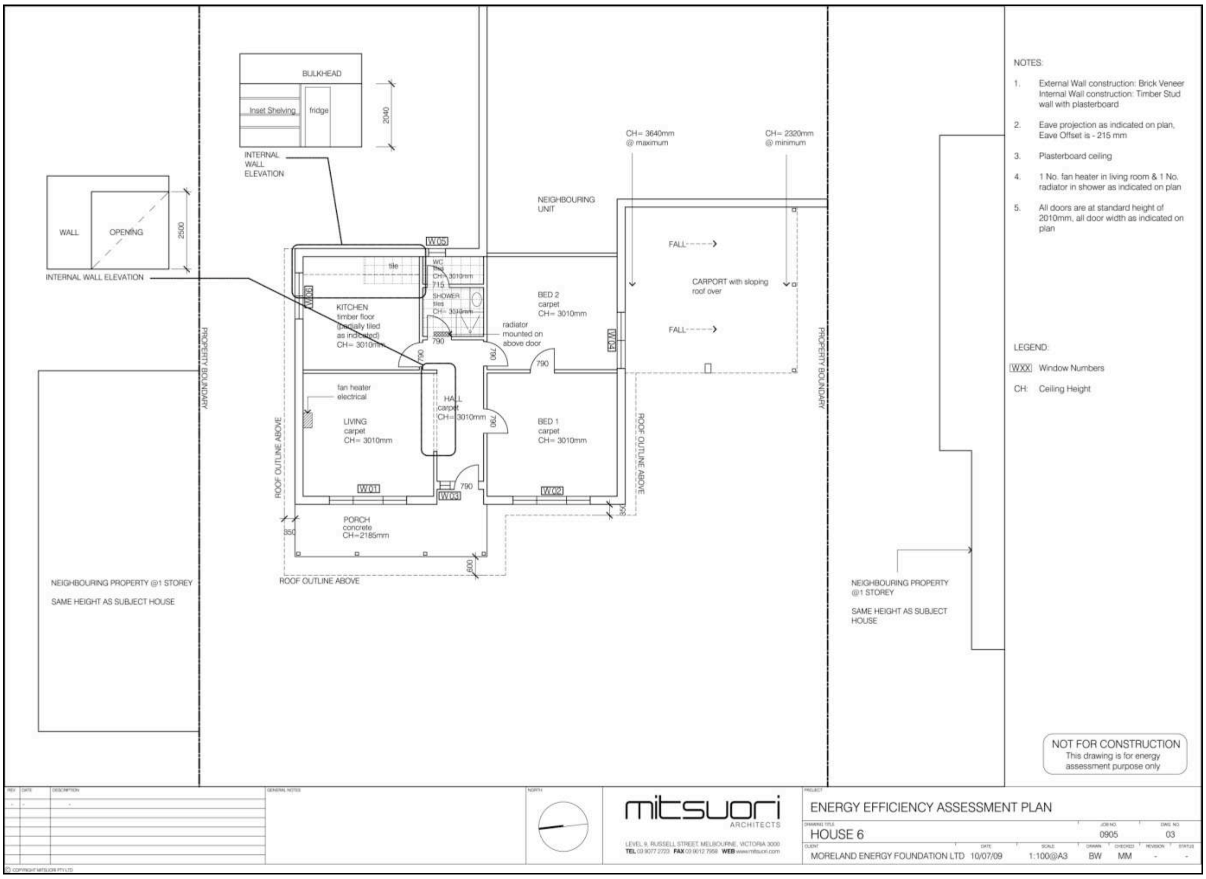
Description

Table 1 provides a basic description of House 6, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 6 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Semi-detached • Brick veneer • Suspended timber floor
Age	1960s
Floor area (m2)	75.1
Existing star rating	0.7
Main type of heating	Reverse cycle air-conditioner
Main type of cooling	Reverse cycle air-conditioner
Percentage of total floor area conditioned	32%
Existing insulation and air leakage status	• No ceiling insulation • 1.82 ACH

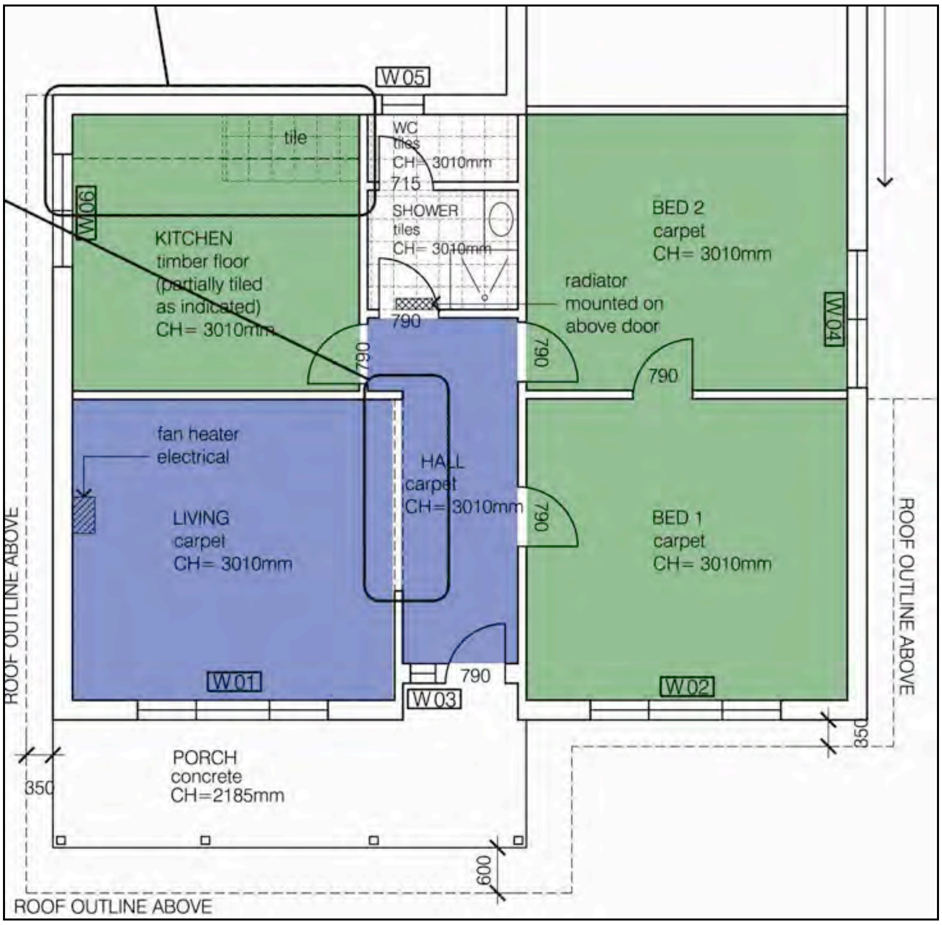
Figure 1: Floor plan of House 6



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 6 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 6 it is possible to achieve a 4.8 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	0.7	N/A
Upgrade 1: Ceiling insulation (easy)	Yes	75.1m^2 upgraded from no insulation to R3.5	2.1	$974
Upgrade 2: Draught proofing	Yes	Reduced from 1.82 ACH to 0.5 ACH	2.8	$456
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 4: Drapes and pelmets	Yes	10.1m^2 of drapes and 5.8m of pelmets installed	2.9	$1,734
Upgrade 5: External awnings	Yes	1.8m^2 of canvas awnings installed	3	$282
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	83.6m^2 of R1.5 wall insulation installed	4.7	$1,673
Upgrade 8: Double glazed windows	Yes	10.1m^2 of double glazing installed	4.8	$5,881

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 6 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	Yes	75.1m^2 upgraded from no insulation to R3.5	$974
Upgrade 2: Draught proofing	Yes	Reduced from 1.82 ACH to 0.5 ACH	$456
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	3m^2 of drapes installed	$327
Upgrade 5: External awnings	No	No unshaded windows in conditioned zones	$0
Upgrade 6: Ceiling insulation (hard)	No	No hard to access ceiling space	N/A
Upgrade 7: Wall insulation	Yes	83.6m^2 of R1.5 wall insulation installed	$1,673

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 8: Double glazed windows	Yes	2.9m^2 of double glazing installed	$1,718

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$974	$167	1,076	6
Draught sealing	$456	$61	88	7
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$327	$4	21	79
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$1,673	$56	289	30
Double glazed windows	$1,718	$4	20	462

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 6 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Hardie dux	Yes - 12 year old 3.2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Samsung	Yes - 9 year old 3.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Top loader	Fisher&Paykel	Yes - 15 year old clothes washer upgraded to 4 star clothes washer

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Dishwasher	N/A	N/A	N/A
Heater	Reverse cycle air conditioner	Kelvinator	Yes - 8 year old 263% efficient electric heater upgraded to 87% efficient gas heater
Air conditioner	AC wall box (reverse cycle)	N/A	Yes - 8 year old 283% efficient air conditioner upgraded to 396% efficient air conditioner
Lighting	N/A	N/A	No

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,906	3,128	$128	$34	175	4
Refrigerator (kWh)	469	172	$733	$29	188	25
Clothes washer (MJ)*	479	198	$103	$2	11	48
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	0	$0	$0	0	N/A
Heater upgrade (MJ)	4,799	-10,826	$1,091	$55	586	20
Air conditioner upgrade (MJ)	276	79	$877	$4	24	236

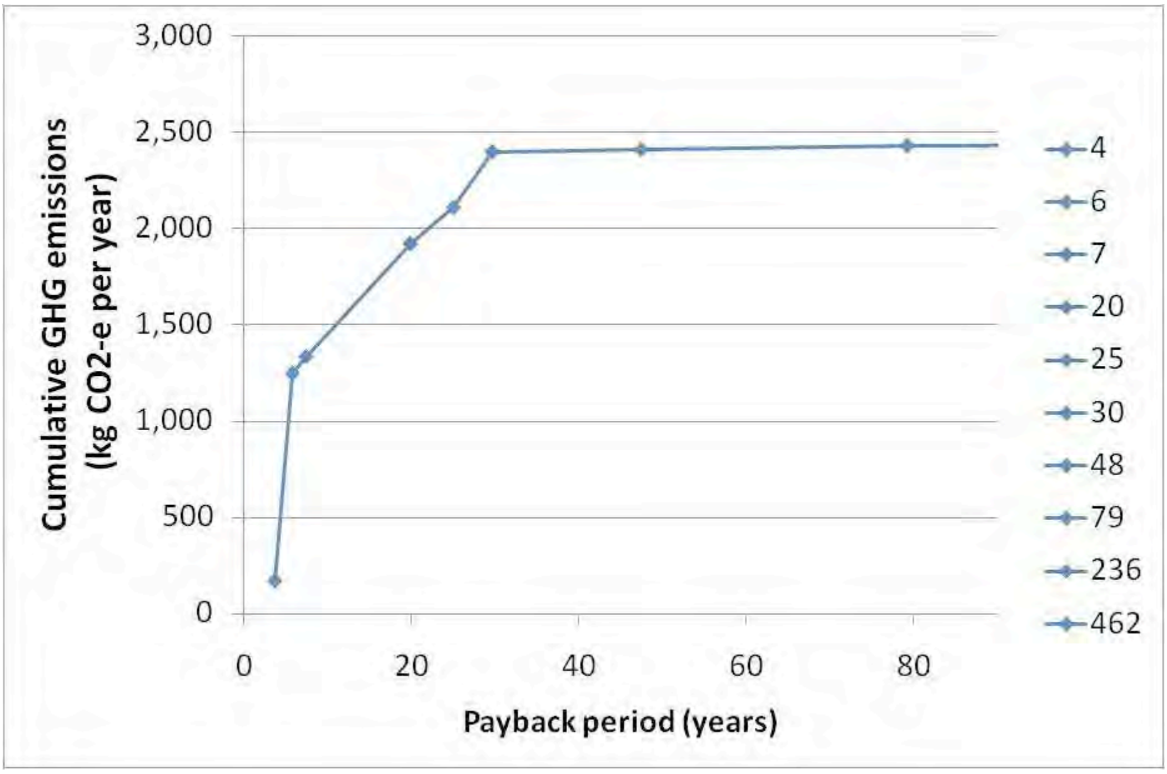
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 6 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 6



The cost curve above only shows the results of upgrades with a payback lower than 90 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Hot water system	Yes - 12 year old 3.2 star HWS upgraded to 5 star gas storage HWS	$128	$34	175	4
Ceiling insulation	75.1m^2 upgraded from no insulation to R3.5	$974	$167	1,076	6
Draught sealing	Reduced from 1.82 ACH to 0.5 ACH	$456	$61	88	7
Heater upgrade	Yes - 8 year old 263% efficient electric heater upgraded to 87% efficient gas heater	$1,091	$55	586	20
Refrigerator	Yes - 9 year old 3.5 star refrigerator upgraded to 5 star refrigerator	$733	$29	188	25
Wall insulation	83.6m^2 of R1.5 wall insulation installed	$1,673	$56	289	30
Clothes washer	Yes - 15 year old clothes washer upgraded to 4 star clothes washer	$103	$2	11	48
Drapes & pelmets	3m^2 of drapes installed	$327	$4	21	79
Air conditioner upgrade	Yes - 8 year old 283% efficient air conditioner upgraded to 396% efficient air conditioner	$877	$4	24	236
Double glazed windows	2.9m^2 of double glazing installed	$1,718	$4	20	462

Summary and discussion

The cost curve analysis reveals that almost 78% of the total greenhouse gas savings can be achieved by implementing the four upgrades with the shortest payback periods. The top four upgrades in order of shortest to longest payback are:

- hot water system
- ceiling insulation
- draught sealing
- heater upgrade

These actions are estimated to result in nearly two tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 7

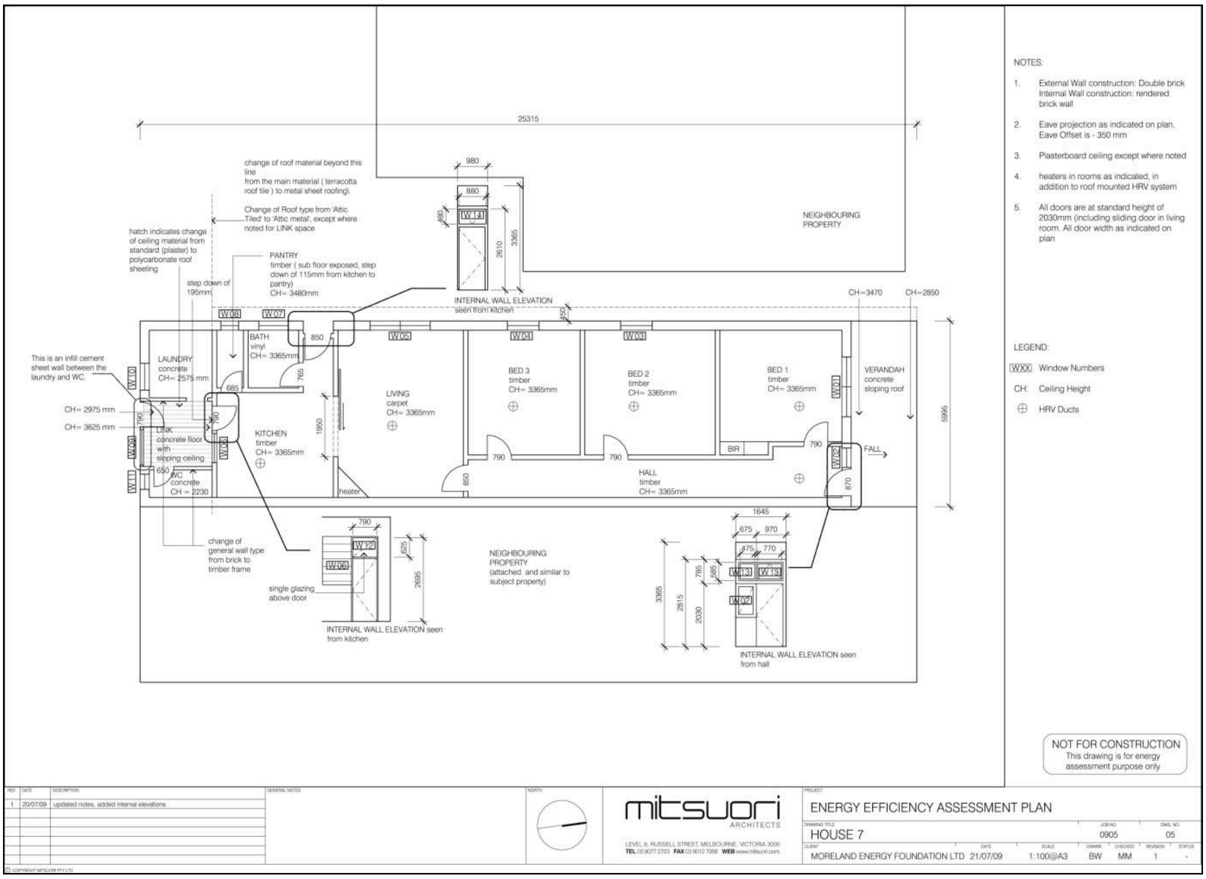
Description

Table 1 provides a basic description of House 7, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 7 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Semi-detached • Brick cavity • Suspended timber floor/concrete slab on ground
Age	1930s
Floor area (m2)	114.3
Existing star rating	2.6
Main type of heating	Gas space heating
Main type of cooling	N/A
Percentage of total floor area conditioned	47%
Existing insulation and air leakage status	• R2.5 ceiling insulation except in flat roof • 1.43 ACH

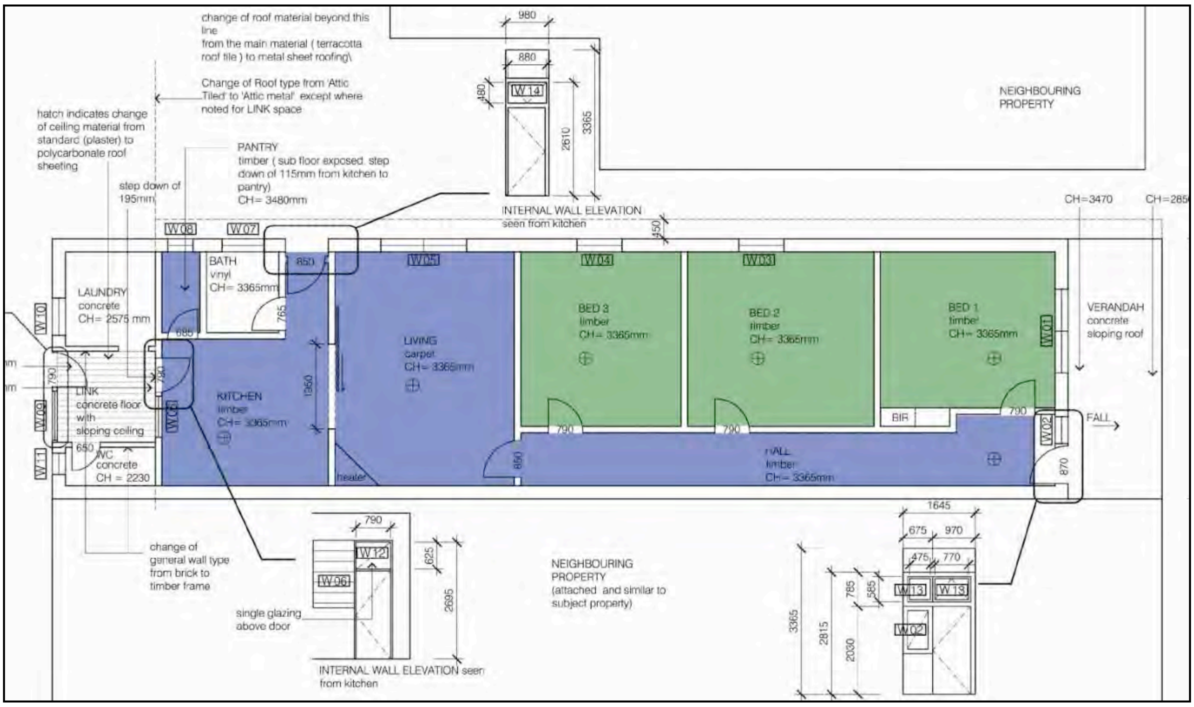
Figure 1: Floor plan of House 7



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 7 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 7 it is possible to achieve a 4.6 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	2.6	N/A
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.43 ACH to 0.5 ACH	3.3	$630
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	11.5m^2 of drapes and 6.6m of pelmets installed	3.5	$1,965

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 5: External awnings	Yes	4.5m^2 of canvas awnings installed	3.5	$688
Upgrade 6: Ceiling insulation (advanced)	Yes	9.3m^2 upgraded from no insulation to R2.5	3.5	$213
Upgrade 7: Wall insulation	Yes	83.4m^2 of R1.5 wall insulation installed	4.5	$1,667
Upgrade 8: Double glazed windows	Yes	9.3m^2 of double glazing installed	4.6	$5,371

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 7 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.43 ACH to 0.5 ACH	$630
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	4.2m^2 of drapes and 2.5m of pelmets installed	$737
Upgrade 5: External awnings	No	No air-conditioner so no external awnings installed	N/A
Upgrade 6: Ceiling insulation (hard)	Yes	9.3m^2 upgraded from no insulation to R2.5	$213
Upgrade 7: Wall insulation	Yes	83.4m^2 of R1.5 wall insulation installed	$1,667

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 8: Double glazed windows	Yes	5.7m^2 of double glazing installed	$3,312

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$630	$104	526	6
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$737	$17	88	42
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$213	$4	21	50
Wall insulation	$1,667	$74	378	22
Double glazed windows	$3,312	$10	51	331

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 7 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas instantaneous	Valliant	Yes - 30 year old 3 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Westinghouse	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Ariston	Yes - 1 year old 3 star clothes washer upgraded to 4 star clothes washer

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Dishwasher	NA	N/A	N/A
Heater	Gas space-radiant	Pyrox	Yes - 25 year old 71% efficient heater upgraded to 83% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	Yes - 3 incandescent lamps and 3 low voltage halogen down-lights replaced with 6 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,777	2,999	$128	$33	167	4
Refrigerator (kWh)	410	113	$1,099	$19	124	57
Clothes washer (MJ)*	377	96	$948	$1	5	899
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	162	$129	$28	178	5
Heater upgrade (MJ)	39,451	5,704	$266	$63	318	4
Air conditioner upgrade (MJ)	0	0	$0	$0	0	N/A

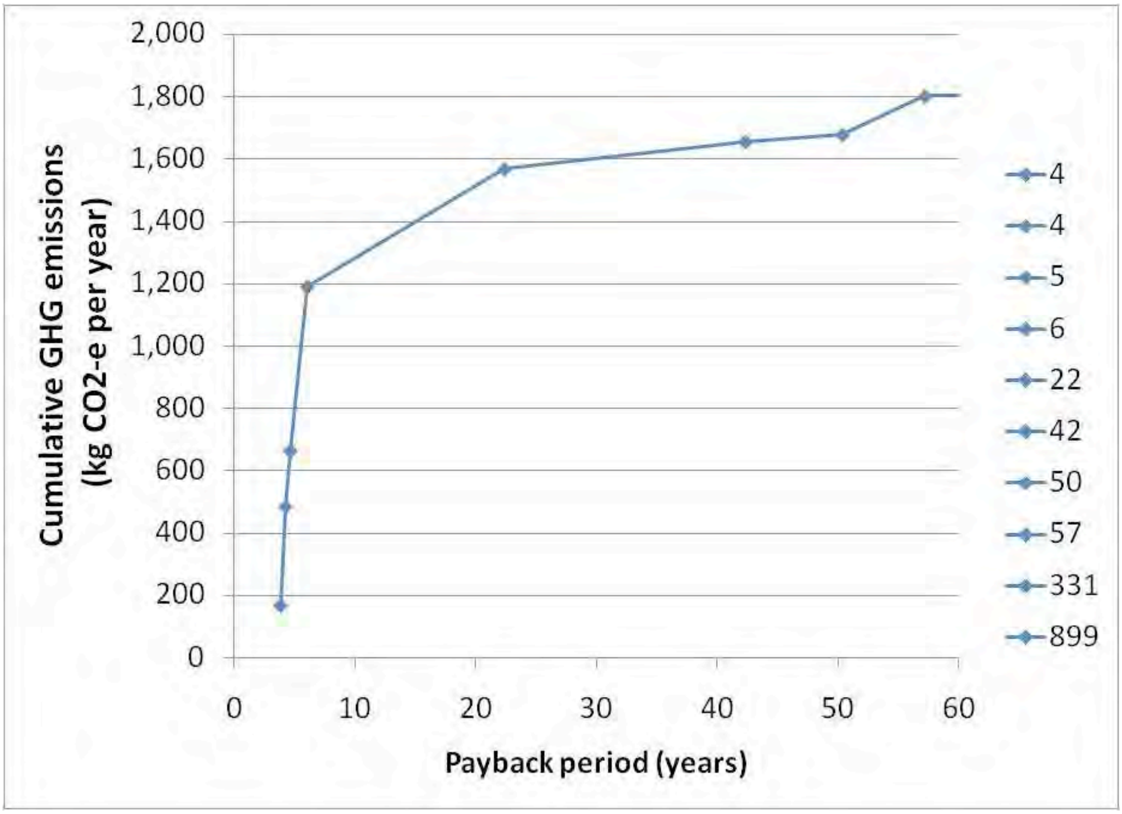
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 7 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 7



The cost curve above only shows the results of upgrades with a payback lower than 60 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Hot water system	Yes - 30 year old 3 star HWS upgraded to 5 star gas storage HWS	$128	$33	167	4
Heater upgrade	Yes - 25 year old 71% efficient heater upgraded to 83% efficient heater	$266	$63	318	4
Lighting	Yes - 3 incandescent lamps and 3 low voltage halogen down-lights replaced with 6 CFLs	$129	$28	178	5
Draught sealing	Reduced from 1.43 ACH to 0.5 ACH	$630	$104	526	6
Wall insulation	83.4m^2 of R1.5 wall insulation installed	$1,667	$74	378	22
Drapes & pelmets	4.2m^2 of drapes and 2.5m of pelmets installed	$737	$17	88	42
Ceiling insulation (advanced)	9.3m^2 upgraded from no insulation to R2.5	$213	$4	21	50
Refrigerator	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator	$1,099	$19	124	57
Double glazed windows	5.7m^2 of double glazing installed	$3,312	$10	51	331
Clothes washer	Yes - 1 year old 3 star clothes washer upgraded to 4 star clothes washer	$948	$1	5	899

Summary and discussion

The cost curve analysis reveals that 84% of the total greenhouse gas savings can be achieved by implementing the five upgrades with the shortest payback periods. The top five upgrades in order of shortest to longest payback are:

- hot water system
- heater upgrade
- lighting
- draught sealing
- wall insulation

These actions are estimated to result in over one and a half tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 8

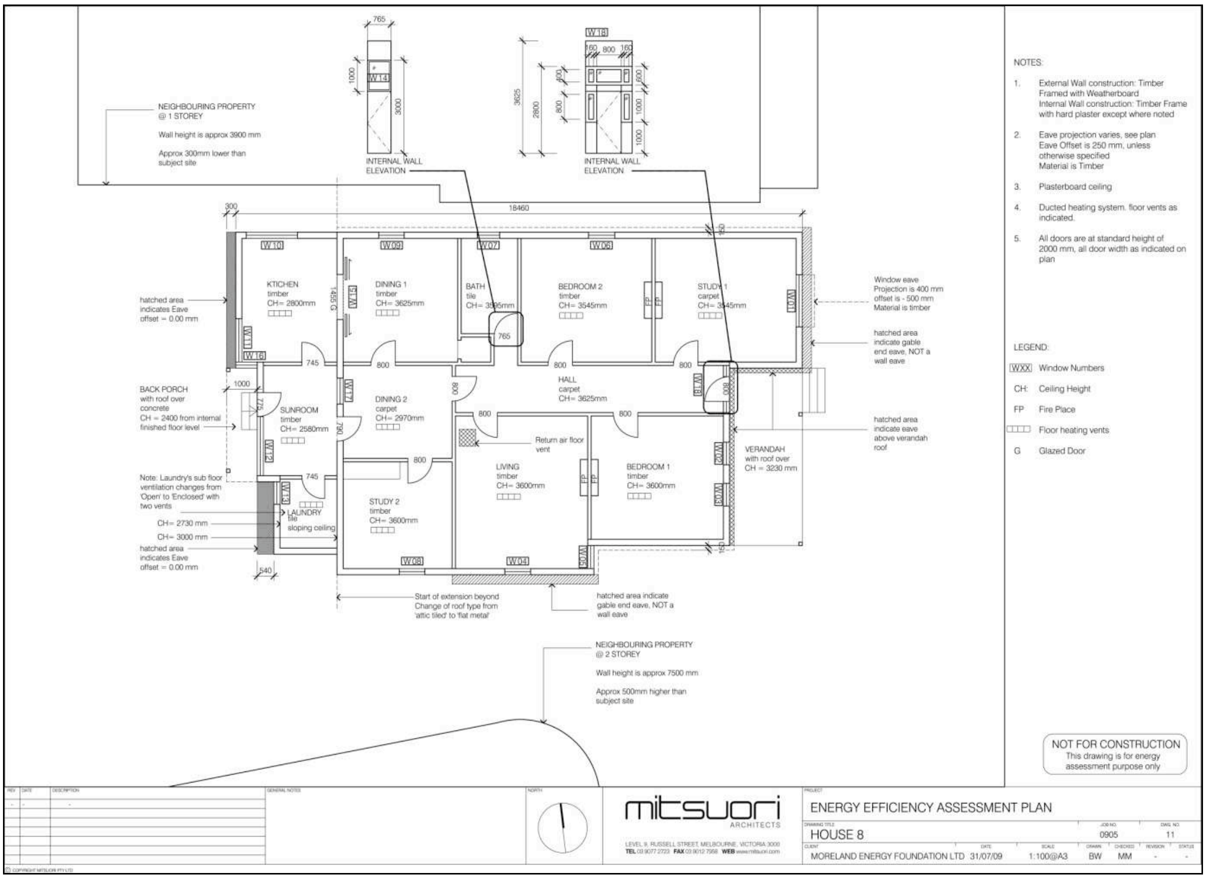
Description

Table 1 provides a basic description of House 8, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 8 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Weatherboard • Suspended timber floor
Age	1910s
Floor area (m2)	157.5
Existing star rating	0
Main type of heating	Gas central heating
Main type of cooling	N/A
Percentage of total floor area conditioned	96%
Existing insulation and air leakage status	• No ceiling insulation • 1.14 ACH

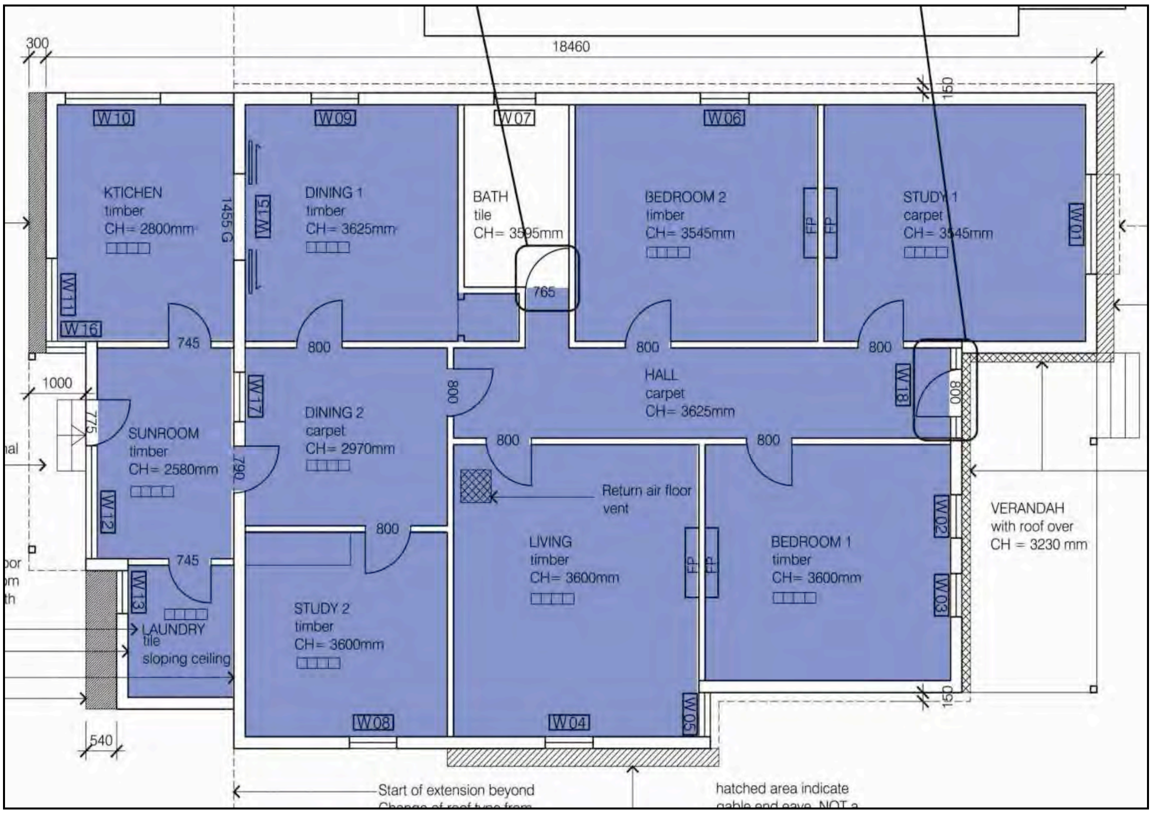
Figure 1: Floor plan of House 8



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 8 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 8 it is possible to achieve a 3.9 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	0	N/A
Upgrade 1: Ceiling insulation (easy)	Yes	132.4m^2 upgraded from no insulation to R3.5	0.8	$1,716
Upgrade 2: Draught proofing	Yes	Reduced from 1.14 ACH to 0.5 ACH	1.1	$776
Upgrade 3: Underfloor insulation	Yes	157m^2 of R1.5 floor insulation installed	1.4	$2,157
Upgrade 4: Drapes and pelmets	Yes	19.3m^2 of drapes and 7.5m of pelmets installed	1.5	$2,930

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 5: External awnings	Yes	18.9m^2 of canvas awnings installed	1.6	$2,922
Upgrade 6: Ceiling insulation (advanced)	Yes	25.1m^2 upgraded from no insulation to R2.5	2	$576
Upgrade 7: Wall insulation	Yes	176.7m^2 of R2.5 wall insulation installed	3.7	$3,535
Upgrade 8: Double glazed windows	Yes	22.5m^2 of double glazing installed	3.9	$13,100

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 2 are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$1,716	$830	4,214	2
Draught sealing	$776	$257	1,306	3
Underfloor insulation	$2,157	$289	1,467	7
Drapes & pelmets	$2,930	$53	270	55
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$576	$167	846	3
Wall insulation	$3,535	$671	3,407	5
Double glazed windows	$13,100	$43	218	305

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 8 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Vulcan	Yes - 13 year old 3.2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Fisher & Paykel	Yes - 3 year old 3.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Miele	Yes - 3 year old 3.5 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	N/A	N/A
Heater	Gas central	Braemar	Yes - 17 year old 65% efficient heater upgraded to 91% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	Yes - 14 incandescent lamps and 3 low voltage halogen down-lights replaced with 17 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,960	3,182	$128	$35	178	4
Refrigerator (kWh)	479	183	$1,282	$31	200	41
Clothes washer (MJ)*	160	-281	$776	$4	160	173
Dishwasher (kWh)	--	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	171	$184	$29	187	6
Heater upgrade (MJ)	186,213	51,607	$398	$568	2,881	1
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

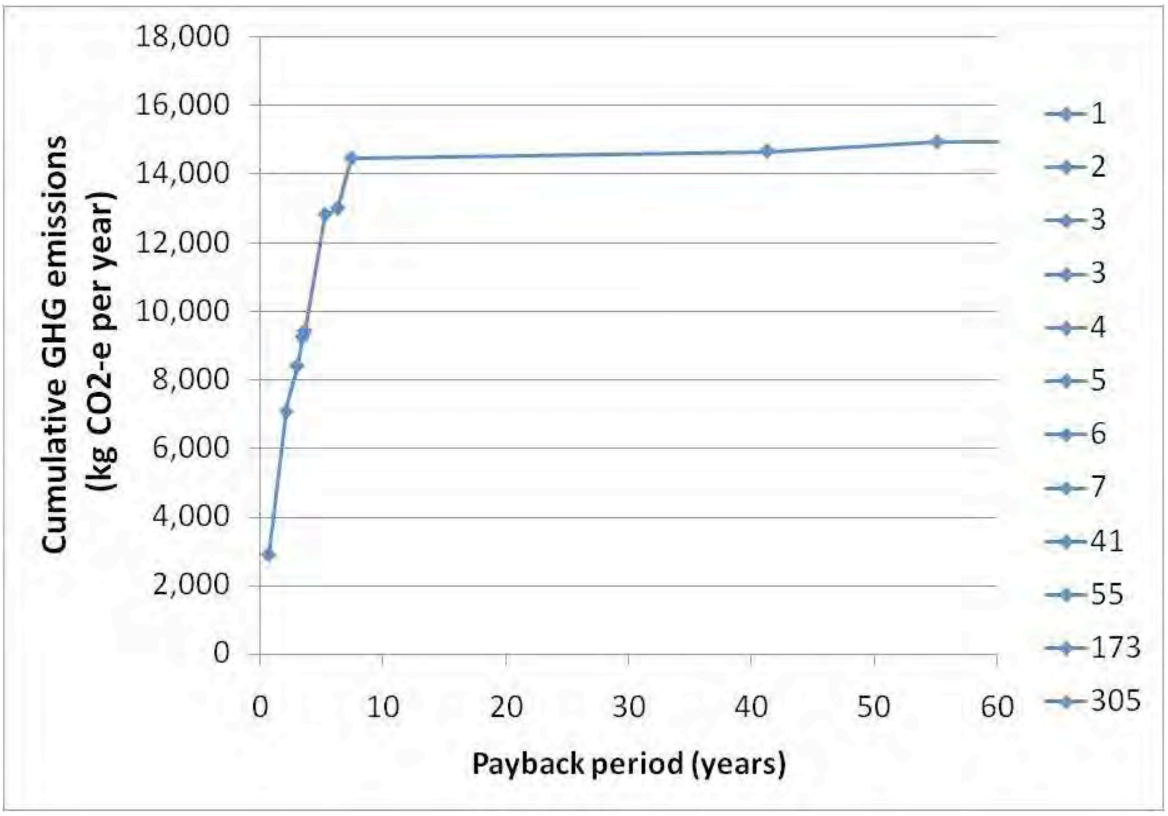
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 8 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 8



The cost curve above only shows the results of upgrades with a payback lower than 60 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Heater upgrade	Yes - 17 year old 65% efficient heater upgraded to 91% efficient heater	$398	$568	2,881	1
Ceiling insulation	132.4m^2 upgraded from no insulation to R3.5	$1,716	$830	4,214	2
Draught sealing	Reduced from 1.14 ACH to 0.5 ACH	$776	$257	1,306	3
Ceiling insulation (advanced)	25.1m^2 upgraded from no insulation to R2.5	$576	$167	846	3
Hot water system	Yes - 13 year old 3.2 star HWS upgraded to gas 5 star HWS	$128	$35	178	4
Wall insulation	176.7m^2 of R2.5 wall insulation installed	$3,535	$671	3,407	5
Lighting	Yes - 14 incandescent lamps and 3 low voltage halogen down-lights replaced with 17 CFLs	$184	$29	187	6
Underfloor insulation	157m2 of R1.5 floor insulation installed	$2,157	$289	1,467	7
Refrigerator	Yes - 3 year old 3.5 star refrigerator upgraded to 5 star refrigerator	$1,282	$31	200	41
Drapes & pelmets	19.3m^2 of drapes and 7.5m of pelmets installed	$2,930	$53	270	55
Clothes washer	Yes - 3 year old 3.5 star clothes washer upgraded to 4 star clothes washer	$776	$4	160	173
Double glazed windows	22.5m^2 of double glazing installed	$13,100	$43	218	305

Summary and discussion

The cost curve analysis reveals that almost 94% of the total greenhouse gas savings can be achieved by implementing the eight upgrades with the shortest payback periods. The top eight upgrades in order of shortest to longest payback are:

- heater upgrade

- ceiling insulation
- draught sealing
- ceiling insulation (advanced)
- hot water system
- wall insulation
- lighting
- underfloor insulation

These actions are estimated to result in over fourteen tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 9

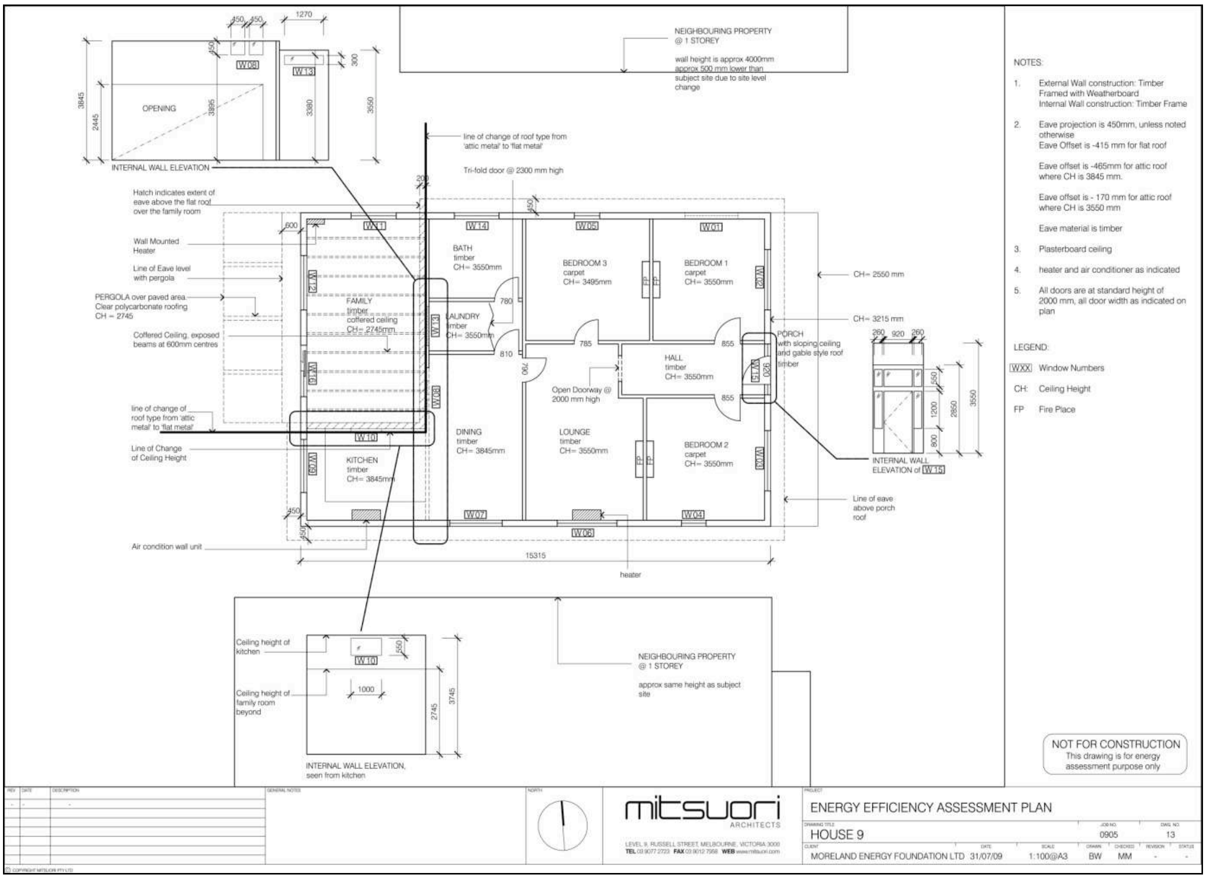
Description

Table 1 provides a basic description of House 9, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 9 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Weatherboard • Suspended timber floor
Age	1900s
Floor area (m2)	139.2
Existing star rating	1.1
Main type of heating	Gas space heating
Main type of cooling	Reverse cycle air-conditioner
Percentage of total floor area conditioned	58%
Existing insulation and air leakage status	• R3.0 ceiling insulation except in flat roof • 0.87 ACH

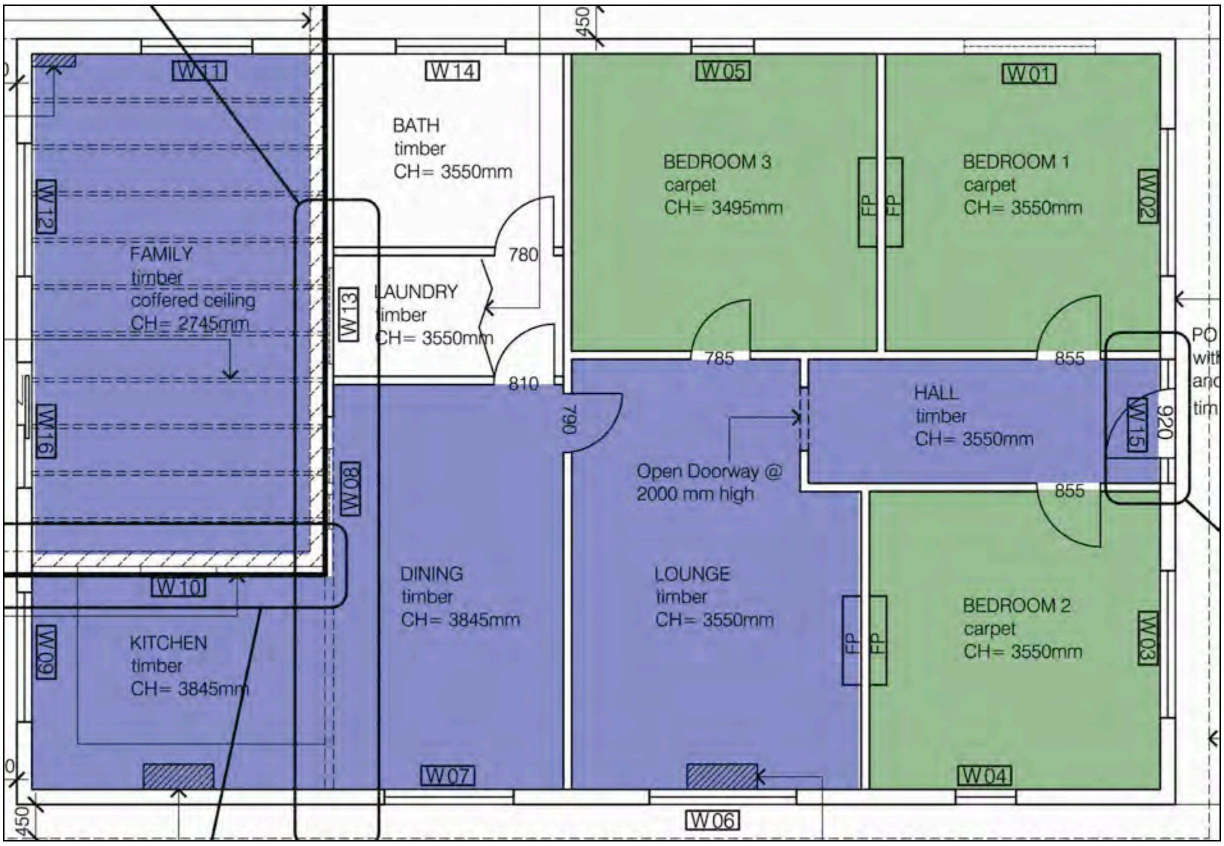
Figure 1: Floor plan of House 9



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 9 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 9 it is possible to achieve a 3.5 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.1	N/A
Upgrade 1: Ceiling insulation (easy)	No	R3.0 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 0.87 ACH to 0.5 ACH	1.3	$426
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 4: Drapes and pelmets	Yes	25.9m^2 of drapes and 12.4m of pelmets installed	1.5	$4,168
Upgrade 5: External awnings	Yes	17.6m^2 of canvas awnings installed	1.5	$2,716
Upgrade 6: Ceiling insulation (advanced)	Yes	25.7m^2 upgraded from no insulation to R2.5	2	$588
Upgrade 7: Wall insulation	Yes	150.1m^2 of R2.5 wall insulation installed	3.3	$3,002
Upgrade 8: Double glazed windows	Yes	29.5m^2 of double glazing installed	3.5	$17,104

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 9 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	No	R3.0 already installed	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 0.87 ACH to 0.5 ACH	$426
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	14.2m^2 of drapes and 5.1m of pelmets installed	$2,105
Upgrade 5: External awnings	Yes	6.9m^2 of canvas awnings installed	$1,072
Upgrade 6: Ceiling insulation (hard)	Yes	25.7m^2 upgraded from no insulation to R2.5	$588

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 7: Wall insulation	Yes	150.1m^2 of R2.5 wall insulation installed	$3,002
Upgrade 8: Double glazed windows	Yes	17.3m^2 of double glazing installed	$10,073

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$426	$67	341	6
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$2,105	$24	123	88
External window treatment	$1,072	$4	26	260
Ceiling insulation (advanced)	$588	$145	747	4
Wall insulation	$3,002	$326	1,686	9
Double glazed windows	$10,073	$20	103	508

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 9 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem	Yes - 10 year old 3.2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Westinghouse	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Clothes washer	Front loader	Simpson	Yes - 5 year old 3 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Asko	Yes - 4 year old 2.5 star dishwasher upgraded to 4 star dishwasher
Heaters	Gas space-1 convection/1 wall furnace	Rinnai/Vulcan	Yes – Two 8&30 year old 71% efficient heaters upgraded to 87% efficient heaters
Air conditioner	AC split (reverse cycle)	N/A	Yes - 1 year old 308% efficient air conditioner upgraded to 320% efficient air conditioner
Lighting	N/A	N/A	Yes - 1 incandescent lamp and 6 low voltage halogen down-lights replaced with 7 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	19,906	3,128	$213	$34	175	6
Refrigerator (kWh)	396	99	$1,099	$17	109	65
Clothes washer (MJ)*	334	53	$603	$1	3	1,038
Dishwasher (kWh)	177	58	$1,266	$10	63	129
Lighting (kWh)	Not estimated	237	$233	$40	259	6
Heater upgrade (MJ)	82,459	15,165	$1,249	$167	847	7
Air conditioner upgrade (MJ)	1,021	38	$2,427	$2	12	1,342

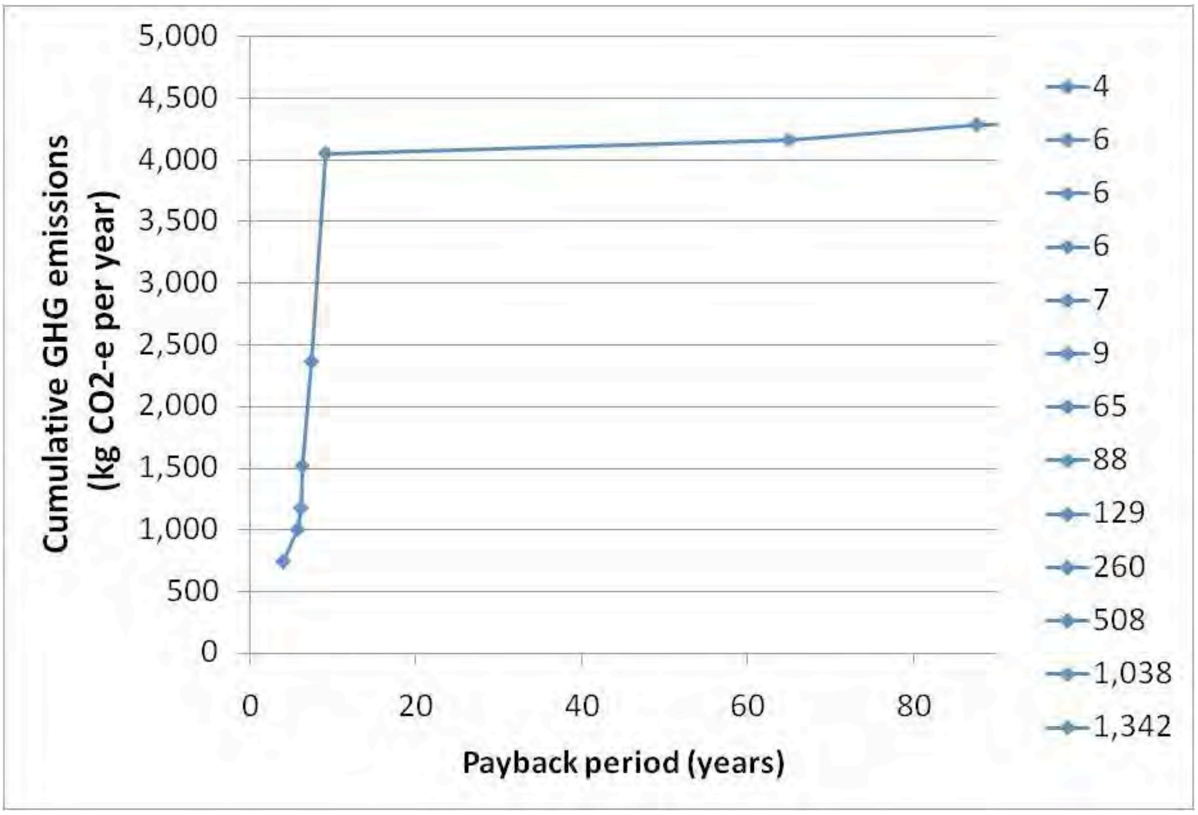
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 9 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 9



The cost curve above only shows the results of upgrades with a payback lower than 90 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Ceiling insulation (advanced)	25.7m^2 upgraded from no insulation to R2.5	$588	$145	747	4
Lighting	Yes - 1 incandescent lamp and 6 low voltage halogen down-lights replaced with 7 CFLs	$233	$40	259	6
Hot water system	Yes - 10 year old 3.2 star HWS upgraded to 5 star gas storage HWS	$213	$34	175	6
Draught sealing	Reduced from 0.87 ACH to 0.5 ACH	$426	$67	341	6
Heater upgrade	Yes - Two 8&30 year old 71% efficient heaters upgraded to 87% efficient heaters	$1,249	$167	847	7
Wall insulation	150.1m^2 of R2.5 wall insulation installed	$3,002	$326	1,686	9
Refrigerator	Yes - 5 year old 4 star refrigerator upgraded to 5 star refrigerator	$1,099	$17	109	65
Drapes & pelmets	14.2m^2 of drapes and 5.1m of pelmets installed	$2,105	$24	123	88
Dishwasher	Yes - 4 year old 2.5 star dishwasher upgraded to 4 star dishwasher	$1,266	$10	63	129
External window treatment	6.9m^2 of canvas awnings installed	$1,072	$4	26	260
Double glazed windows	17.3m^2 of double glazing installed	$10,073	$20	103	508
Clothes washer	Yes - 5 year old 3 star clothes washer upgraded to 4 star clothes washer	$603	$1	3	1,038
Air conditioner upgrade	Yes - 1 year old 308% efficient air conditioner upgraded to 320% efficient air conditioner	$2,427	$2	12	1,342

Summary and discussion

The cost curve analysis reveals that almost 90% of the total greenhouse gas savings can be achieved by implementing the six upgrades with the shortest payback periods. The top six upgrades in order of shortest to longest payback are:

- ceiling insulation (advanced)
- lighting
- hot water system
- draught sealing
- heater upgrade
- wall insulation

These actions are estimated to result in over four tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The installation of double glazing and internal and external window treatments also have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 10

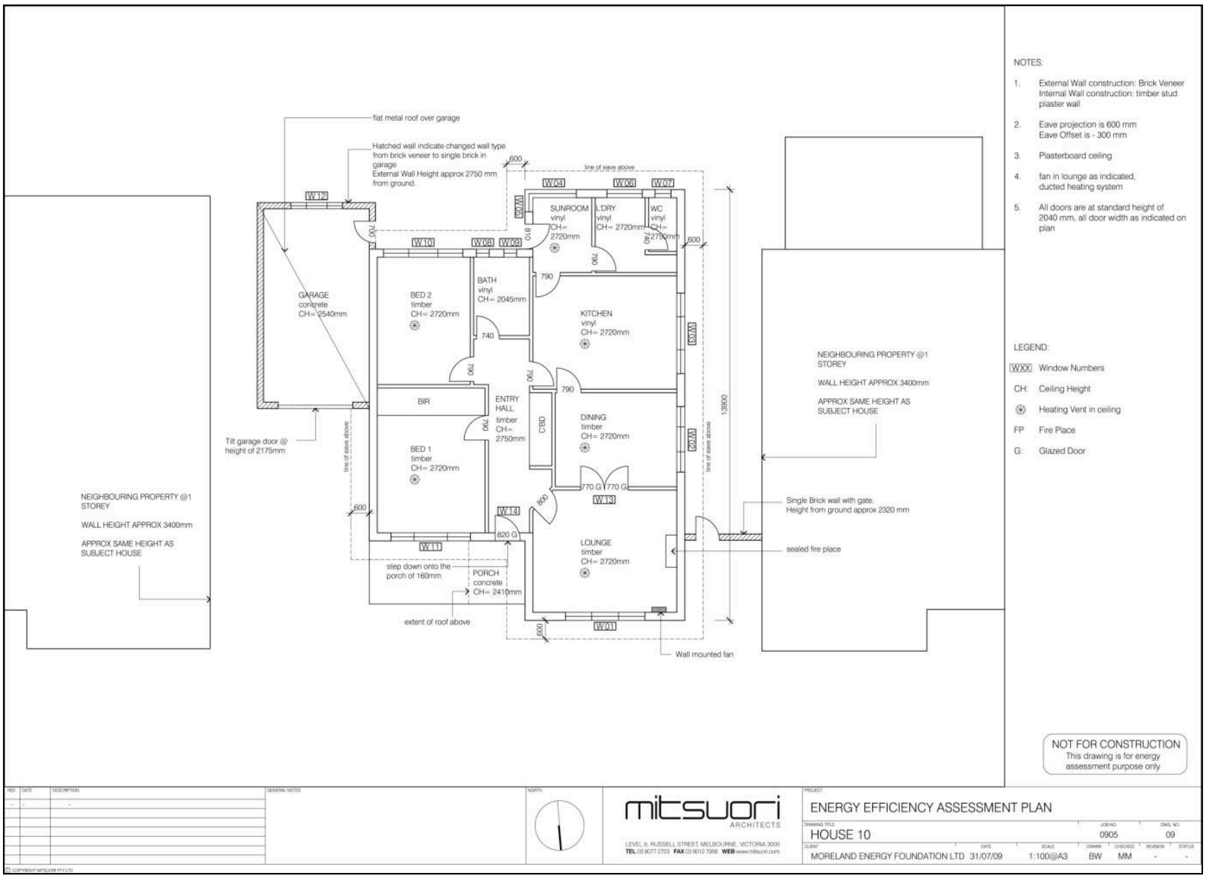
Description

Table 1 provides a basic description of House 10, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 10 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick veneer • Suspended timber floor
Age	1950s
Floor area (m2)	124.2
Existing star rating	1.8
Main type of heating	Gas central heating
Main type of cooling	Refrigerative air-conditioner
Percentage of total floor area conditioned	74%
Existing insulation and air leakage status	• R3.0 ceiling insulation • 1.68 ACH

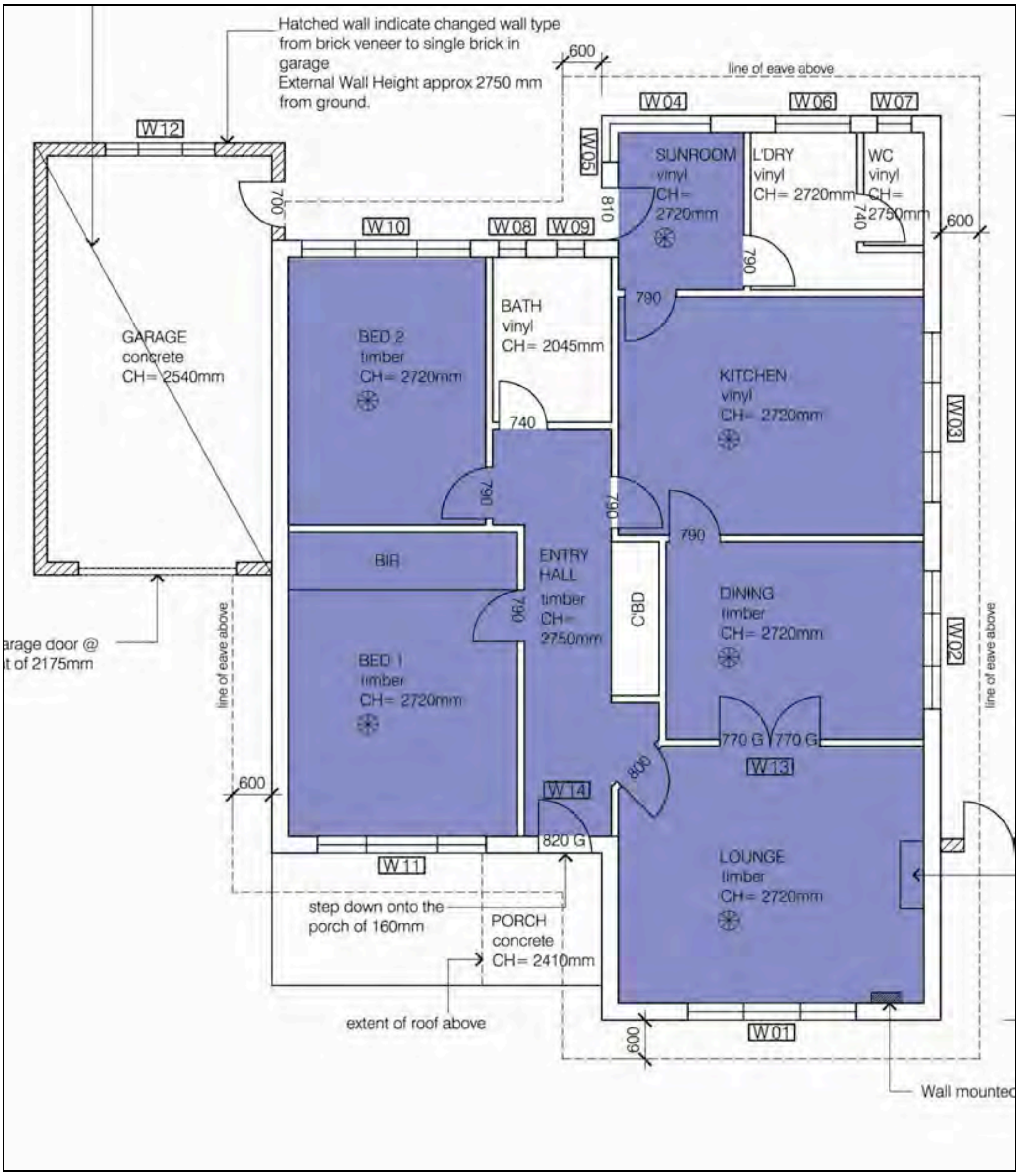
Figure 1: Floor plan of House 10



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 10 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 10 it is possible to achieve a 4.3 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.8	N/A
Upgrade 1: Ceiling insulation (easy)	No	R3.0 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.68 ACH to 0.5 ACH	2.4	$458
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	19.7m^2 of drapes installed	2.6	$2,180
Upgrade 5: External awnings	Yes	3.4m^2 of canvas awnings installed	2.6	$521
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	105.6m^2 of R1.5 wall insulation installed	3.8	$2,112
Upgrade 8: Double glazed windows	Yes	24.6m^2 of double glazing installed	4.3	$14,289

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 2 are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$458	$132	673	3
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$2,180	$58	295	38

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
External window treatment	$521	$0	0	9,478
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$2,112	$192	977	11
Double glazed windows	$14,289	$47	242	302

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 10 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas instantaneous	Rinnai	Yes - 3 year old 5.1 star HWS upgraded to solar HWS
Refrigerator	2 door fridge	Kelvinator	Yes - 7 year old 3.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Whirlpool	Yes - 1 year old 3 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Electrolux	Yes - 1 year old 3.5 star dishwasher upgraded to 4 star dishwasher
Heater	Gas central	Brivis	No - 4 year old 91% efficient heater
Air conditioner	AC wall box (cooling only)	N/A	Yes - 25 year old 184% efficient air conditioner upgraded to 320% efficient air conditioner
Lighting	N/A	N/A	Yes - 2 incandescent lamps replaced with 2 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	15,525	9,193	$3,279	$103	526	32
Refrigerator (kWh)	454	158	$916	$27	173	34
Clothes washer (MJ)*	133	39	$948	$0	2	2,204
Dishwasher (kWh)	123	4	$1,741	$1	5	2,422
Lighting (kWh)	Not estimated	21	$10	$4	23	3
Heater upgrade (MJ)	61,958	0	$0	$0	0	N/A
Air conditioner upgrade (MJ)	312	133	$313	$6	40	50

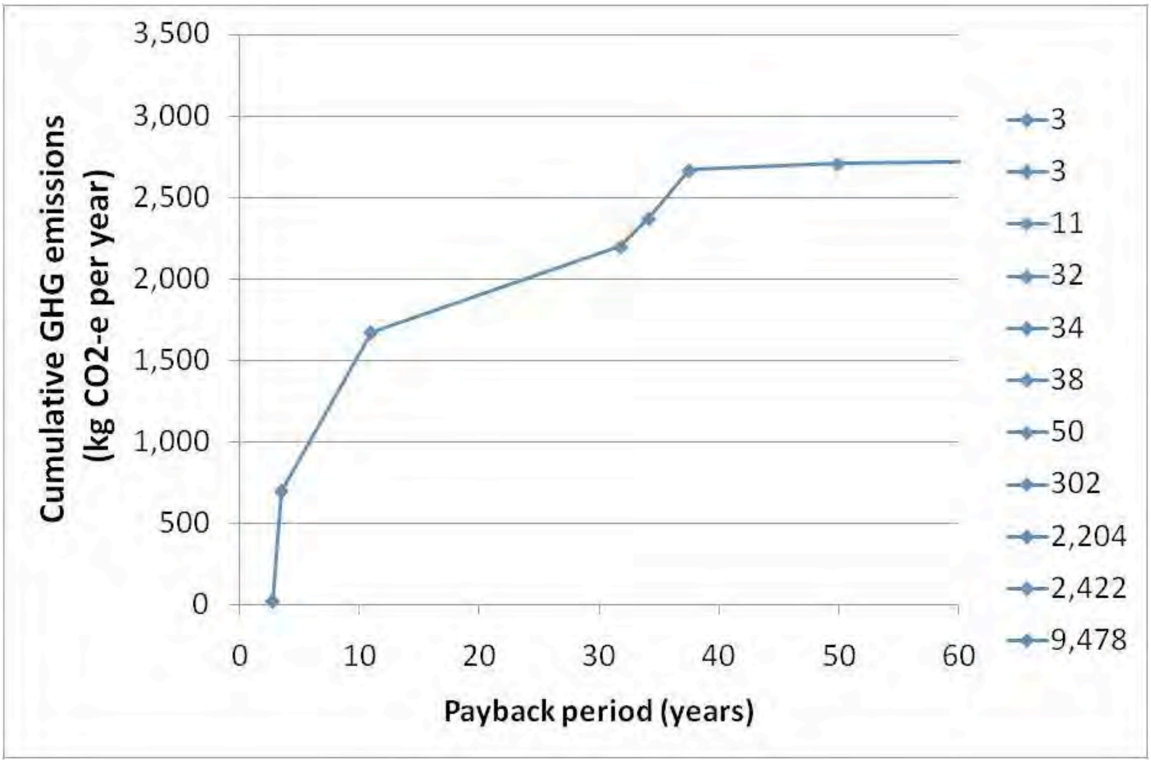
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 10 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 10



The cost curve above only shows the results of upgrades with a payback lower than 60 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Lighting	Yes - 2 incandescent lamps replaced with 2 CFLs	$10	$4	23	3
Draught sealing	Reduced from 1.68 ACH to 0.5 ACH	$458	$132	673	3
Wall insulation	105.6m^2 of R1.5 wall insulation installed	$2,112	$192	977	11
Hot water system	Yes - 3 year old 5.1 star HWS upgraded to solar HWS	$3,279	$103	526	32
Refrigerator	Yes - 7 year old 3.5 star refrigerator upgraded to 5 star refrigerator	$916	$27	173	34
Drapes & pelmets	19.7m^2 of drapes installed	$2,180	$58	295	38
Air conditioner upgrade	Yes - 25 year old 184% efficient air conditioner upgraded to 320% efficient air conditioner	$313	$6	40	50
Double glazed windows	24.6m^2 of double glazing installed	$14,289	$47	242	302
Clothes washer	Yes - 1 year old 3 star clothes washer upgraded to 4 star clothes washer	$948	$0	2	2,204
Dishwasher	Yes - 1 year old 3.5 star dishwasher upgraded to 4 star dishwasher	$1,741	$1	5	2,422
External window treatment	3.4m^2 of canvas awnings installed	$521	$0	0	9,478

Summary and discussion

The cost curve analysis reveals that 56% of the total greenhouse gas savings can be achieved by implementing the three upgrades with the shortest payback periods. The top three upgrades in order of shortest to longest payback are:

- lighting
- draught sealing
- wall insulation

These actions are estimated to result in over one and a half tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The installation of double glazing and internal and external window treatments also have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 11

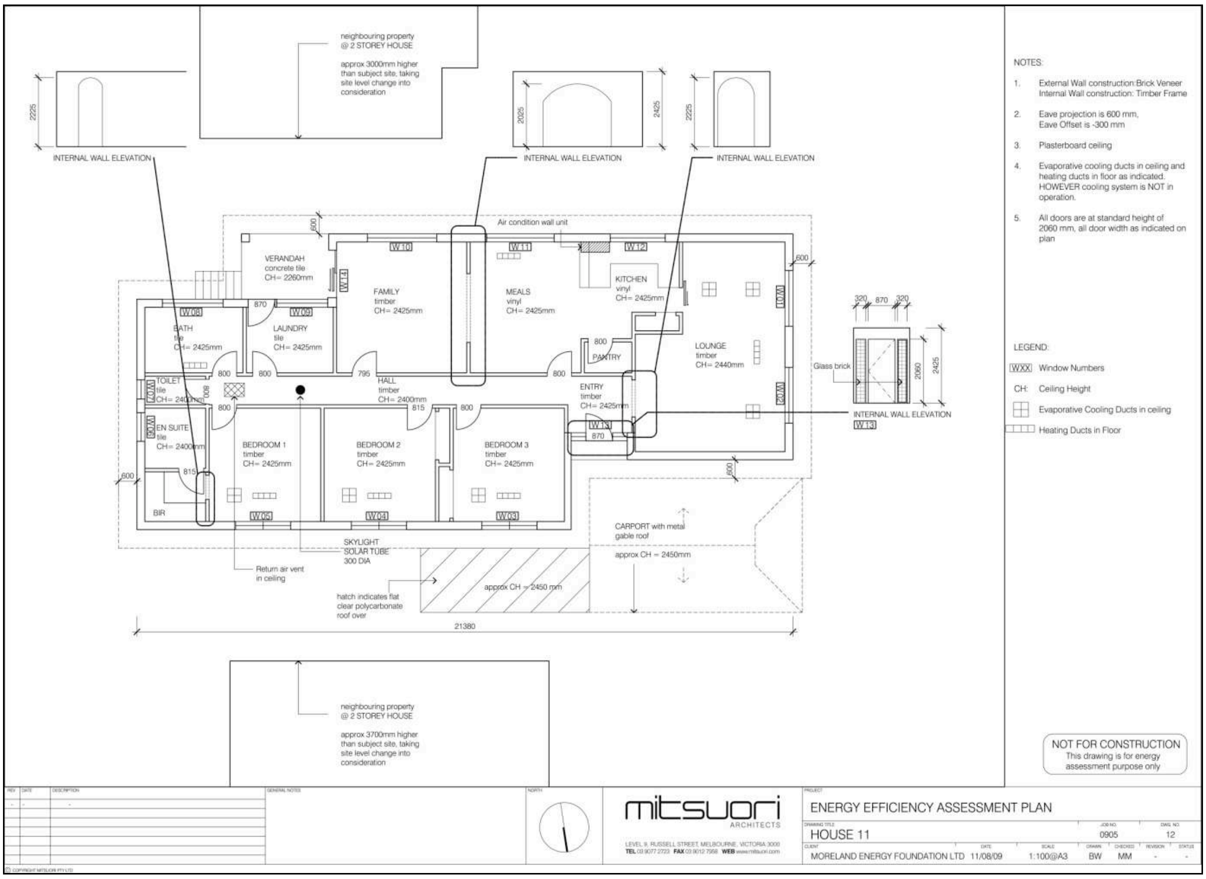
Description

Table 1 provides a basic description of House 11, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 11 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick veneer • Suspended timber floor
Age	1970s
Floor area (m2)	149.8
Existing star rating	2.4
Main type of heating	Gas central heating
Main type of cooling	Refrigerative air-conditioner (cooling only)
Percentage of total floor area conditioned	92%
Existing insulation and air leakage status	• R2.5 ceiling insulation • 0.85 ACH

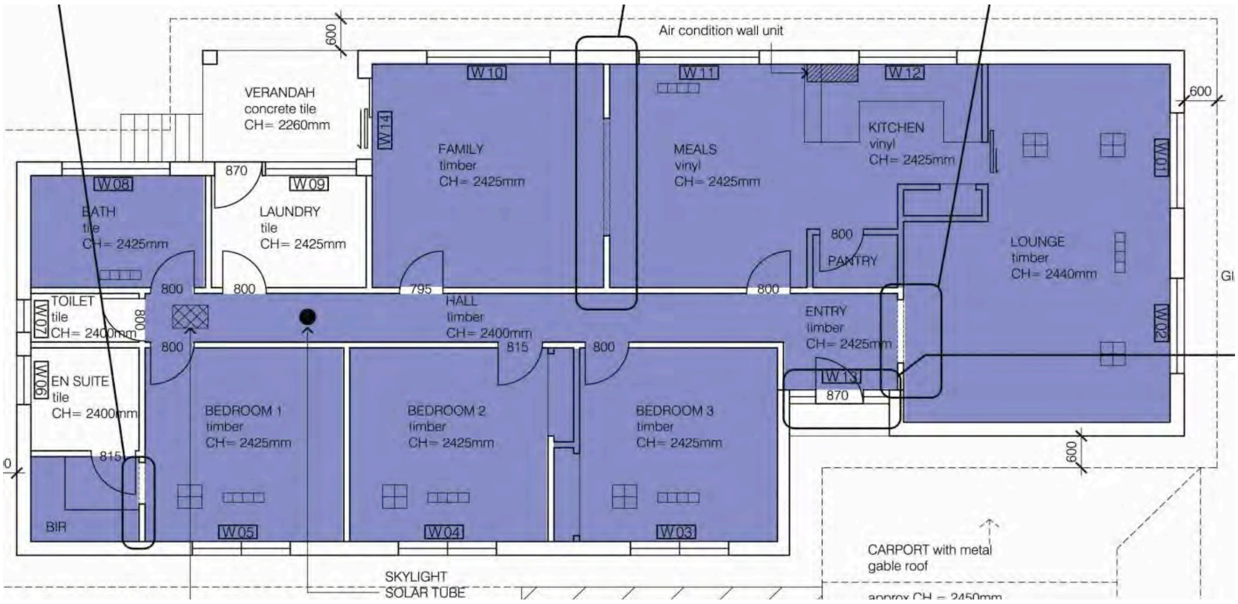
Figure 1: Floor plan of House 11



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 11 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 11 it is possible to achieve a 4.8 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	2.4	N/A
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 0.85 ACH to 0.5 ACH	2.5	$505
Upgrade 3: Underfloor insulation	Yes	149.8m^2 of R1.5 floor insulation installed	3	$2,051
Upgrade 4: Drapes and pelmets	Yes	23.6m^2 of drapes and 6m of pelmets installed	3.2	$3,248
Upgrade 5: External awnings	No	No unshaded windows in conditioned zones	N/A	N/A
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	119m^2 of R1.5 wall insulation installed	4.5	$2,380

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 8: Double glazed windows	Yes	18m^2 of double glazing installed	4.8	$10,446

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 2 are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$505	$78	396	6
Underfloor insulation	$2,051	$236	1,188	9
Drapes & pelmets	$3,248	$48	241	68
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$2,380	$278	1,415	9
Double glazed windows	$10,446	$42	217	247

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 11 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Solar, gas boosted	Solarhart	No - 7 year old solar HWS
Refrigerator	2 door fridge	Westinghouse	Yes - 8 year old 2.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Asko	Yes - 5 year old 4.5 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Miele	Yes - 3 year old 2 star dishwasher upgraded to 4 star dishwasher
Heater	Gas central	Brivis	Yes - 20 year old 65% efficient heater upgraded to 91% efficient heater
Air conditioner	AC split (cooling only)	N/A	Yes - 15 year old 207% efficient air conditioner upgraded to 320% efficient air conditioner
Lighting	N/A	N/A	Yes - 30 low voltage halogen down-lights replaced with 30 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	0	0	$0	$0	0	N/A
Refrigerator (kWh)	648	352	$824	$60	385	14
Clothes washer (MJ)*	140	-94	$603	$6	147	109
Dishwasher (kWh)	171	52	$1,583	$9	57	178
Lighting (kWh)	Not estimated	1,030	$1,640	$175	1,127	9
Heater upgrade (MJ)	115,087	31,896	$265	$351	1,781	1
Air conditioner upgrade (MJ)	647	228	$263	$11	69	24

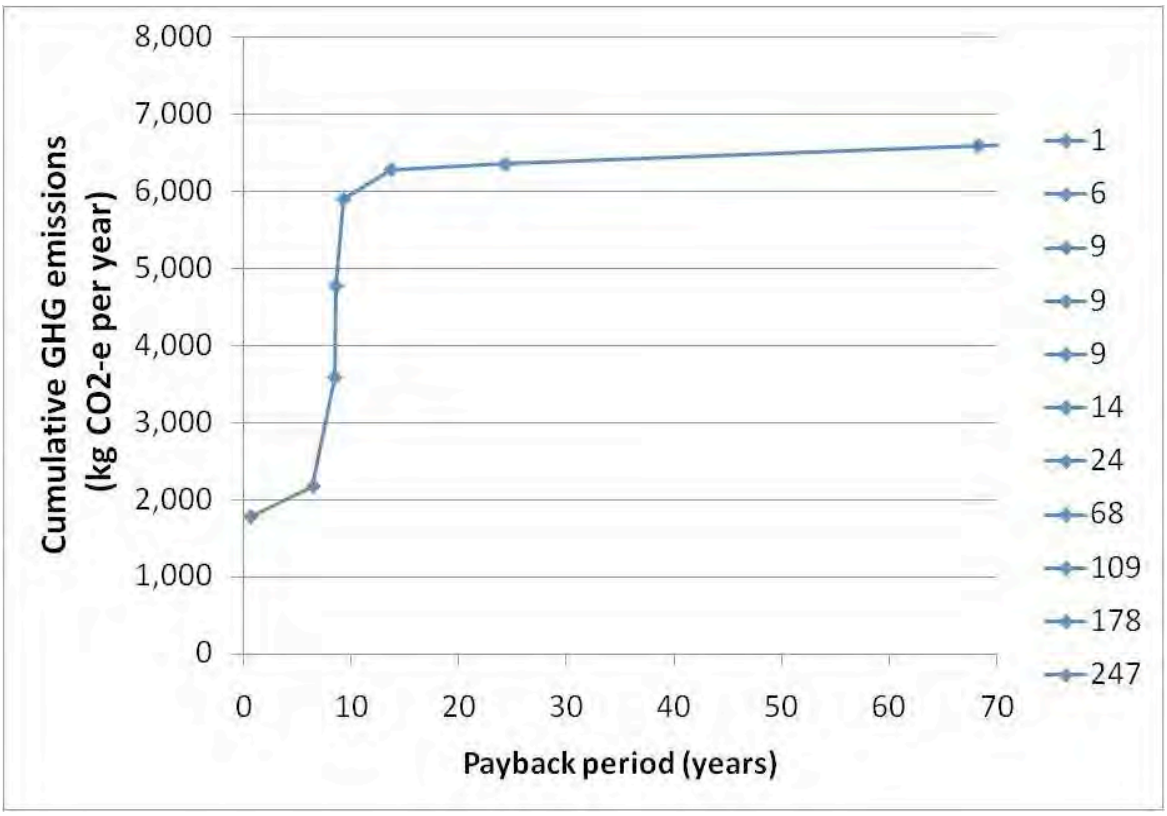
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 11 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 11



The cost curve above only shows the results of units with a payback lower than 70 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Heater upgrade	Yes - 20 year old 65% efficient heater upgraded to 91% efficient heater	$265	$351	1,781	1
Draught sealing	Reduced from 0.85 ACH to 0.5 ACH	$505	$78	396	6
Wall insulation	119m^2 of R1.5 wall insulation installed	$2,380	$278	1,415	9
Underfloor insulation	149.8m^2 of R1.5 floor insulation installed	$2,051	$236	1,188	9
Lighting	Yes - 30 low voltage halogen down-lights replaced with 30 CFLs	$1,640	$175	1,127	9
Refrigerator	Yes - 8 year old 2.5 star refrigerator upgraded to 5 star refrigerator	$824	$60	385	14
Air conditioner upgrade	Yes - 15 year old 207% efficient air conditioner upgraded to 320% efficient air conditioner	$263	$11	69	24
Drapes & pelmets	23.6m^2 of drapes and 6m of pelmets installed	$3,248	$48	241	68
Clothes washer	Yes - 5 year old 4.5 star clothes washer upgraded to 4 star clothes washer	$603	$6	147	109
Dishwasher	Yes - 3 year old 2 star dishwasher upgraded to 4 star dishwasher	$1,583	$9	57	178
Double glazed windows	18m^2 of double glazing installed	$10,446	$42	217	247

Summary and discussion

The cost curve analysis reveals that almost 90% of the total greenhouse gas savings can be achieved by implementing the six upgrades with the shortest payback periods. The top six upgrades in order of shortest to longest payback are:

- heater upgrade
- draught sealing
- wall insulation

- underfloor insulation
- lighting
- refrigerator

These actions are estimated to result in over six tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 12

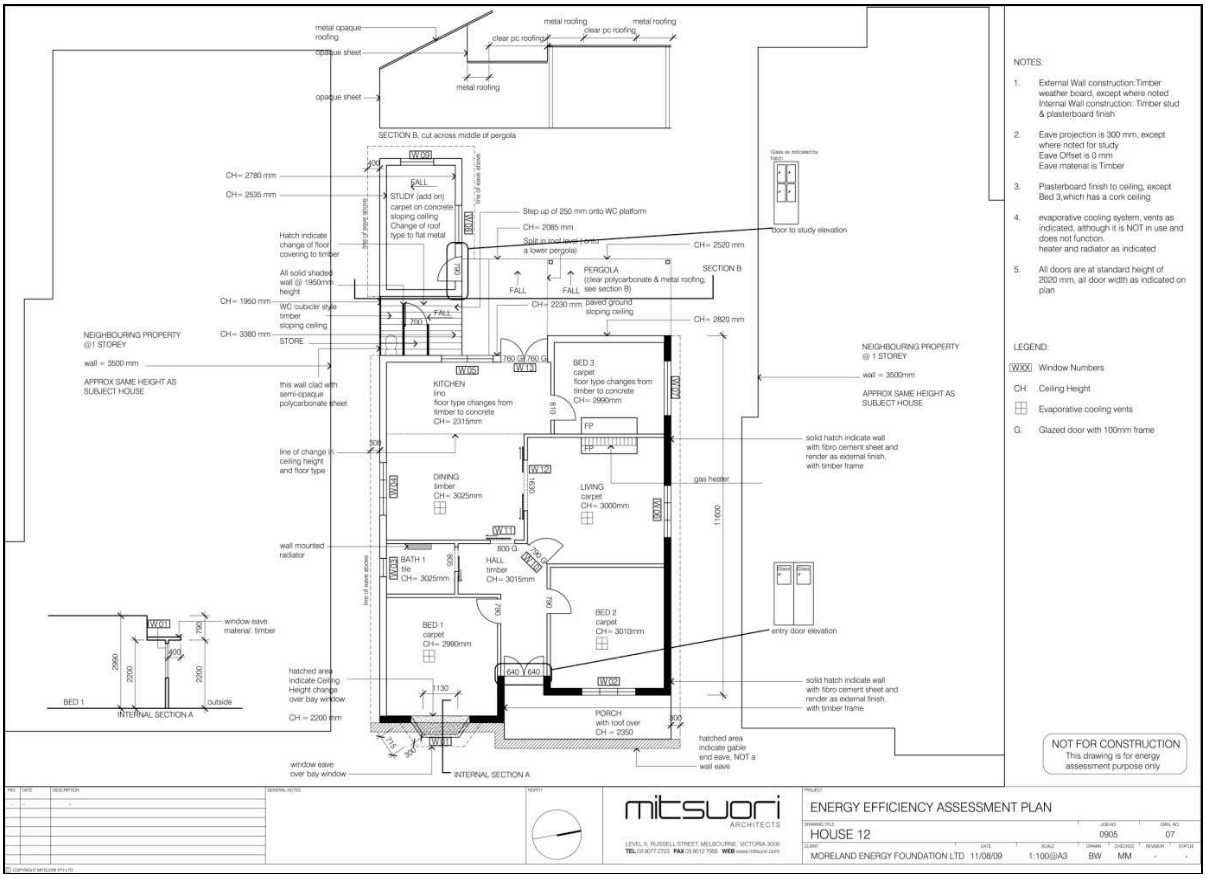
Description

Table 1 provides a basic description of House 12, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 12 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Weatherboard/cement sheeting • Suspended timber floor/concrete slab on ground
Age	1930s
Floor area (m2)	108
Existing star rating	1.2
Main type of heating	Gas space heating
Main type of cooling	N/A
Percentage of total floor area conditioned	50%
Existing insulation and air leakage status	• R2.5 ceiling insulation • 1.4 ACH

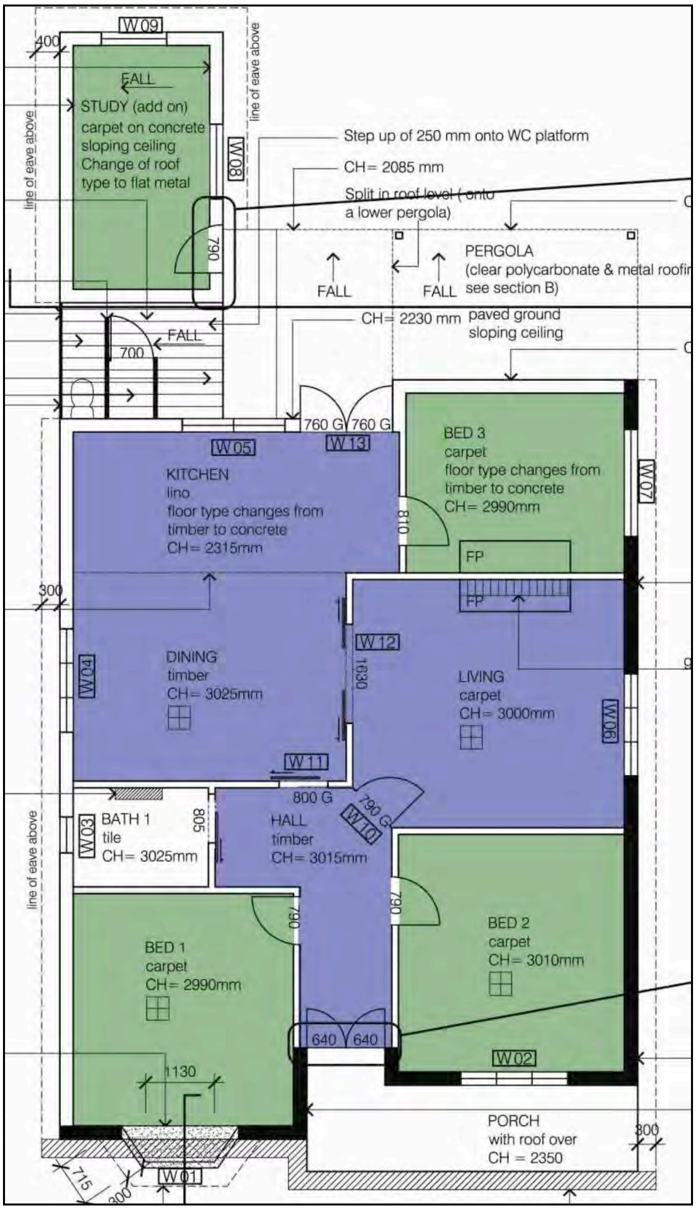
Figure 1: Floor plan of House 12



Zoning profiles used in FirstRate5 analysis

Figure2 below is a floor plan of House 12 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 12 it is possible to achieve a 3.7 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.2	N/A
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.40 ACH to 0.5 ACH	1.5	$620
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	14.8m^2 of drapes and 6.6m of pelmets installed	1.6	$2,329
Upgrade 5: External awnings	Yes	12.3m^2 of canvas awnings installed	1.6	$1,895
Upgrade 6: Ceiling insulation (advanced)	No	Hard to access ceiling space already insulated	N/A	N/A
Upgrade 7: Wall insulation	Yes	104.4m^2 of R2.5 wall insulation installed	3.5	$2,087
Upgrade 8: Double glazed windows	Yes	19.8m^2 of double glazing installed	3.7	$11,455

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 12 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.40 ACH to 0.5 ACH	$620

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	4.1m^2 of drapes installed	$456
Upgrade 5: External awnings	No	No air-conditioner so no external awnings installed	N/A
Upgrade 6: Ceiling insulation (hard)	No	Hard to access ceiling space already insulated	N/A
Upgrade 7: Wall insulation	Yes	104.4m^2 of R2.5 wall insulation installed	$2,087
Upgrade 8: Double glazed windows	Yes	8.6m^2 of double glazing installed	$4,988

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$620	$64	327	10
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$456	$10	50	46
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$2,087	$116	588	18
Double glazed windows	$4,988	$17	84	302

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 12 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Rheem	Yes - 13 year old 2 star HWS upgraded to 5 star gas storage HWS
Refrigerator	2 door fridge	Electrolux	Yes - 1 year old 5 star refrigerator upgraded to more efficient 5 star refrigerator
Clothes washer	Front loader	LG	No - 5 year old 4 star clothes washer
Dishwasher	N/A	Electrolux	No - 3 year old 3.5 star dishwasher upgraded to 4 star dishwasher
Heater	Gas space-radiant	Vulcan	Yes - 19 year old 71% efficient heater upgraded to 83% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	Yes - 2 incandescent lamps and 5 low voltage halogen down-lights replaced with 7 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	22,251	5,474	$128	$60	306	2
Refrigerator (kWh)	345	48	$1,465	$8	53	178
Clothes washer (MJ)*	137	0	$0	$0	0	N/A
Dishwasher (kWh)	123	0	$0	$0	0	N/A
Lighting (kWh)	Not estimated	207	$250	$35	227	7
Heater upgrade (MJ)	45,678	6,406	$266	$70	358	4
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

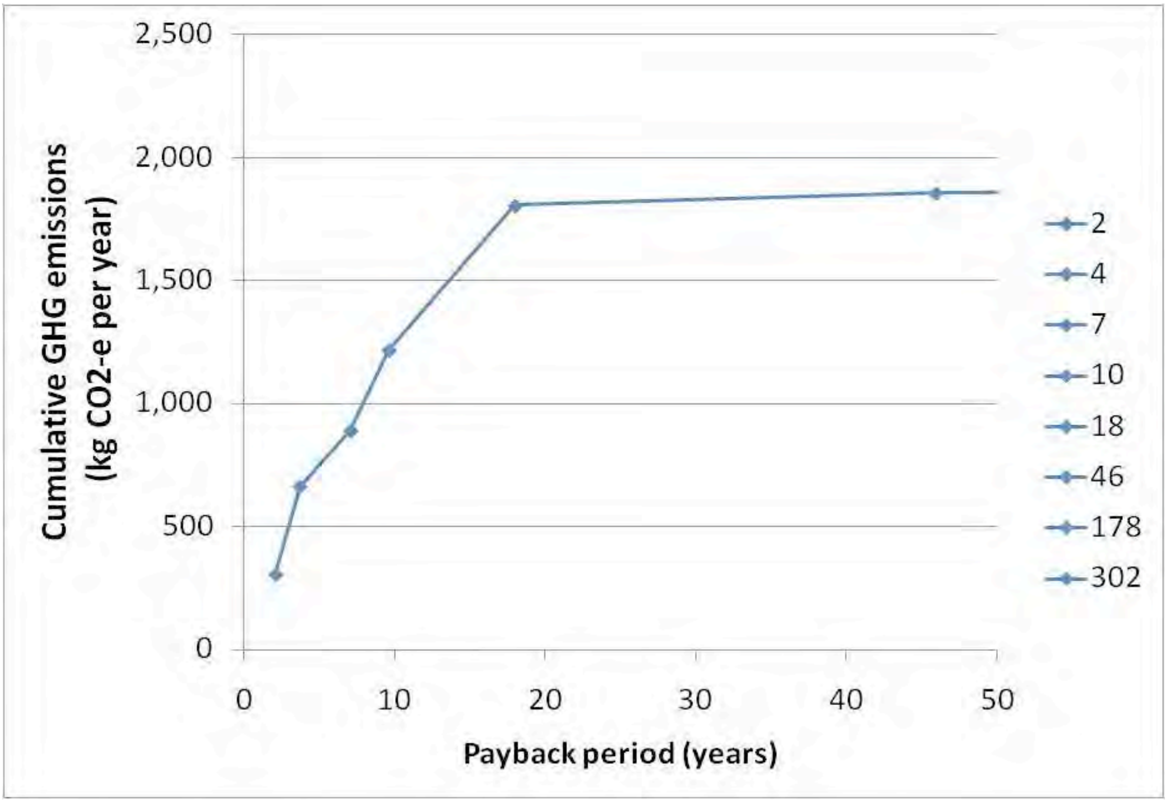
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 12 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 12



The cost curve above only shows the results of upgrades with a payback lower than 50 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Hot water system	Yes - 13 year old 2 star HWS upgraded to 5 star gas storage HWS	$128	$60	306	2
Heater upgrade	Yes - 19 year old 71% efficient heater upgraded to 83% efficient heater	$266	$70	358	4
Lighting	Yes - 2 incandescent lamps and 5 low voltage halogen down-lights replaced with 7 CFLs	$250	$35	227	7
Draught sealing	Reduced from 1.40 ACH to 0.5 ACH	$620	$64	327	10
Wall insulation	104.4m^2 of R2.5 wall insulation installed	$2,087	$116	588	18
Drapes & pelmets	4.1m^2 of drapes installed	$456	$10	50	46
Refrigerator	Yes - 1 year old 5 star refrigerator upgraded to more efficient 5 star refrigerator	$1,465	$8	53	178
Double glazed windows	8.6m^2 of double glazing installed	$4,988	$17	84	302

Summary and discussion

The cost curve analysis reveals that almost 91% of the total greenhouse gas savings can be achieved by implementing the five upgrades with the shortest payback periods. The top five upgrades in order of shortest to longest payback are:

- hot water system
- heater upgrade
- lighting
- draught sealing
- wall insulation

These actions are estimated to result in nearly two tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 13

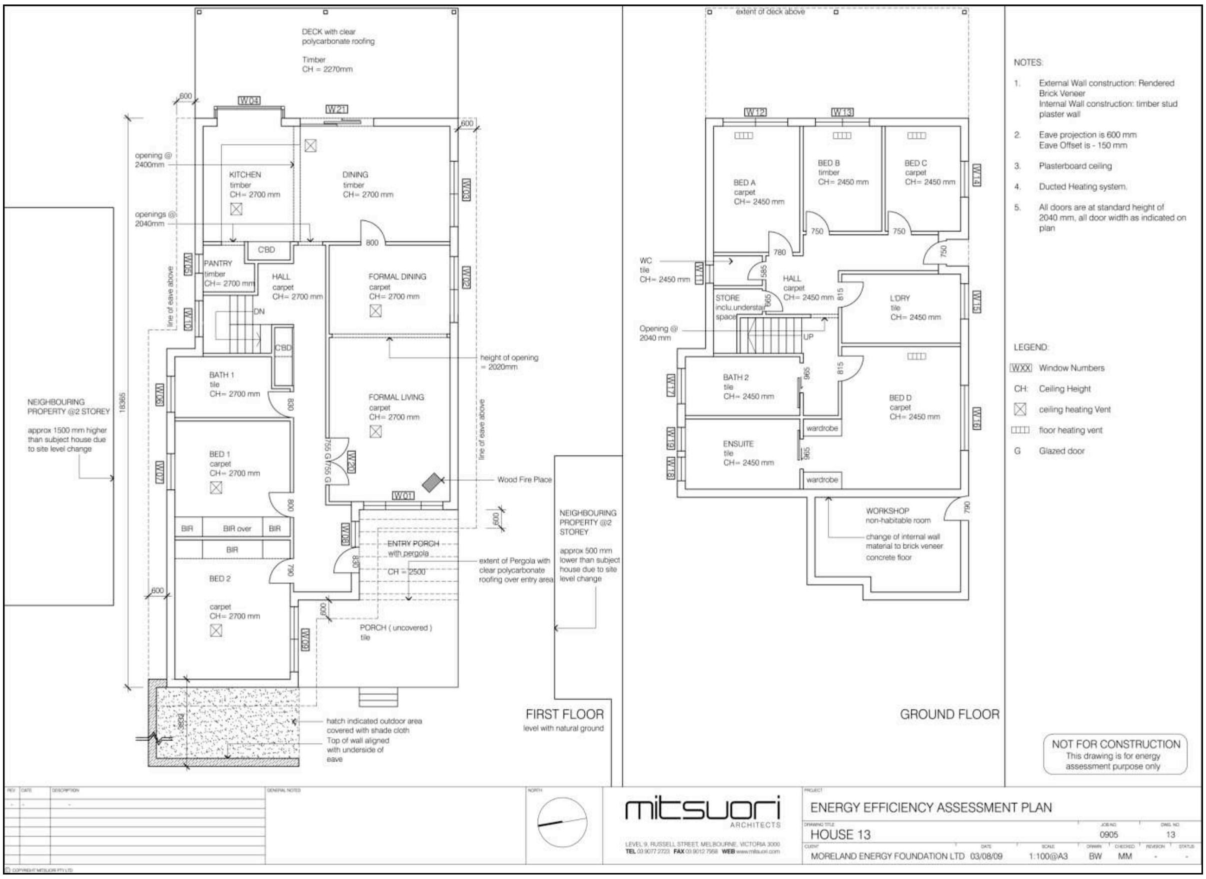
Description

Table 1 provides a basic description of House 13, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 13 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Double storey • Detached • Brick veneer • Suspended timber floor
Age	1960s
Floor area (m2)	226.3
Existing star rating	1.6
Main type of heating	Gas central heating
Main type of cooling	N/A
Percentage of total floor area conditioned	79%
Existing insulation and air leakage status	• R2.0 ceiling insulation • 1.65 ACH

Figure 1: Floor plan of House 13



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 13 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode

Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 13 it is possible to achieve a 4.3 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.6	N/A
Upgrade 1: Ceiling insulation (easy)	*Yes	124.3m^2 topped up from R2.0 to R3.5	1.7	$915
Upgrade 2: Draught proofing	Yes	Reduced from 1.65 ACH to 0.5 ACH	2.3	$795
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 4: Drapes and pelmets	Yes	31.9m^2 of drapes and 21.9m of pelmets installed	2.7	$5,833
Upgrade 5: External awnings	Yes	14.6m^2 of canvas awnings installed	2.7	$2,257
Upgrade 6: Ceiling insulation (advanced)	No	No hard to access ceiling space	N/A	N/A
Upgrade 7: Wall insulation	Yes	219.7m^2 of R1.5 wall insulation installed	4	$4,394
Upgrade 8: Double glazed windows	Yes	32.2m^2 of double glazing installed	4.3	$18,699

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

The greenhouse gas (GHG) savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 2 are presented in Table 3. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 3: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$915	$35	179	26
Draught sealing	$795	$442	2,244	2
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$5,833	$117	594	50
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$4,394	$396	2,011	11
Double glazed windows	$18,699	$66	337	282

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 13 are listed in Table 4, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 4: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Aquamax	Yes - 5 year old 5 star HWS upgraded to solar HWS
Refrigerator	Two door fridge	Kelvinator	Yes - 7 year old 3.5 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Top loader	AEG	Yes - 12 year old clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	AEG	Yes - 10 year old 2.5 star dishwasher upgraded to 4 star dishwasher
Heater	Gas central	Hevac	Yes - 20 year old 65% efficient heater upgraded to 91% efficient heater
Air conditioner	N/A	N/A	N/A
Lighting	N/A	N/A	Yes - 10 incandescent lamps and 39 low voltage halogen down-lights replaced with 49 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 5.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 5. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 5: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	16,778	10,446	$3,141	$106	596	30
Refrigerator (kWh)	454	158	$1,145	$27	173	43
Clothes washer (MJ)*	160	66	$103	$1	4	142
Dishwasher (kWh)	166	47	$317	$8	51	40
Lighting (kWh)	Not estimated	1,210	$1,732	$206	1,323	8
Heater upgrade (MJ)	168,418	46,676	$272	$513	2,606	1
Air conditioner upgrade (MJ)	N/A	0	$0	$0	0	N/A

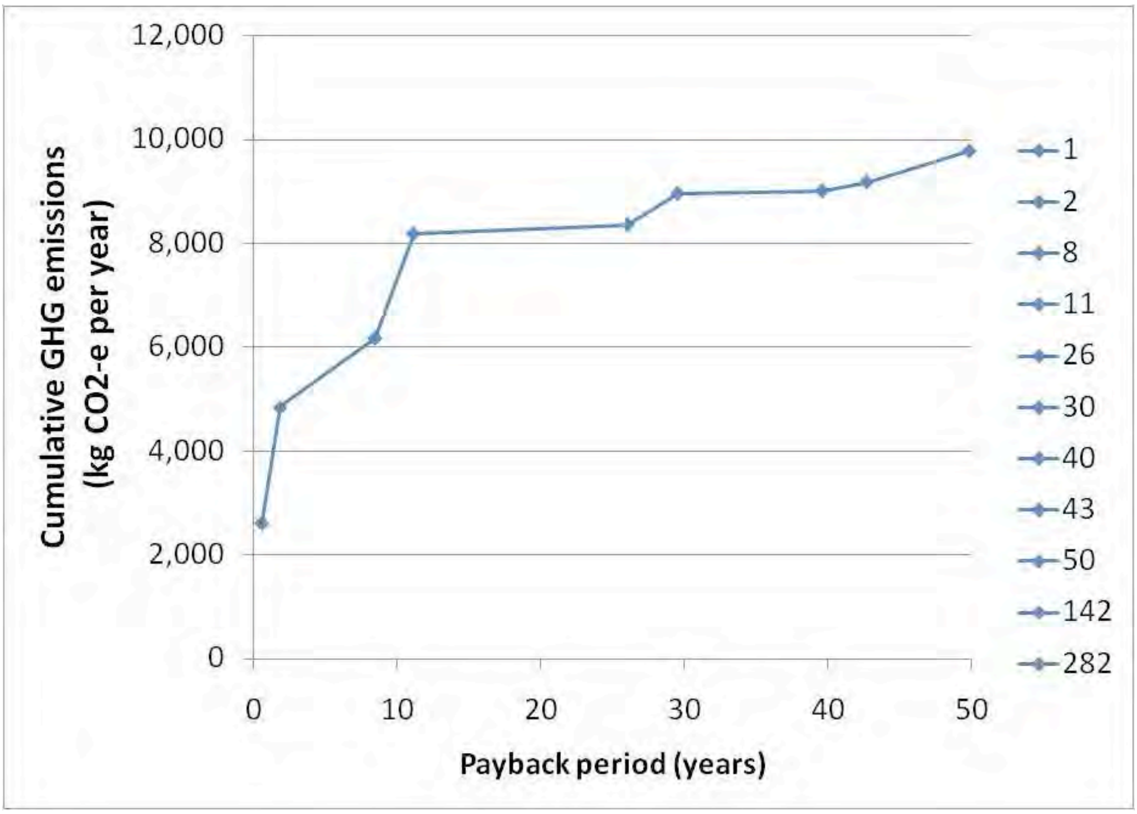
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 13 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 6 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 13



The cost curve above only shows the results of upgrades with a payback lower than 50 years as the range between the longest and shortest paybacks is too large.

Table 6: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Heater upgrade	Yes - 20 year old 65% efficient heater upgraded to 91% efficient heater	$272	$513	2,606	1
Draught sealing	Reduced from 1.65 ACH to 0.5 ACH	$795	$442	2,244	2
Lighting	Yes - 10 incandescent lamps and 39 low voltage halogen down-lights replaced with 49 CFLs	$1,732	$206	1,323	8
Wall insulation	219.7m^2 of R1.5 wall insulation installed	$4,394	$396	2,011	11
Ceiling insulation	124.3m^2 topped up from R2.0 to R3.5	$915	$35	179	26
Hot water system	Yes - 5 year old 5 star HWS upgraded to solar HWS	$3,141	$106	596	30
Dishwasher	Yes - 10 year old 2.5 star dishwasher upgraded to 4 star dishwasher	$317	$8	51	40
Refrigerator	Yes - 7 year old 3.5 star refrigerator upgraded to 5 star refrigerator	$1,145	$27	173	43
Drapes & pelmets	31.9m^2 of drapes and 21.9m of pelmets installed	$5,833	$117	594	50
Clothes washer	Yes - 12 year old clothes washer upgraded to 4 star clothes washer	$103	$1	4	142
Double glazed windows	32.2m^2 of double glazing installed	$18,699	$66	337	282

Summary and discussion

The cost curve analysis reveals that almost 81% of the total greenhouse gas savings can be achieved by implementing the four upgrades with the shortest payback periods. The top four upgrades in order of shortest to longest payback are:

- heater upgrade
- draught sealing

- lighting
- wall insulation

These actions are estimated to result in over eight tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 14

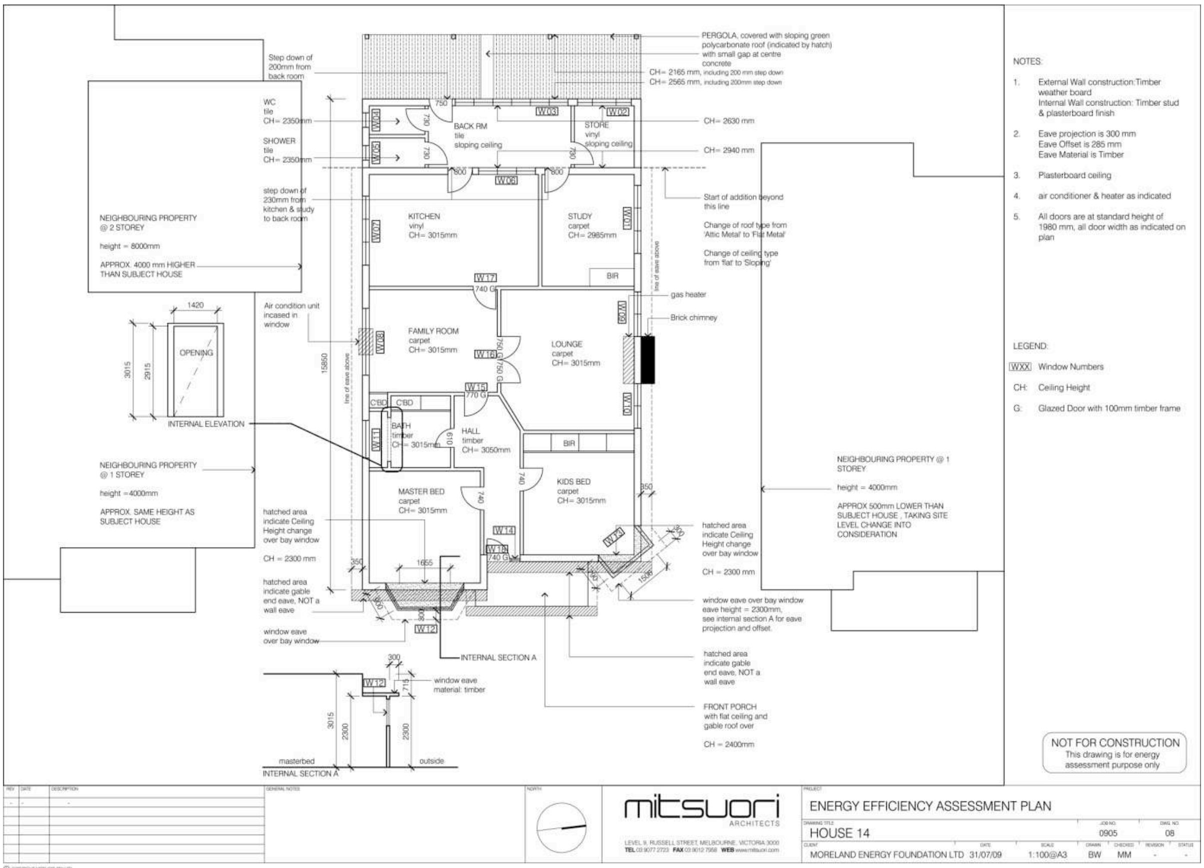
Description

Table 1 provides a basic description of House 14, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 14 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Weatherboard • Suspended timber floor
Age	1940s
Floor area (m2)	123.4
Existing star rating	1.8
Main type of heating	Gas space heating
Main type of cooling	Refrigerative air-conditioner (cooling only)
Percentage of total floor area conditioned	33%
Existing insulation and air leakage status	• R2.5 ceiling insulation • 1.35 ACH

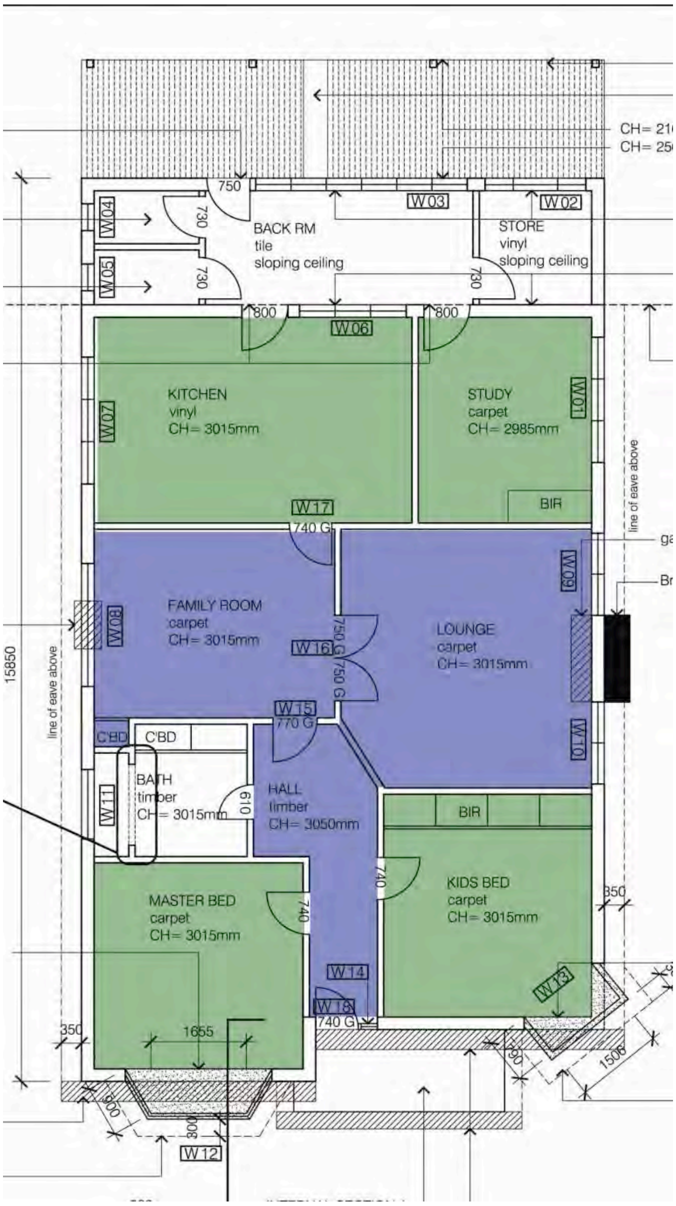
Figure 1: Floor plan of House 14



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 14 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 14 it is possible to achieve a 3.8 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.8	N/A
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A	N/A
Upgrade 2: Draught proofing	Yes	Reduced from 1.35 ACH to 0.5 ACH	2.1	$404
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	22.3m^2 of drapes and 10.4m of pelmets installed	2.3	$3,551
Upgrade 5: External awnings	Yes	8.3m^2 of canvas awnings installed	2.3	$1,283
Upgrade 6: Ceiling insulation (advanced)	Yes	16.4m^2 upgraded from no insulation to R2.5	2.4	$376
Upgrade 7: Wall insulation	Yes	113m^2 of R2.5 wall insulation installed	3.5	$2,261
Upgrade 8: Double glazed windows	Yes	21.5m^2 of double glazing installed	3.8	$12,470

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 14 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	No	R2.5 already installed	N/A

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 2: Draught proofing	Yes	Reduced from 1.35 ACH to 0.5 ACH	$404
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	6m^2 of drapes installed	$659
Upgrade 5: External awnings	No	No unshaded windows in conditioned zones	$0
Upgrade 6: Ceiling insulation (hard)	Yes	16.4m^2 upgraded from no insulation to R2.5	$376
Upgrade 7: Wall insulation	Yes	113m^2 of R2.5 wall insulation installed	$2,261
Upgrade 8: Double glazed windows	Yes	7.4m^2 of double glazing installed	$4,309

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$0	$0	0	N/A
Draught sealing	$404	$53	273	8
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$659	$14	75	46
External window treatment	$0	$0	0	N/A
Ceiling insulation (advanced)	$376	$4	23	85
Wall insulation	$2,261	$78	401	29
Double glazed windows	$4,309	$15	79	287

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 14 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Electric storage	Rheem	Yes - 12 year old HWS upgraded to 5 star gas storage HWS
Refrigerator	Two door fridge	Bosch	Yes - 10 year old 3 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Bosch	Yes - 4 year old 3 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Bosch	Yes - 2 year old 3.5 star dishwasher upgraded to 4 star dishwasher
Heater	Gas space-radiant	Rinnai	Yes - 19 year old 65% efficient heater upgraded to 83% efficient heater
Air conditioner	AC wall box (cooling only)	N/A	Yes - 19 year old 198% efficient air conditioner upgraded to 320% efficient air conditioner
Lighting	N/A	N/A	Yes - 3 incandescent lamps replaced with 3 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	14,035	N/A, changed to gas	$203	$127	3,328	2
Refrigerator (kWh)	582	285	$649	$49	312	13
Clothes washer (MJ)*	163	-281	$776	$5	162	169
Dishwasher (kWh)	141	22	$1,583	$4	24	430
Lighting (kWh)	Not estimated	24	$15	$4	26	4
Heater upgrade (MJ)	38,130	8,021	$266	$88	448	3
Air conditioner upgrade (MJ)	1,104	422	$313	$20	128	16

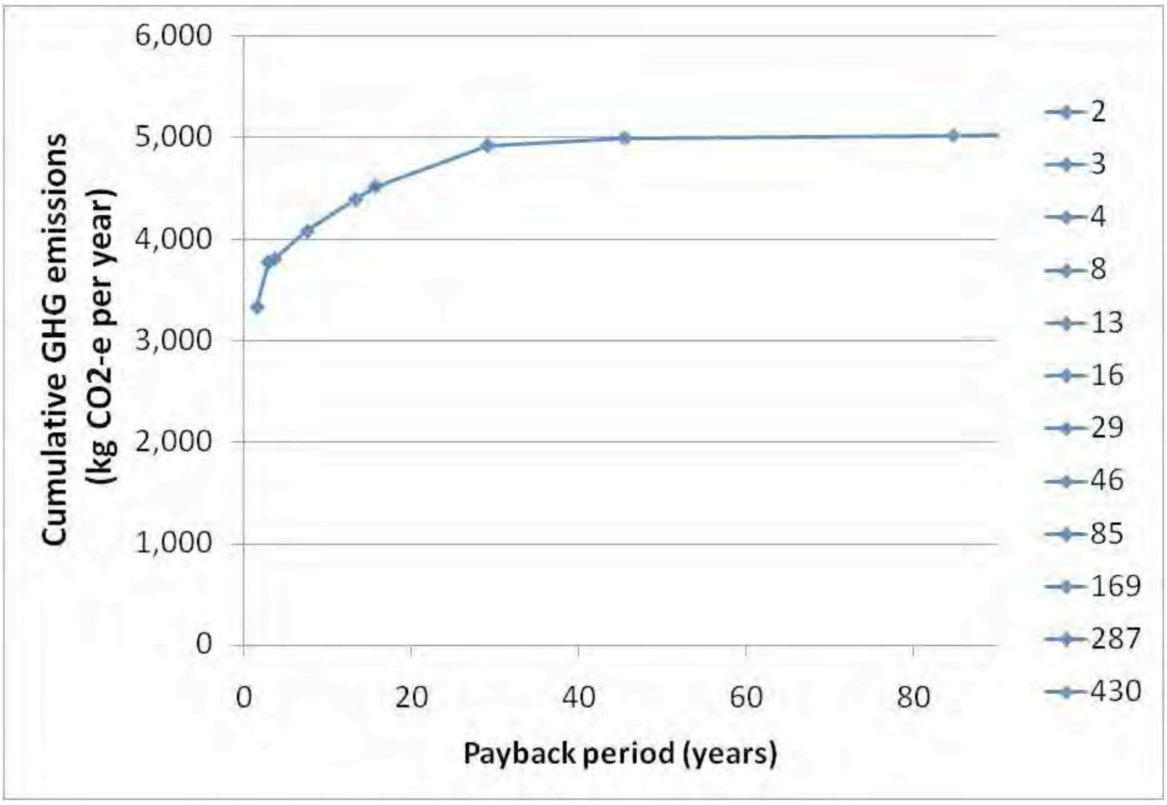
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 14 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 14



The cost curve above only shows the results of upgrades with a payback lower than 90 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Hot water system	Yes - 12 year old HWS upgraded to 5 star gas storage HWS	$203	$127	3,328	2
Heater upgrade	Yes - 19 year old 65% efficient heater upgraded to 83% efficient heater	$266	$88	448	3
Lighting	Yes - 3 incandescent lamps replaced with 3 CFLs	$15	$4	26	4
Draught sealing	Reduced from 1.35 ACH to 0.5 ACH	$404	$53	273	8
Refrigerator	Yes - 10 year old 3 star refrigerator upgraded to 5 star refrigerator	$649	$49	312	13
Air conditioner upgrade	Yes - 19 year old 198% efficient air conditioner upgraded to 320% efficient air conditioner	$313	$20	128	16
Wall insulation	113m^2 of R2.5 wall insulation installed	$2,261	$78	401	29
Drapes & pelmets	6m^2 of drapes installed	$659	$14	75	46
Ceiling insulation (advanced)	16.4m^2 upgraded from no insulation to R2.5	$376	$4	23	85
Clothes washer	Yes - 4 year old 3 star clothes washer upgraded to 4 star clothes washer	$776	$5	162	169
Double glazed windows	7.4m^2 of double glazing installed	$4,309	$15	79	287
Dishwasher	Yes - 2 year old 3.5 star dishwasher upgraded to 4 star dishwasher	$1,583	$4	24	430

Summary and discussion

The cost curve analysis reveals that almost 86% of the total greenhouse gas savings can be achieved by implementing the six upgrades with the shortest payback periods. The top six upgrades in order of shortest to longest payback are:

- hot water system

- heater upgrade
- lighting
- draught sealing
- refrigerator
- air conditioner upgrade

These actions are estimated to result in nearly five tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The double glazing and drapes and pelmets upgrades have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Individual report for House 15

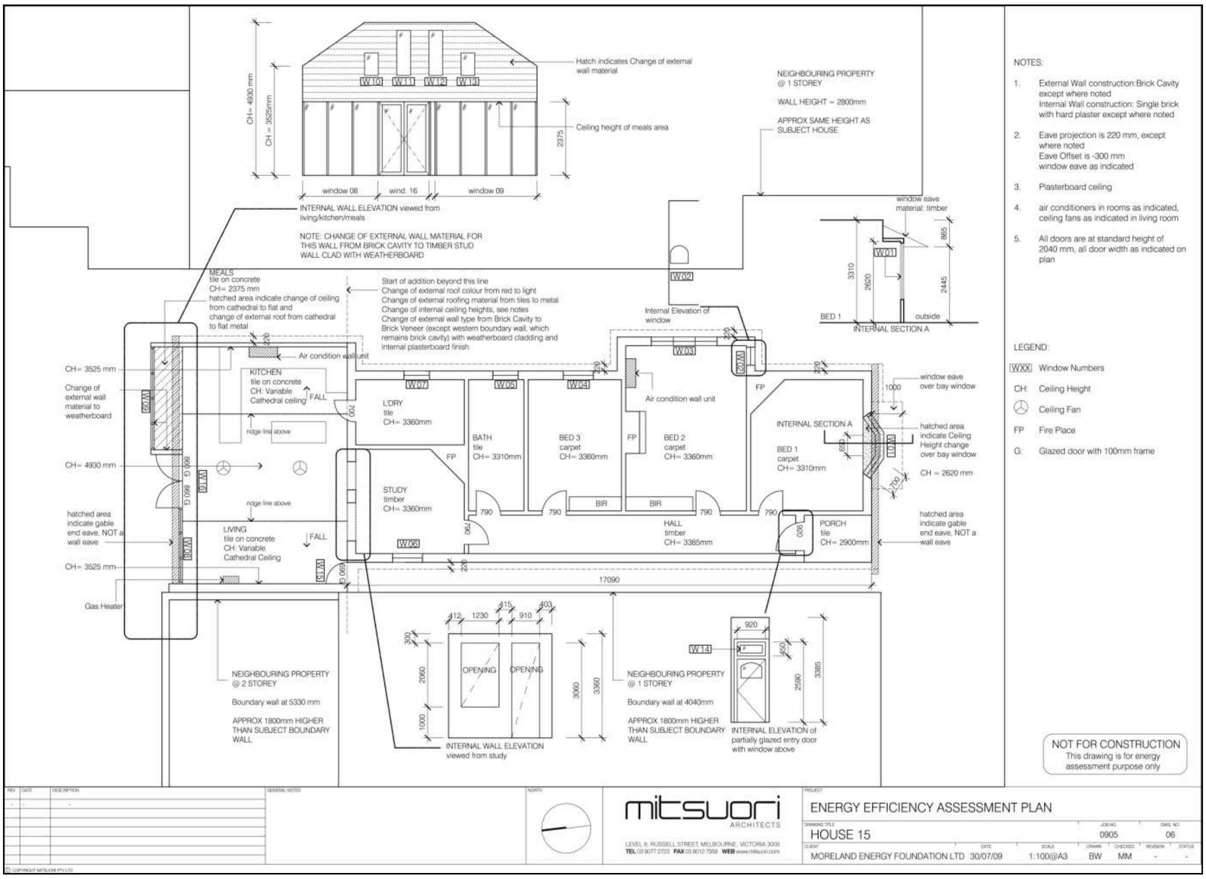
Description

Table 1 provides a basic description of House 15, including the energy rating of the house before any upgrades were modelled. The existing insulation level and air leakage status are listed, as is the percentage of total floor area that was set as conditioned in FirstRate5 when determining actual energy consumption for conditioning. Air leakage is expressed as air changes per hour (ACH) at ambient air pressure. Figure 1 on the following page is a floor plan of House 15 with north indicated.

Table 1: Description of existing house

Characteristic	Description
Construction	• Single storey • Detached • Brick cavity/brick veneer • Suspended timber floor/concrete slab on ground
Age	1930s
Floor area (m2)	134.4
Existing star rating	1.4
Main type of heating	Gas space heating
Main type of cooling	Reverse cycle air-conditioner
Percentage of total floor area conditioned	52%
Existing insulation and air leakage status	• No ceiling insulation in pitched roof • R2.5 ceiling insulation in flat roof • 0.98 ACH

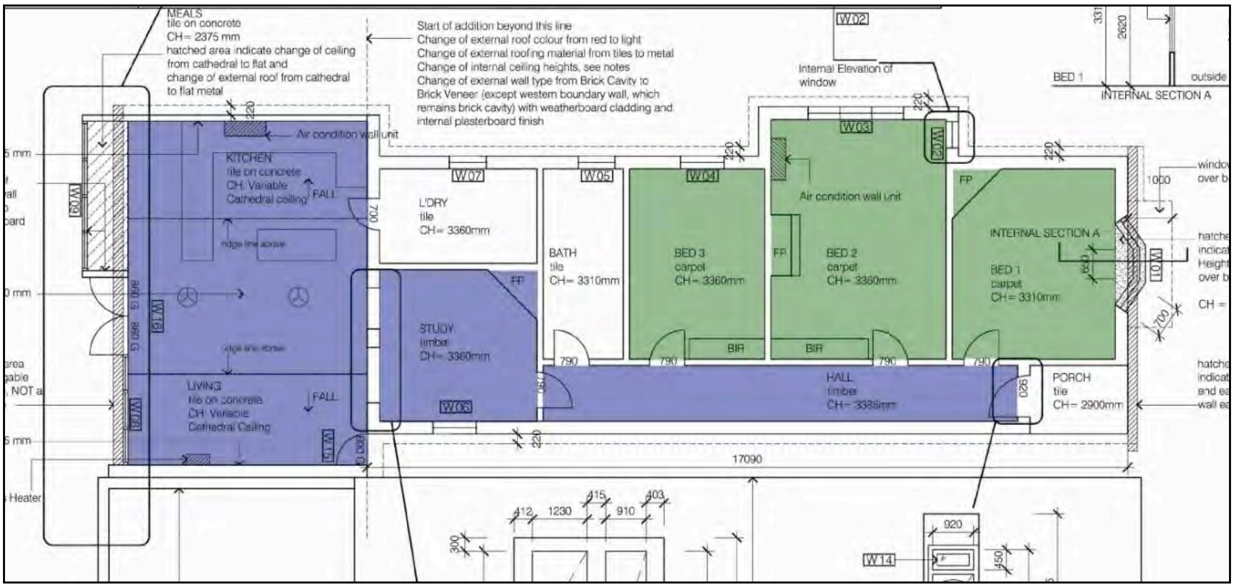
Figure 1: Floor plan of House 15



Zoning profiles used in FirstRate5 analysis

Figure 2 below is a floor plan of House 15 showing the zones that were set as conditioned in energy rating mode and actual conditioning mode. Zones set as conditioned in actual conditioning mode are coloured blue. Zones set as conditioned in energy rating mode include both blue and green coloured zones. In the case of centrally conditioned houses zones will only be shaded blue because the zones that are set as conditioned in energy rating mode and actual conditioning mode correspond.

Figure 2: Conditioned zones in energy rating mode and actual conditioning mode



Energy rating of the existing house and after building shell upgrades

The current energy rating of the house and its energy rating after the progressive application of building shell upgrades are shown in Table 2. In the case of House 15 it is possible to achieve a 4.6 star rating after the application of all possible building shell upgrades.

Table 2: Energy rating of existing house and after the application of building shell upgrades

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Existing house	N/A	N/A	1.4	N/A
Upgrade 1: Ceiling insulation (easy)	Yes	90.3m^2 upgraded from no insulation to R3.5	2.3	$1,170
Upgrade 2: Draught proofing	Yes	Reduced from 0.98 ACH to 0.5 ACH	2.7	$747
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A	N/A
Upgrade 4: Drapes and pelmets	Yes	24.9m^2 of drapes and 11.9m of pelmets installed	3	$4,000
Upgrade 5: External awnings	Yes	23.1m^2 of canvas awnings installed	3	$3,565
Upgrade 6: Ceiling insulation (advanced)	No	Hard to access ceiling space already insulated	N/A	N/A
Upgrade 7: Wall insulation	Yes	168m^2 of R1.5 wall insulation installed	4.4	$3,360

Upgrade	Upgrade applied (Y/N)	Description	Star	Estimated cost
Upgrade 8: Double glazed windows	Yes	32.6m^2 of double glazing installed	4.6	$18,925

* = Top-up ceiling insulation installed

Potential energy, greenhouse gas emissions and cost savings from building shell upgrades

Table 3 presents the cost and description of the building shell upgrades applied to House 15 when determining the impact of these upgrades on energy use, greenhouse gas (GHG) emissions and energy costs. The upgrade costs and upgrade descriptions for drapes and pelmets, external awnings and double glazing may differ between Table 2 and Table 3 in the case of space conditioned houses. This difference is due to the manner in which a space conditioned home must be modelled in FirstRate5 to determine its energy rating. A full explanation can be found in the methodology section of the main report.

Table 3: Upgrades applied when determining energy, cost and GHG emissions impacts

Upgrade	Measure applied (Y/N)	Description	Estimate cost
Upgrade 1: Ceiling insulation (easy)	Yes	90.3m^2 upgraded from no insulation to R3.5	$1,170
Upgrade 2: Draught proofing	Yes	Reduced from 0.98 ACH to 0.5 ACH	$747
Upgrade 3: Underfloor insulation	No	Sub-floor not accessible	N/A
Upgrade 4: Drapes and pelmets	Yes	15.5m^2 of drapes and 6.7m of pelmets installed	$2,429
Upgrade 5: External awnings	Yes	17.5m^2 of canvas awnings installed	$2,702
Upgrade 6: Ceiling insulation (hard)	No	Hard to access ceiling space already insulated	N/A
Upgrade 7: Wall insulation	Yes	168m^2 of R1.5 wall insulation installed	$3,360
Upgrade 8: Double glazed windows	Yes	23m^2 of double glazing installed	$13,340

The GHG savings, energy cost savings, and payback periods of the building shell upgrades listed in Table 3 are presented in Table 4. It should be noted that the impact of external awnings was only analysed for houses that actually had air conditioning systems installed. While external awnings can increase occupant comfort during summer for all homes, they will only save energy in homes which are air conditioned.

Table 4: Impact of building shell upgrades

Upgrade	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Payback (years)
Ceiling insulation (easy)	$1,170	$143	734	8
Draught sealing	$747	$56	286	13
Underfloor insulation	$0	$0	0	N/A
Drapes & pelmets	$2,429	$40	202	61
External window treatment	$2,702	$7	44	400
Ceiling insulation (advanced)	$0	$0	0	N/A
Wall insulation	$3,360	$123	627	27
Double glazed windows	$13,340	$20	106	664

Potential energy efficiency improvements to appliances

The brand and type of the main appliances found in House 15 are listed in Table 5, together with a description of the efficiency upgrade undertaken. A list of the high efficiency appliances used to model the upgrades is in Appendix B of the main report.

Table 5: Details of existing main appliances and lighting

Existing appliance	Type of appliance	Brand	Upgrade undertaken
Hot water system	Gas HWS storage	Aquamax	Yes - 1 year old 5 star HWS upgraded to solar HWS
Refrigerator	Two door fridge	Fisher & Paykel	Yes - 18 year old 2 star refrigerator upgraded to 5 star refrigerator
Clothes washer	Front loader	Westinghouse	Yes - 6 year old 4 star clothes washer upgraded to 4 star clothes washer
Dishwasher	N/A	Asko	Yes - 10 year old 2.5 star dishwasher upgraded to 4 star dishwasher
Heater	Gas space-convection	Rinnai	Yes - 10 year old 82% efficient heater upgraded to 87% efficient heater
Air conditioner	AC split (reverse cycle)	N/A	Yes - 6 year old 230% efficient air conditioner upgraded to 320% efficient air conditioner
Lighting	N/A	N/A	Yes - 3 incandescent lamps replaced with 3 CFLs

The impacts of the potential appliance upgrades on the energy use, GHG emissions and energy costs of this home have been analysed in Table 6.

Two types of appliance upgrade costs and paybacks were calculated for all appliances.

Firstly, a simple payback was calculated which took the *total upgrade* cost and divided it by the annual energy cost saving. This provides a simple estimate of how many years would be required to recover the expense of undertaking the upgrade.

Secondly, an adjusted upgrade cost and adjusted payback was calculated taking into account the age of the existing appliances. This was done to recognise the fact that appliances that are close to the end of their useful life will need to be replaced eventually and upgrading them earlier is just a way of bringing this investment forward. Upgrade costs were adjusted according to the percentage of the typical appliance life remaining for the existing appliance. This meant that appliances that were only a few years old would be allocated most of the full replacement cost, while appliances close to the end of their lives would be allocated only a percentage of the full upgrade cost. Appliances that were at or past the typical appliance life were allocated 10% of the full capital cost instead of being reduced to zero or a negative cost.

A different method was used to calculate the adjusted cost and adjusted payback for the gas boosted solar water heater (SWH) upgrade due to the significant cost difference between a SWH and a high efficiency gas water heater. The different methods used are described in detail in the methodology section of the main report.

Only the adjusted cost and payback to recoup the replacement cost are listed in Table 6. The main report lists full and adjusted upgrade costs and payback periods for all appliance upgrades.

Table 6: Impact of appliance and lighting upgrades

Appliance upgraded	Current energy use (MJ or kWh/yr)	Potential energy savings (MJ or kWh/yr)	Adjusted cost of upgrade ($)	Energy cost savings ($/yr)	Greenhouse savings (kg/yr)	Adjusted payback period (years)
Hot water system (MJ)	16,778	10,446	$3,567	$106	596	34
Refrigerator (kWh)	792	496	$156	$84	542	2
Clothes washer (MJ)*	184	-94	$517	$8	196	68
Dishwasher (kWh)	200	81	$317	$14	88	23
Lighting (kWh)	Not estimated	42	$15	$7	46	2
Heater upgrade (MJ)	43,547	2,428	$648	$27	136	24
Air conditioner upgrade (MJ)	696	196	$1,416	$9	60	153

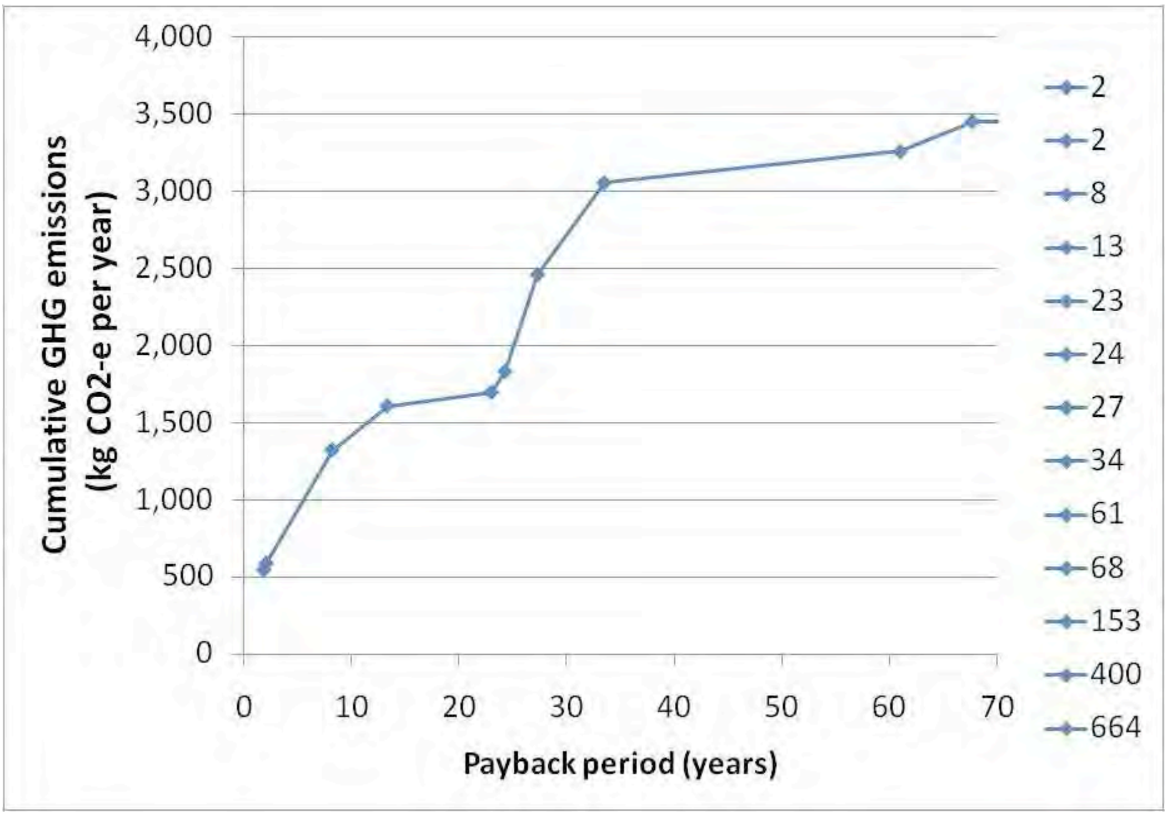
* = only shows energy used for water heating

Cost curve

A cost curve was constructed for all the different appliance and building shell upgrades applied to House 15 to provide a better understanding of the cost effectiveness and impact of the upgrades. To develop the cost curve individual measures were first ranked by payback. These payback points were then mapped against the cumulative greenhouse savings, starting with the upgrade with the shortest payback. This curve is displayed below and clearly shows the extent of variation in the feasibility and effectiveness of the different upgrades. For the cost curve age adjusted paybacks were used for the appliance upgrades as it was decided that this would give the most accurate impression of the cost effectiveness of these upgrades.

Table 7 provides background information on each upgrade shown in Figure 3.

Figure 3: Cost curve for all appliance and building shell upgrades applied to House 15



The cost curve above only shows the results of upgrades with a payback lower than 70 years as the range between the longest and shortest paybacks is too large.

Table 7: Impact of all upgrades ranked by payback

Upgrade	Description	Estimated cost of upgrade ($)	Energy cost savings ($/yr)	GHG savings (kg/yr)	Payback (years)
Refrigerator	Yes - 18 year old 2 star refrigerator upgraded to 5 star refrigerator	$156	$84	542	2
Lighting	Yes - 3 incandescent lamps replaced with 3 CFLs	$15	$7	46	2
Ceiling insulation	90.3m^2 upgraded from no insulation to R3.5	$1,170	$143	734	8
Draught sealing	Reduced from 0.98 ACH to 0.5 ACH	$747	$56	286	13
Dishwasher	Yes - 10 year old 2.5 star dishwasher upgraded to 4 star dishwasher	$317	$14	88	23
Heater upgrade	Yes - 10 year old 82% efficient heater upgraded to 87% efficient heater	$648	$27	136	24
Wall insulation	168m^2 of R1.5 wall insulation installed	$3,360	$123	627	27
Hot water system	Yes - 1 year old 5 star HWS upgraded to solar HWS	$3,567	$106	596	34
Drapes & pelmets	15.5m^2 of drapes and 6.7m of pelmets installed	$2,429	$40	202	61
Clothes washer	Yes - 6 year old 4 star clothes washer upgraded to 4 star clothes washer	$517	$8	196	68
Air conditioner upgrade	Yes - 6 year old 230% efficient air conditioner upgraded to 320% efficient air conditioner	$1,416	$9	60	153
External window treatment	17.5m^2 of canvas awnings installed	$2,702	$7	44	400
Double glazed windows	23m^2 of double glazing installed	$13,340	$20	106	664

Summary and discussion

The cost curve analysis reveals that almost 44% of the total greenhouse gas savings can be achieved by implementing the four upgrades with the shortest payback periods. The top four upgrades in order of shortest to longest payback are:

- refrigerator
- lighting
- ceiling insulation
- draught sealing

These actions are estimated to result in nearly two tonnes of GHG savings.

The other appliance upgrades do not appear to be cost effective but these upgrades should be considered when the appliances need replacing at the end of their operating lives. The installation of double glazing and internal and external window treatments also have long paybacks and do not deliver significant savings.

It should also be noted that the energy, GHG emissions and cost savings reported above are based on a range of assumptions and average occupancy and usage patterns and may differ from the actual savings that would be achieved by the current occupants of the house. A complete discussion of the methodology used for this project is in the main report.

Appendix D: Air leakage test report

The following report was produced by Air Barrier Technologies.

Introduction

Air Barrier Technologies (ABT) was commissioned by Moreland Energy Foundation on behalf of Sustainability Victoria to undertake a fan pressurization study on fifteen domestic dwellings to quantify the volume of air leakage through the building envelope. An air leakage audit of the building envelopes was also conducted to identify the sources of air leakage so the cost of retrofitting the dwellings and the potential energy savings of doing so could be estimated.

Testing

Fan pressurization tests were conducted in each house in line with the UK standard TM 23.

The houses were depressurized and pressurized at different pressures in a 15-60 Pa range. The houses were tested as they would be inhabited with external doors and windows closed.

Results

Results of the fan pressurization tests are summarized below:

Building	ACH50Pa	ACH4Pa	Floor Area (m^2)	Exposed Envelope Area (m^2)	Vol. (m^3)	Flow @ 50 Pa (m^3/hr)	Flow @ 4 Pa (m^3/hr)	Permeability @50Pa (m^3/hr/m^2)	EQLA @10Pa (m^2)
House 2	21.75	4.84	89.5	359	286	6,219	1,383	17.3	0.27
House 1	23.18	4.59	217	609	521	12,075	1,391	19.8	0.48
House 12	28.06	6.13	100	329	301	8,446	1,843	25.7	0.36
House 8	22.83	5.31	168	635	565	12,900	3,002	20.3	0.50
House 14	27.05	6.02	148	420	408	11,037	2,455	26.3	0.47
House 3	34.21	6.63	160	583	521	17,825	3,451	30.6	0.70
House 4	39.97	9.7	100	314	243	9,712	2,360	30.9	0.38
House 6	36.45	7.06	79	267	237	8,637	1,672	32.4	0.34
House 7	28.63	7.1	128	476	430	12,312	3,054	25.9	0.57
House 9	17.49	4.51	158	502	533	9,312	2,404	18.6	0.44
House 13	32.97	4.26	155	566	626	10,637	2,668	36.46	0.63
House 15	19.55	5.7	152	530	554	10,833	3,158	20.44	0.55
House 5	53.3	14.88	79	267	240	12,792	3,571	48.3	0.64
House 10	33.58	9.15	105	322	272	9,134	2,488	28.4	0.45
House 11	17.06	3.83	154	450	526	8,973	2,014	19.9	0.39
Averages	**29.1**	**6.6**	**133**	**441**	**418**	**10,723**	**2,461**	**26.8**	**0.49**

Discussion

The most useful value calculated for each house is the Air Changes per Hour at 50 Pa (ACH50). The ACH50 figure represents how many times the total volume of air in the house changes in one hour at 50Pa pressure differential of inside to outside the house (which is equivalent of a 35 km/h wind blowing on all sides of the house). This is a value used internationally and therefore allows comparison of the dwellings in this study with other studies:

Dwelling Type	**Average ACH50**
Passive house standard (Super Efficient European homes)[1]	0.2 - 0.6
327 new houses tested in USA[1]	6.2
98 existing houses tested USA[1]	12.7
Pre 1950's houses tested USA[1]	8-24
15 existing house tested in Melbourne 2009	29.1
New five star rated houses tested by ABT in Australia	4.5 - 28

The above values show that the houses tested in this study can be considered to be excessively leaky by standards used in other countries but are consistent with other existing Australian houses tested by ABT. The target figure for retrofitting these houses would be 10 ACH50 which would give an average annual natural ACH of 0.5.

Since the figure of ACH50 is affected by the volume of the house, the permeability @ 50Pa is another useful figure because it expresses air leakage per square metre of the building envelope. This gives a better indication of the leakiness of the facade than ACH50 but can't be used for energy saving predictions like ACH50 can. Permeability is more commonly used in the U.K. A study of 191 existing dwellings in the U.K. ([2]) showed an average permeability@50 of 17.35 ($m^3/hr/m^2$) which is only 64% of the average in this study of 26.8 ($m^3/hr/m^2$)

The Equivalent Leakage Area @ 10Pa is an approximation of the total gap size in the house and is useful to visualize the extent of leakage. The average EQLA10 was $0.48m^2$ for this study. A standard 300mm diameter exhaust fan has a leakage area of $0.05\ m^2$ so the average house in this study has approximately nine and a half exhaust fan sized holes in it.

The average house floor area in the sample was $133m^2$ which is quite small compared to modern houses. The average floor area of Victorian houses built in 2007 was $237m^2$ ([3]). The larger the house size, the more volume of air will need to be conditioned for the same ACH value so the potential for energy savings for the average Victorian house may be underestimated by using this sample group.

Air leakage Audit

House 1

This house had an ACH50Pa of 23.18 and a permeability of 19.8 which is below average in the study.

The following sources of air leakage were identified:

- 20 recessed downlights
- 20 Wall vents
- 4 External doors with ineffective seals
- External windows with ineffective seals
- A ducted evaporative cooling system with no damper.

It is estimated that the cost of labour and materials to reduce air leakage from 23 ACH50 to 10 ACH50 would be $1090.

House 2

This house had an ACH50 of 21.75 which is also typical of existing Victorian housing stock but it should be noted that due to the small building volume the volume of air leaking at 50Pa was nearly half of the bigger house at House 1. This obviously reduces the potential energy savings but the retrofit would be cheaper.

The following sources of air leakage were identified:

- 6 wall vents
- 2 exhaust fans
- Manhole cover with ineffective seals
- Open fireplace with ineffective damper
- Doors and windows with ineffective seals

The cost of labour and materials to retrofit this house would be approximately $635.

House 12

With an ACH50 of 28.06 and a permeability of 25.7 this house has significant air leakage and a large potential return on a retrofit. Main sources of air leakage identified were:

- 5 wall vents
- 1 exhaust fan
- 5 downlights
- 12 poorly sealed windows
- 2 entrance doors with inadequate seals

The cost of labour and materials to seal these sources of air leakage would be approximately $620.

House 8

With an ACH50 of 22.83 and a permeability of 20.3 this house was below the average of this study. Main sources of air leakage identified were:

- 10 wall vents
- 3 exhaust fan
- 3 downlights
- 94m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- 2 chimney flues

The cost of labour and materials to seal these sources of air leakage would be approximately $776.

House 14

With an ACH50 of 27.05 and a permeability of 26.3 this house was of average leakiness this study. Main sources of air leakage identified were:

- 8 wall vents
- 2 roof vents
- 6m of window perimeter with inadequate seals
- 4 louvered windows
- 2 entrance doors with inadequate seals

The cost of labour and materials to seal these sources of air leakage would be approximately $404.

House 3

With an ACH50 of 34.21 and a permeability of 30.6 this house was one of the leakier houses of this study. Main sources of air leakage identified were:

- 13 wall vents
- 1 exhaust fan
- 100m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- 2 chimney flues
- 124m of unsealed skirting boards

The cost of labour and materials to seal these sources of air leakage would be approximately $1098.

House 4

With an ACH50 of 39.97 and a permeability of 30.9 this house has excessive leakage and has large potential savings. Main sources of air leakage identified were:

- 11 wall vents
- 1 exhaust fan
- 4 ceiling vents
- IXL tastic in bathroom
- 3 entrance doors with inadequate seals
- evaporative cooler

The cost of labour and materials to seal these sources of air leakage would be approximately $1050.

House 6

With an ACH50 of 36.45 and a permeability of 32.4 this house was above the average leakiness of this study but has the equal smallest floor area. Main sources of air leakage identified were:

- 8 wall vents
- 3 exhaust fans
- 24m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- wall mounted air-conditioner

The cost of labour and materials to seal these sources of air leakage would be approximately $456.

House 7

With an ACH50 of 28.63 and a permeability of 25.9 this house was about average in this study. Main sources of air leakage identified were:

- 9 wall vents
- 2 exhaust fan
- 6 downlights
- 40m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- Air change unit with possible leaks

The cost of labour and materials to seal these sources of air leakage would be approximately $630.

House 9

With an ACH50 of 17.49 and a permeability of18.6 this house has the second lowest leakage figures of this study. Main sources of air leakage identified were:

- 2 exhaust fans
- manhole cover leaking
- 44m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- 1 chimney flues
- hole in ceiling

The cost of labour and materials to seal these sources of air leakage would be approximately $426.

House 13

With an ACH50 of 32.97 and a permeability of 36.46 this house has excessive air leakage. Main sources of air leakage identified were:

- 11 wall vents
- 7 exhaust fans
- 42 downlights
- 2 entrance doors with inadequate seals
- 1 chimney flues

The cost of labour and materials to seal these sources of air leakage would be approximately $795.

House 15

With an ACH50 of 19.55and a permeability of 20.44 this house was below the average of this study. Main sources of air leakage identified were:

- 5 wall vents
- 2 exhaust fans
- 10 downlights
- 38m of window perimeter with inadequate seals
- leaking skirting boards
- 2 entrance doors with inadequate seals
- 3 chimney flues

The cost of labour and materials to seal these sources of air leakage would be approximately $747.

House 5

With an ACH50 of 53.3 and a permeability of 48.3 this house has the highest air leakage of this study and the second highest air leakage of houses tested by ABT to date. It does, however, have the equal smallest floor area of the study.

Main sources of air leakage identified were:

- 9 wall vents
- 1 exhaust fan
- leaking manhole cover
- 12m of window perimeter with inadequate seals
- leaking skirting boards
- 2 entrance doors with inadequate seals
- 2 chimney flues
- 1 louvered window

The cost of labour and materials to seal these sources of air leakage would be approximately $578.

House 10

With an ACH50 of 33.58 and a permeability of 28.4 this house slightly above average of this study. Main sources of air leakage identified were:

- 8 wall vents
- 1 exhaust fan
- 2 downlights
- 32m of window perimeter with inadequate seals
- 2 entrance doors with inadequate seals
- manhole cover leaking

The cost of labour and materials to seal these sources of air leakage would be approximately $458.

House 11

With an ACH50 of 17.06 and a permeability of 19.9 this house was the tightest house in this study. Main sources of air leakage identified were:

- 13 wall vents
- 2 exhaust fan
- 27 downlights
- manhole cover leaking
- 2 entrance doors with inadequate seals

The cost of labour and materials to seal these sources of air leakage would be approximately $505.

Conclusions

The average predicted cost of sealing each house is $684. If this brought the average ACH50 down to 10, the average reduction in ambient flow would be approximately 400 m^3/hr per house assuming ambient flow is flow at 50 Pa divided by 20.

The reduction in energy consumption during extreme weather conditions e.g. hot days with strong northerly winds, would decrease peak demand and therefore lower the need for infrastructure expansion.

The houses tested in this case study were consistent with other existing houses tested by ABT in Victoria. The average ACH50 of 29.1 is similar to findings in the USA for houses 50 years old or older but much higher than a study of more modern houses which had an ACH50 of 12.7. This illustrates how poorly Victorian houses compare to those built in other countries and the potential for energy savings through building envelope sealing schemes as practised in other countries.