DECARBONISING THE AUSTRALIAN HOUSING STOCK FOR CLIMATE CHANGE

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John Clarke is the Acting Research Group Leader, Projections, Products and Services, CSIRO Climate Science Centre. He has over 25 years’ experience in the fields of climate change impacts and adaptation, and in conservation ecology, and coordinated the development of the latest version of the Climate Change in Australia website. His team develops climate change projections and tailored datasets used by practitioners and researchers in Australia and internationally, to quantify impacts and plan appropriate responses.

ABSTRACT

Australia has committed to the global effort to keep temperature rises below 1.5 Kelvin but has a building stock with one of the world’s worst carbon emissions per person. This paper presents PhD findings that rank the cost-effectiveness of retrofits to lower heating and cooling energy and carbon emissions for three existing representative Australian houses. The method modelled the Adelaide climate in 2050, carried out thermal simulation modelling of 50 affordable retrofits with the AccuRate package, considered best practice decarbonisation approaches, and used a do-it-yourself (DIY) simple payback period cost benefit analysis. The results show that the most cost-effective single retrofits are 1) partial conditioning of the house; 2) ceiling insulation; 3) optimum weather-stripping; and 4) cavity insulation of the external wall, with others depending on the type of house construction. The cost-optimal retrofit combinations were medium payback periods for all house types, with energy savings from 25% to 80% costing between $2,000 and $7,000 DIY. Strategies and government incentives were found for tenants including using small payback periods with a cost of less than $1,500 for energy savings up to 50% across all house types. So, the Australian housing stock can be rapidly decarbonised by adopting best practice infrastructure decarbonisation approaches; by undertaking retrofit combinations with small and medium payback period; by encouraging retrofits for the active renovation movement; and by providing government incentives. Limitations with the simulation assumptions mean that adjustments may be required to apply these findings, particularly with regard to occupancy intensity and the conditioning of most rooms, but the ranking of retrofits should remain the same per house type.

Keywords: affordable retrofits, low-carbon retrofits, existing houses, climate change, simulation

Theme: Building Energy Simulation: Research

1. INTRODUCTION

World surface temperatures are still rising at an accelerated rate (Nuccitelli, 2016) and natural disasters have tripled in the last 35 years with around $4 trillion dollars in property damage.
(MunichRe et al., 2015, pp. 43–44). With the volume of greenhouse gases already released into the troposphere, temperatures will continue to accelerate, leading to more severe natural disasters. Australia has committed to keep temperature rise below 1.5 Kelvin at the 2015 Paris Conference of Parties (COP21) which implies a zero carbon economy by 2050 (ASBEC, 2016, p. 21). However, Australia’s building stock has one of the world’s worst carbon emissions per person (WRI, 2005; ASBEC, 2008, p. 8), and the residential sector makes up 50% of the carbon emissions of the building sector.

It is therefore important to rapidly lower the carbon emissions of existing housing and to adapt it to global warming (Ren, Wang and Chen, 2014; Blumer and Mayers, 2017). In reality however, this can be a difficult problem due to issues such as:

- the large number of stakeholders in the residential sector (WBCSD, 2009),
- split incentives for landlords and tenants, where those paying for energy efficiency upgrades do not enjoy the benefits (WBCSD, 2009, p. 20; ASBEC, 2016, p. 97), and
- the large renovation movement in Australia (HIA, 2016) which includes few retrofits (Pears, 1998).

Performance upgrades are more likely to be adopted if they are convenient and affordable (Bond, Pacifici and Newman, 2011). In this respect, do-it-yourself (DIY) retrofits can keep costs low (Williams et al., 2013), and the first author has had requests for these during energy auditing. So the aim of this paper is to find affordable DIY retrofits to reduce operational carbon emissions in 2050 for existing Australian housing for a warm temperate climate in which around 50% of the population lives (BZE et al., 2013, p. Appendix 2), based on the findings of a retrofit PhD program (Shiel, 2017).

### 2. METHOD

Figure 1 shows the methodology used in this study with 1) the AccuRate 2050 weather input files from climate change modelling; 2) housing and retrofit energy analyses; and 3) a carbon and cost benefit analysis.
Figure 1. The method for estimating house retrofit cost benefits, including climate change scenarios

2.1 Modelling climate change

Climate change modelling (Shiel, 2017) was carried out for 2050 using the Australian Climate Futures (ACF) on-line tool (CSIRO and BoM, 2015), for two scenarios:

- Extreme Climate Change, where emissions follow the current path of “business as usual” (Peters et al., 2013, p. 5). This assumes fossil fuels are plentiful and corresponds with the IPCC’s AR5 RCP8.5, where RCP is a Representative Concentration Pathway (RCP) (van Vuuren et al., 2011), and
- Scarce Resources (reported here) where resource depletion can cause prices to rise for energy and materials (including those for construction), which slows economic growth and therefore carbon emissions (Victor, 2008; Heinberg, 2011; Klare, 2012).

The climate change modelling developed annual hourly weather input files for the AccuRate simulation program to represent Adelaide in 2050 by selecting a General Circulation Model (aka a Global Climate Model; GCM); finding the projected change in the ‘temperature’ and ‘humidity’ climate parameters for 2050; and transforming the global climate projection to a regional level using a downscaling method. The Change Factor Method (CFM) was used for downscaling, where Belcher’s “morphing” technique (Belcher, Hacker, and Powell 2005) was used with Adelaide’s weather data from NatHERS’ 1990 Reference Meteorological Year (RMY) climate file.
2.2 Housing and retrofit energy analyses

Thermal simulations were conducted on models of three existing Australian houses (see Figure 2) with the NatHERS accredited AccuRate software package, for the Warm Temperate climate of Adelaide. The houses were selected to match the three eras of 1950s, 1980s and 2010, having appropriate floor types, and the three most common wall construction types in Australia: weatherboard lightweight walls (House 1), cavity brick walls (House 2), and brick veneer walls (House 3) (DEWHA, 2008, p. 104).

Over 50 single retrofits were selected and costed from a suite of around 70 retrofits for each house, and these were simulated, energy savings calculated and ranked by simple payback period (SPP). Passive solar principles governed the retrofit designs, including solar access for northerly windows; window shade control; perimeter insulation; optimum infiltration levels; optimum thermal mass; and cross-ventilation. In addition, consideration was given to the low exergy principles of using the lowest quality energy from sources such as the sun to heat occupants in a similar manner to passive solar principles, or from the wind or rain (Aynsley and Shiel, 2017; Alterman, 2017) to naturally cool occupants. This is contrasted with relying on high quality energy such as electricity which needs three times the delivered or final energy of home appliances in primary energy generated from centralised power stations, and including transmission and appliance energy losses. Infiltration levels were estimated in AccuRate using an unsealed exhaust fans approach (MEFL, 2010, pp. 107–108) to find the volume of air exchange required for a room based on its size and the air changes per hour (ACH).

Figure 2. Existing houses chosen to represent 3 eras and common construction types for Australia.

Source: (Shiel, 2017)
The main retrofit categories simulated were:

- partial air conditioning (of the living room and kitchen only),
- insulation of the perimeter,
- radiation changes with window treatments,
- weather-stripping, and
- extra thermal mass.

2.3 Carbon and cost benefit analysis

The savings in energy costs and carbon emissions per year were estimated for each retrofit using a split system air conditioner popular in South Australia (ABS, 2014). The state’s electricity carbon intensity factor of 0.64 kgCO₂-e/kWh (DEE, 2016) was used with an electricity rate of $0.35 per kWh.

A simple payback period (SPP) approach was used for the cost benefit analysis, although it does not take into account future energy price increases; replacement, repair or refinishing costs; or inflation. The SPP was estimated from the DIY capital costs and the annual cost savings (Shiel, 2017).

2.4 Selecting cost-effective retrofits

Affordable practical retrofits were simulated based on the primary author’s experimental results, and the advice of Architects and product suppliers. These included standard retrofits such as bulk and reflective foil insulation for the ceiling and roof, as well as novel retrofits such as exterior corrugated galvanised iron cladding; tree and vegetation shading; and shrubs for wing walls. Some of these novel retrofits did not meet NatHERS protocols, but were used to lower temperatures rather than gain a better star rating.

The retrofits were ranked as those most cost-effective, but some retrofits which were assumed to have a zero DIY cost (e.g. if they were hobbies or already part of the house e.g. aquariums, wine racks, or a PV system) were included although they had low carbon savings.

2.5 Combining retrofits

Retrofits were combined using a unique approach of selecting multiple cost-effective single retrofits that affected internal temperatures for the same envelope component, such as a ceiling or floor. This approach contrasts with others that conform to star-rating protocols where a few single retrofits are selected on an intuitive basis, or many retrofits are simulated using a brute force computer search approach. The retrofits were combined for three sets of costs with small, medium and large payback periods to suit the occupant categories (see the Appendix):

- tenants (T), those who would like to carry out a few retrofits, or those with low disposable incomes e.g. owners with a large mortgage, with an SPP less than 3 years,
- owners (O) with some mortgage, landlords who may wish to keep expenses low, or those wanting to do more retrofits than above, with an SPP greater than 3 years but less than 10 years, and
- those desiring deeper retrofits (D), or with more disposable income, or with a long-term occupancy with an SPP greater than 10 years but perhaps less than 20 years.
2.6 Best practices for rapidly decarbonising

With the high demand for housing in Australia, a life-cycle carbon analysis should be undertaken before retrofitting a house, since older houses on large lots close to public transport may justify consolidated development (Norman, MacLean and Kennedy, 2006; Randolph et al., 2007; Iyer-Raniga, 2010).

Best practice strategies continue to evolve (Shiel, 2009) but based on current climate science and expert opinion (Snow and Prasad, 2011; IPCC-AR5, 2015; Larson and iiSBE, 2017), it is important to maintain infrastructure which:

- has the greatest longevity;
- is in reasonable condition;
- is 20m above sea level;
- is located near public transport;
- is in regions with high population; and
- has high fuel carbon intensities e.g. for electricity, the states of Victoria and NSW/ACT.

So, housing with these characteristics, and which has the largest operational carbon emissions and the best solar access for a photovoltaic (PV) system should have the highest priority for retrofits.

3. RESULTS

The Scarce Resource scenario and DIY costings are reported here, and the retrofit contractor costings and the Extreme Climate Change scenario are in the dissertation (Shiel, 2017).

3.1 Climate change

The HadGEM2-ES GCM was selected as the most appropriate GCM for both scenarios, and Table 1 shows the projected changes in temperature and humidity from 1995 to 2050.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Projected annual mean change in the monthly surface temperature (Kelvin)</th>
<th>Projected annual mean change in Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP4.5</td>
<td>1.2</td>
<td>-1.1</td>
</tr>
</tbody>
</table>

Table 1. The projected changes in Adelaide temperature and humidity, from 1995 to 2050 for the Scarce Resources scenario

Source: Shiel with data from ACF (CSIRO and BoM, 2015)

3.2 Single retrofits

The carbon savings of the single retrofits compared to the base case house configuration are plotted against the DIY simple payback period (SPP), together with a label identifying that SPP in:

- Figure 3 for the 1950s weatherboard timber floor (House 1), including a colour code for the type of retrofit,
- Figure 4 for the 1980s cavity brick timber floor (House 2), and
- Figure 5 for the 2010 brick veneer concrete floor (House 3).

Each figure also contains a table listing each of the effective retrofits ranked in SPP order.
3.3 Retrofit combinations

Figure 6 shows the percentage of conditioned energy saved by retrofit combinations against their cost for each house type, while Figure 7 shows the carbon savings of those retrofit combinations against payback periods. Figure 7 also includes the indicative occupant categories for each payback period separated by dashed lines, for all house types. The Appendix contains Table 2 which shows the retrofit combination details for each of the houses, payback periods and occupant categories, including which retrofits are applicable.

Figure 3. The carbon savings by payback period for single DIY retrofits of House 1, a 1950s weatherboard timber floor house for the Adelaide 2050 Scarce Resource scenario. The retrofits are colour coded for thermal mass (dark blue bolded), roof and ceiling insulation (light blue), sealing (bolded black), floors (brown), cavity walls (purple bolded), wall cladding (purple), vegetation (green), and other (black).

4. DISCUSSION

4.1 Climate change

The Scarce Resource scenario was selected based on the critical status of some socio-economic and earth system indicators from the Anthropocene research (Steffen et al., 2015) and from other researchers, as cited in Shiel (2017). These include fresh water availability per person and domesticated land for crops, grazing and cities. This appears to be driven by the growth in spending (real GDP) (Zovanyi, 2013, p. 25) and by the rapid expansion of the middle class on a finite planet.
(Kharas, 2017; Shiel, 2017), which could lead to further price rises as resources diminish (Rubin, 2009, p. 22).

From Table 1, while there is little change in humidity from 1995 to 2050, the 1.2 K increase in projected temperature is very significant, for this scenario with a lesser degree of climate change. This is because measurements have already shown a 1 K increase in average global temperatures since 1850 (IPCC-AR5, 2015, p. 3), and with another 1.2 K, the COP21 target of keeping the temperature rise below 1.5 K level will be exceeded by 30% in 2050 ((2.2-1.5)/2.2*100).

**Figure 4. The carbon savings by payback period for single DIY retrofits of House 2, a 1980s cavity brick timber floor house for the Adelaide 2050 Scarce Resource scenario.**

### 4.2 Single retrofits

The most cost-effective single retrofits across all house types (see Figures 3-5) for the Scarce Resource scenario in 2050 for Adelaide are 1) partial conditioning of only the living room and kitchen; 2) ceiling insulation; 3) optimum weather-stripping; and 4) cavity insulation of the external wall. For houses with access to a concrete floor, an internal brick wall is cost-effective for thermal mass, and for older timber-floored houses, extra roof and underfloor insulation and galvanised iron cladding to the external wall are also cost-effective.
4.2.1 Optimum infiltration levels

A retrofit with a recommended optimum level of infiltration (Lstiburek, 2002; Ambrose et al., 2013, p. 59) of ten air changes per hour (10ACH\textsubscript{50}) was simulated, as well as an ultra-sealed level, which corresponded to minimum gap settings because NatHERS rewards tightly sealed house designs with higher star ratings. The ultra-sealed level was developed as two retrofits, since they were costed with and without an Energy Recovery Ventilation (ERV) system. Envelopes sealed below 10ACH\textsubscript{50} have greater carbon savings, but can have poor indoor air quality without an ERV unit, affecting occupant health (Aynsley and Shiel, 2017). When the cost of an ERV unit is added, the ultra-sealed level is less cost-effective, whereas the optimum infiltration level remains affordable. So this optimum level of infiltration was an important retrofit for climate change because older houses tend to have high infiltration rates (Ambrose et al., 2013), which is detrimental to good thermal performance.

![Retrofit Carbon Savings](image)

Figure 5. The carbon savings by payback period for single DIY retrofits of House 3, a 2010 brick veneer concrete floor house for the Adelaide 2050 Scarce Resource scenario.

4.2.2 High thermal mass but low embodied energy materials

To keep internal temperatures constant for a conditioned house with dynamic external temperatures, a low conductivity envelope is required. However, if the goal is to reduce the conditioned energy with a free running or naturally conditioned house, a low diffusivity envelope is needed (Barrios et al., 2011), where diffusivity is conductivity divided by thermal mass.
Hence high thermal mass retrofits are needed for temperate and subtropical climates with large diurnal temperature swings, but the challenge is to find retrofits with low or negative embodied energy. Options include:

- hempcrete and solid timber, which sequester carbon and are carbon negative (Envirootecture, 2015; FWPA and Dewsbury, 2016);
- zero carbon bricks (Clarke, 2014, p. 71);
- removing carpet from a concrete floor; and
- low carbon earth-walls, second hand bricks and pavers, and liquids e.g. stored in aquariums or wine racks.

Liquids, carpet removal from concrete floors and new brick walls were simulated in this research. The aquariums and wine racks had a small effect and were assumed to have zero cost because the occupant enjoys those activities. Also, an internal wall retrofit proved to be cost-effective even with new bricks, and so second-hand bricks would be even more cost-effective.

4.2.3 Comparison of retrofits across house types

Figures 3-5 show similar retrofits across each house type, with the most cost-effective retrofits ranked in the table in each figure for particular house constructions. The most cost-effective retrofit across all houses is the partial air-conditioning retrofit (Number 56).

The ceiling insulation had interesting effects across the houses. R2 m²K/W ceiling insulation reduced the conditioned energy by 29% and 32% for the 1950s and 1980s houses respectively, but only by 12% for the 2010s house type. This is because the 2010s house type already had R1 ceiling insulation, whereas the other houses had no insulation. However, increasing the insulation value to R3 only reduced the conditioned energy by a further 1-2% for the 1950s and 1980s houses but by a more substantial 5% for the 2010s house. Finally, increasing the ceiling insulation further to R4 and R5 had a negligible effect on the conditioned energy savings of all houses.

Another retrofit which had unusual effects across houses was underfloor insulation e.g. retrofit number 18 which used R2.5 polystyrene batts. This reduced the conditioned energy of the 1950s house by 15% whereas the reduction for the 1980s house was only 3%, and of course did not apply to the 2010s house with a concrete slab.
4.3 Retrofit combinations for rapid decarbonisation

Figure 6 shows the percentage energy saved from DIY retrofit combinations by cost and for the large payback period retrofit combinations, it shows:

- an 85% reduction in conditioned energy for the 1950s weatherboard house for $12,500 (see Figure 7 for more accurate costs) with an 8-year payback period,
- almost an 80% reduction in conditioned energy for the 1980s cavity brick house for around $15,000 with a 13-year payback period, and
- almost a 30% reduction in conditioned energy for the 2010s brick veneer house for $6,000, also with a 13-year payback period.
Figure 7. Carbon savings of combined retrofits by payback period for house type, with labels being the retrofit combination DIY costs (AUD dollars). This provides a rapid housing decarbonisation approach to suit house types and match selected occupant categories – See the Appendix for details.

Figure 7 shows cost-effective retrofit combination carbon savings for payback periods to suit each occupant category. It shows that occupants desiring deep retrofits can save per annum:

- almost 3 tonnes of CO2-e for the 1950s weatherboard house,
- around 2 tonnes of CO2-e for the 1980s cavity brick house, and
- around 0.9 tonnes of CO2-e for the 2010s brick veneer house.

On the other hand, while tenants in 1950s weatherboard houses and the 1980s cavity brick houses can save around 1.5 tonnes of CO2-e per year, tenants in the 2010s brick veneer houses can only save around 0.8 tonnes of CO2-e per year.

The optimum energy- and carbon-saving level of retrofit combinations from a purely cost point of view for each house type, is indicated in Figure 6 by the retrofit combinations with a medium payback period due to the asymptotic nature of each curve. For example, for House 1, with weatherboard walls and timber floor, around 77% of the conditioned energy can be saved with the medium payback period DIY retrofit combination costing $7,300 (from Figure 7). However for 85% savings in conditioned energy, $12,500 is required, ie. around $5,000 extra is needed for a further 8% saving in energy. However, this introduces a dilemma for tenants who may not be motivated to undertake this level of retrofit combination due to the larger investment or length of time for payback.

To assist with the split incentives issue, tenants could negotiate a lease at a constant rental tariff longer than the payback period of the retrofits they undertake, or else negotiate a lower rental tariff for the duration of the payback period.
If the government introduced Mandatory Disclosure for dwellings (where a star rating is needed when the property is sold or leased), which is under consideration, this would encourage landlords, as well as owners, to undertake retrofits.

So tenants could invest less than $1,500 to retrofit all house types with the retrofit combination with a small payback period to save between 0.8 tonnes (22% of the conditioned energy) and 1.5 tonnes (55% of the conditioned energy) of CO$_2$-e per year (from Figures 6 and 7). This could be at a small profit if the lease terms above were negotiated, assisting to overcome the split incentives problem. If the landlord carried out retrofits as well, then the retrofit combinations could approach the medium payback period levels of retrofits.

So the cost-optimum retrofit levels for all house types are:

- the retrofit combinations with medium payback period, for owners, deep retrofit households and the government, and
- the retrofit combinations with a small payback period for tenants.

The best practice rapid decarbonisation approach mentioned above should be considered to prioritise the selection of houses for the retrofits identified here, and the active renovation movement should be encouraged to adopt them as well.

4.4 Government assistance and incentives

Government subsidies and rebate schemes could be introduced to encourage retrofits since they can assist in meeting local, state and federal government greenhouse gas targets; in reducing energy poverty and deprivation (Liu and Judd, 2017); and also in reducing the peak power requirements of each state’s electricity network.

In particular, government incentives may be required to encourage retrofits for tenants, particularly if rental agreements such as those described above cannot be negotiated or the landlord does not permit retrofits to be carried out.

4.5 The reliability of the approach

The climate was modelled to 2050 because durable houses have up to a 100 year lifespan (Snow and Prasad, 2011) and therefore houses of the 1950s era may not have much longevity past 2050. Another factor was because Global Climate Model projections are quite reliable in the short term, but become more uncertain beyond 15 years (CSIRO and BoM, 2015, p. 88).

Limitations were found with the NatHERS protocol (Shiel, 2017) for thermal simulation modelling regarding:

- its occupancy assumptions where a large number of rooms are assumed to be conditioned, over extended time periods, which may not match actual occupant patterns,
- its inability to model in ratings mode thermal lined curtains, phase change materials, and vegetation benefits other than shading e.g. evapotranspiration effects on walls,
- the modelling of cladding, where the 0.4mm corrugated galvanized iron sheeting is very effective, but may be overestimated since the minimum AccuRate material thickness is 1mm, and corrugations cannot be accurately modelled.
5. CONCLUSION

If the Scarce Resource scenario projected temperature rise of 1.2 Kelvin eventuates, natural disasters could increase, and price rises may add to the urgency of retrofitting to lower emissions. Affordable low-carbon single retrofits for all Australian house types were found to be 1) partial conditioning of the house; 2) ceiling insulation; 3) optimum weather-stripping; and 4) cavity insulation of the external wall, and others that depend on the type of house construction. Retrofits for optimum infiltration and added thermal mass were identified as important for climate change. The cost-optimum retrofit combination levels for all house types are 1) those with medium payback period for owners, deep retrofit households and the government where the energy savings were from around 25% to 80% at an optimal DIY cost of between $2,000 and $7,000, and 2) those with a small payback period for tenants with energy savings from 20% to 50% at a cost of less than $1,500. The latter may be able to assist with the split incentives issue if leasing strategies are successful or if the government provides incentives.

This study suggests that rapid decarbonisation of housing is feasible by using the best practice infrastructure decarbonisation approaches identified; by undertaking the two cost-optimum DIY retrofit combinations identified for tenants and owners; by commencing Mandatory Disclosure for residential properties to encourage landlords and owners to adopt retrofitting measures; by encouraging more retrofitting for the active renovation movement; and by providing government incentives.

Limitations with the simulation assumptions mean that adjustments may be needed e.g. with regard to occupancy intensity and the conditioning of most rooms although the ranking of retrofits should not be affected.

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REFERENCES


### 7. APPENDIX – RETROFITS FOR EACH COMBINATION

<table>
<thead>
<tr>
<th>ID</th>
<th>Retrofit Description</th>
<th>Retrofits for each house combination</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>House 1</td>
</tr>
<tr>
<td>76</td>
<td>Lstiburek sealing approx. 10ACH50</td>
<td>Y</td>
</tr>
<tr>
<td>35</td>
<td>Parasol roof in N and W (PV panels)</td>
<td>Y</td>
</tr>
<tr>
<td>32</td>
<td>Low-e film applied to all windows</td>
<td>Y</td>
</tr>
<tr>
<td>34</td>
<td>Low-e film tint to non-North windows</td>
<td>Y</td>
</tr>
<tr>
<td>49</td>
<td>1.4m dia Ceiling fans to living &amp; bed rooms</td>
<td>Y</td>
</tr>
<tr>
<td>42</td>
<td>8 wine racks (564 bottles) in living room</td>
<td>Y</td>
</tr>
<tr>
<td>44</td>
<td>2 large Aquariums in Liv Rm</td>
<td>Y</td>
</tr>
<tr>
<td>45</td>
<td>1 large Aquarium in Liv Rm</td>
<td>Y</td>
</tr>
<tr>
<td>10</td>
<td>Liv/Garage wall R1.5 insulation &amp; Ceiling R2 (not garage)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ceiling R3</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>Ceiling R4</td>
<td>Y</td>
</tr>
<tr>
<td>5</td>
<td>Roof sarking Rfoil &amp; ceiling R1.3 Expanded Polystyrene + Rfoil</td>
<td>Y</td>
</tr>
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<td>53</td>
<td>Roof R1 insulation (No double-sided Rfoil)</td>
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<tr>
<td>58</td>
<td>500 dble-foil backed polyethylene foam to roof</td>
<td>Y</td>
</tr>
<tr>
<td>59</td>
<td>Foil batts in roof under battens</td>
<td>Y</td>
</tr>
<tr>
<td>60</td>
<td>Foil batts in ceiling (over battens)</td>
<td></td>
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<tr>
<td>62</td>
<td>Foil batts stapled under floorboards</td>
<td>Y</td>
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<tr>
<td>16</td>
<td>Underfloor 90mm gap &amp; 1500 bubble Insulation with dbl-sided Rfoil</td>
<td>Y</td>
</tr>
<tr>
<td>18</td>
<td>R2.5 polystyrene batts under timber floor</td>
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</tr>
<tr>
<td>67</td>
<td>Add carpet to timber floor</td>
<td>Y</td>
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<tr>
<td>72</td>
<td>Polystyrene cubes insulation to wall cavity</td>
<td>Y</td>
</tr>
<tr>
<td>74</td>
<td>140mm Polystyrene cubes insulation to full wall cavity with NO sisalation on studs</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>Corrugated galv. iron sheeting as ext wall cladding (not garage)</td>
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<tr>
<td>66</td>
<td>Corrugated galv. iron sheeting as ext North wall cladding only</td>
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<tr>
<td>55</td>
<td>Green ivy on North &amp; West walls - shade only</td>
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<tr>
<td>26</td>
<td>5m high deciduous trees 3m from North, East &amp; West windows</td>
<td>Y</td>
</tr>
</tbody>
</table>

Table 2. The retrofits for each house and combination’s payback period with occupant category, sorted by retrofit type and colours as per Figure 3. (Source: Shiel)