Rapid Decarbonisation of Australian Housing in Warm Temperate Climatic Regions for 2050

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Abstract
Australia has committed to play its part in keeping global temperature rise below 1.5 Kelvin but has one of the world's worst-performing building stocks for thermal performance. This paper reports on a study of cost-effective retrofits of typical Australian houses to rapidly reduce carbon emissions from heating and cooling, including the effects of climate change on a warm temperate climate in 2050. We used the AccuRate Home Energy Rating System (HERS) simulation program to model actual houses modelled in Adelaide, and a typical split system air conditioner appliance. We also show a retrofit method to be a resilient zero-carbon house. The most cost-effective single retrofits were partial conditioning of a house; ceiling and roof insulation; gap sealing to an optimum level; and external wall cavity insulation. Then they were those that suited the house construction such as under-floor insulation, and internal brick walls where there was a concrete floor. Novel successful retrofits include cavity wall insulation and roof 'cool paint', while ineffective retrofits included window awnings, shade cloths, a plastic temporary double glazing, and vegetation for wing walls. Rapid decarbonisation retrofit combinations were found to suit various occupant budgets and payback periods, by combining the most cost-effective retrofits per house type. The results are based on the Australian Nationwide House Energy Ratings Scheme (NatHERS) protocols regarding heating and cooling loads for room types, and occupancy loadings, and these may need to be adjusted in practice.

Keywords: affordable retrofits, existing houses, climate change, zero carbon retrofit method

1. Introduction
The number of natural disasters are increasing at an exponential rate, with a three-fold increase from 1980 to 2014 (MunichRe et al. 2015), and global temperatures are accelerating at an unprecedented rate, twenty times faster than at the end of the last ice age (Nuccitelli 2016). As carbon is added to the troposphere, temperatures will continue to rise, leading to more natural disasters.

To keep its 2015 Paris Conference of Parties (COP21) commitments, implying a zero carbon economy by 2050 (ASBEC 2016), Australia needs to rapidly lower its residential carbon emissions. This is because it has one of the world's worst-performing building stocks per person and residential emissions make up 13% of total building emissions (WRI 2005; ASBEC 2008).

However, this is a difficult problem due to the large number of stakeholders, high retrofit costs, and issues such as split incentives for landlords and tenants, where those who pay for energy efficiency upgrades do not enjoy the benefits (WBCSD 2009; ASBEC 2016). These upgrades will be more likely to be adopted if they are convenient and affordable (Bond et al. 2011).

So this study aimed to find affordable retrofits for 2050 to lower heating and cooling carbon emissions of existing Australian housing in a Warm Temperate climate. This climate is where around 50% of the population lives (BZE et al. 2013), and housing makes up 80% of the residential stock (ABS 2012; DEWHA 2008).

2. Methodology
Three actual Australian houses were modelled with the Australian Nationwide House Energy Ratings Scheme (NatHERS) tool AccuRate for the Warm Temperate climate of Adelaide, with affordable envelope retrofits. We estimated the single retrofit carbon savings and DIY costs and ranked them by simple payback period (SPP). We combined the most cost-effective single retrofits for the three

payback periods, small, medium and large, and calculated their carbon savings and total DIY capital costs. We also presented a method to retrofit a house into a resilient zero carbon state.

2.1 Climate change for 2050

The climate change method developed annual hourly AccuRate weather input files to represent Adelaide in 2050 (Shiel 2017) for the climate scenarios by:

- establishing the change in climate parameters for 2050 from a General Circulation Model (GCM) aka a Global Climate Model, and
- employing the Change Factor Method (CFM) to find the regional climate.

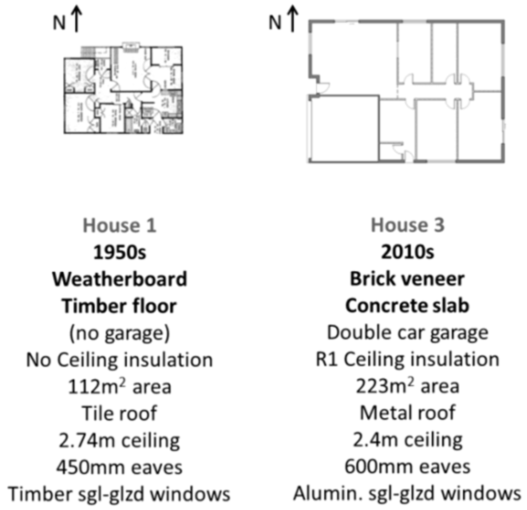
The Australian Climate Futures (ACF) on-line tool (Clarke et al. 2011; Whetton et al. 2012) was used to project changes in the temperature and humidity climate parameters from 1995 to 2050, for two scenarios of climate change. These were an Extreme Climate Change (RCP8.5) scenario which is reported here, where RCP is a Representative Concentration Pathway (van Vuuren et al. 2011), and a Scarce Resource scenario (RCP4.5) with resource depletion affecting energy supply and consumption of materials including for construction (Barrett 2014; Hall 2010; Steffen et al. 2015).

The ACF tool evaluates how many GCMs agree across two spectrums of weather parameters that are relevant to the application, in this case buildings e.g. temperature and rainfall, and also takes account of model skill (Moise et al. 2015). The the HadGEM2-ES GCM was found to best represent the 2050 climate futures with the most number of GCM's, called the "maximum consensus" case (Shiel 2017).

The Change Factor Method (CFM) approach chosen was Belcher's "morphing" technique (Belcher et al. 2005), which is popular with building researchers (Chen et al. 2012; Hacker et al. 2008), and the NatHERS Adelaide 1990 Reference Meteorological Year (RMY) climate file was used as the baseline.

2.2 Houses modelled

While three actual house plans were modelled (Shiel 2017), the two reported here are the 1950's weatherboard lightweight wall and timber floor house and the 2010's brick veneer wall with concrete slab on ground, as shown in Figure 1.



Source: Shiel

Figure 1 – Actual house plans representing 1950's and 2010's eras in Australia.

2.3 Retrofit modelling approach

There were 76 retrofit designs considered for each house, reduced to around 50 for DIY retrofits, including novel ones such as aquariums and wine for added thermal mass, and a PV panel parasol roof.

The main categories of retrofits were: partial air-conditioning (partitioned); conduction controls with perimeter insulation; radiation controls with window re-sizing and treatments including vegetation; convection controls with sealing and weather-stripping; extra thermal inertia with more thermal mass; and additional air movement controls from vegetation wing walls, louvre windows and ceiling fans.

The carbon cost savings per year for each retrofit over the base case were estimated using a typical split system air conditioner for South Australia (SA) (ABS 2014), the state's electricity carbon intensity factor of 0.64 $kgCO_{2-e}$/kWh (DEE 2016), and an average electricity rate of $0.35 per kWh.
One of the novel retrofits was an optimum, healthy level of 10 air changes per hour at 50 Pascals pressure ($10ACH_{50}$) infiltration (Ambrose et al. 2013; Lstiburek 2013). This level was estimated using an unsealed exhaust fans approach from the Moreland Energy Foundation (MEFL 2010), for which Energy Recovery Ventilation (ERV) systems were not required.

2.4 Retrofit combinations to suit occupant categories

Retrofit combinations with small, medium and large payback periods of less than 3 years, 3-10 years and 10-20 years respectively were designed to suit various occupant categories:

- tenants, owners with a large mortgage or short term residency, or those less wealthy to carrying out some retrofits,
- owners with a mortgage, landlords who may wish to keep expenses low, or those wanting to do more retrofits than above, and
- occupants with more disposable income, with long term occupancy, or desiring deeper retrofits.

3. Results

The Extreme Climate Change scenario for two houses and DIY costings are reported here, with contractor costs in (Shiel 2017), and the Scarce Resource scenario results in (Shiel et al. 2017).

3.1 Climate change

The projected surface temperature increase from the HadGEM2-ES GCM from 1995 to 2050 for the Extreme Climate Change scenario is 1.8 Kelvin, with only a 0.9% increase in humidity.

3.2 Single retrofits

There are graphs of the carbon savings of individual retrofits plotted against the DIY SPPs with labels identifying each SPP, and they include a table listing the retrofits ranked by SPP:

- in Figure 2 for the 1950s weatherboard walls with a timber floor (house number 1),
- in Figure 3 for the 2010 brick veneer walls with concrete floor (house number 3).

The most cost-effective retrofits, with the **colour coding** shown in Table 1, were partitions to reduce the conditioned volume (which were not included in the combinations of retrofits); ceiling and roof insulation; **gap sealing to an optimum level;** and **external wall cavity insulation;** and then retrofits that suited the house construction. These included under-floor insulation, **vegetation,** ceiling fans and low-e films to the windows for the weatherboard and timber-floored house, and corrugated galvanised iron sheeting to the external wall for the brick veneer house and **internal brick walls** if there was a concrete floor for added thermal mass (see Table 1 and Figures 2 and 3).

3.3 Retrofit combinations

The retrofits were combined in the order of their cost-effectiveness for each component such as ceiling and wall. These are listed in Table 1 for the large payback period retrofit combination, which may suit deeper retrofit households for each house type.
Figure 4 shows the carbon savings of combined retrofits for the three payback periods for the two houses, with typical occupant categories separated by dashed lines, and a dollar label on each point for the DIY cost of that retrofit combination.

3.4 Resilient zero-carbon retrofit method

Figure 5 shows a method to retrofit a house to become a resilient zero carbon one, with a PV system, battery and additional inverter for operating essential services during power outages.

4. Discussion and conclusion

4.1 Discussion

4.1.1 Climate change

The Extreme Climate Change scenario with RCP8.5 is the current temperature trajectory (Peters et al. 2013) and HadGEM2-ES shows if this trend continues there will be a 1.8 K rise in temperatures from 1995 to 2050 for Adelaide.

4.1.2 Single retrofits

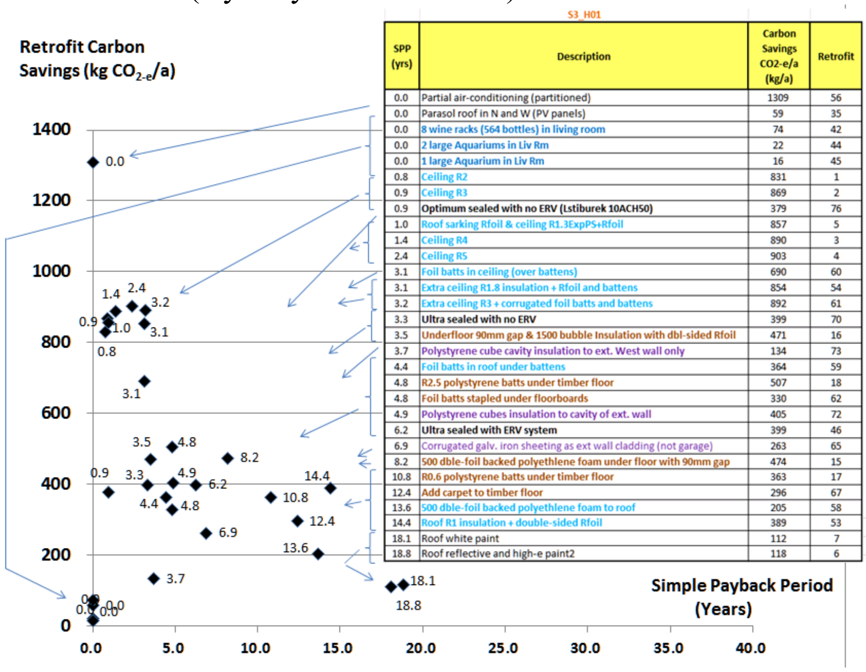
Some of the novel retrofits e.g. partial conditioning, vegetation, liquids for thermal mass, did not comply with the NatHERS star rating protocols, since the goal was to find affordable retrofits that reduced energy and carbon use, not increase the star rating.

Table 1 – The retrofits of the large payback period combination. The retrofits are **colour coded** according to their type and location: **thermal mass**; **floor**; **sealing**; insulation; ext. walls; **ext. wall cavity insulation**; **vegetation;** black for others.

Source: Shiel

House Type	Large Payback Period Retrofit Combination (for Deep Retrofit Households)
H01 – 1950s Weatherboard, timber floor	35 - Parasol roof in N & W roof; **42 - 8 wine racks (564 bottles); 44 & 45 - 3 large Aquariums;** 3 - Ceiling R4 Insulation; 16 - Underfloor 90mm gap & 1500 bubble Insulation with dbl-sided Rfoil; 59 - Foil batts in roof under battens; 62 - Foil batts stapled under floor; **72 - Polystyrene cubes insulation to cavity of ext. wall; 55 - Green ivy on North & West walls; 76 – Lstiburek approx. 10ACH$_{50}$;** 67 - Carpet to timber floor; 53 - Roof R1 insulation; **26 - 5m high deciduous trees to North windows;** 49 - 1.4m dia Ceiling fans; 32 - Low-e film applied to windows
H03 – 2010 Brick veneer (brick cladding on a timber stud wall), concrete floor	35 - Parasol roof in N & W roof; **42 - 8 wine racks (564 bottles); 44 & 45 - 3 large Aquariums; 76 – Optimum sealed & no ERV (Lstiburek 10ACH$_{50}$)**; 3 - Ceiling R4 Insulation; **10 – Add Liv/Garage brick wall with R1.5**; **74 - Polystyrene cubes to full 140mm cavity of ext. wall;** 65 – Corrugated galv. iron sheeting as ext wall; 59 - Foil batts in roof under battens

An optimum level of sealing of 10ACH$_{50}$ was trialled, together with ultra-sealed levels with and without an ERV system, which requires power that may not always be available in a warming world (World Bank 2012; Murdoch 2011; Kempton 2015; Mohr et al. 2015). House designs that have well-sealed envelopes below 10ACH$_{50}$ are rewarded by NatHERS, even though this can impair the indoor air quality. It is noted that Australia has no regulations for minimum ventilation levels (Aynsley and Shiel 2017).

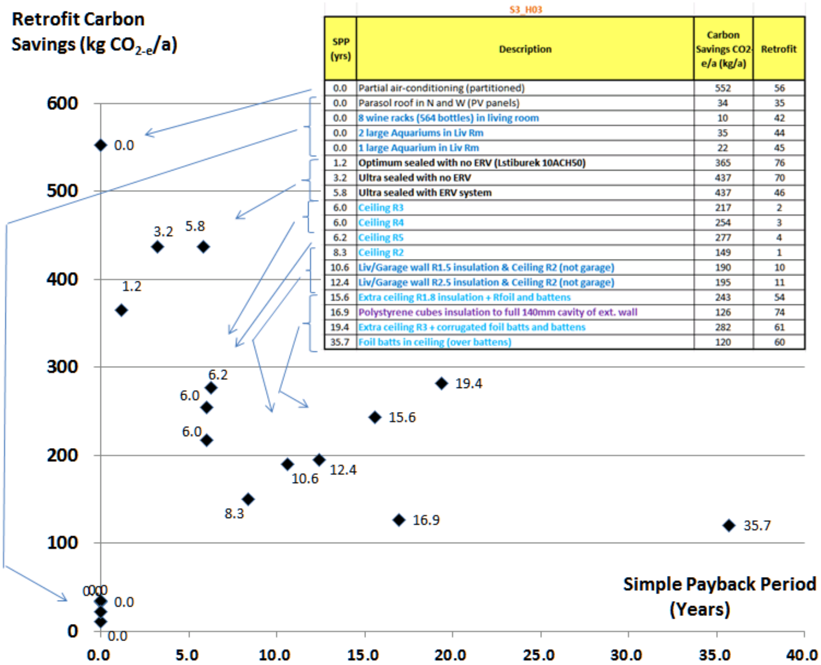


SPP (yrs)	Description	Carbon Savings CO2-e/a (kg/a)	Retrofit
0.0	Partial air-conditioning (partitioned)	1309	56
0.0	Parasol roof in N and W (PV panels)	59	35
0.0	8 wine racks (564 bottles) in living room	74	42
0.0	2 large Aquariums in Liv Rm	22	44
0.0	1 large Aquarium in Liv Rm	16	45
0.8	Ceiling R2	831	1
0.9	Ceiling R3	869	2
0.9	Optimum sealed with no ERV (Lstiburek 10ACH50)	379	76
1.0	Roof sarking Rfoil & ceiling R1.3ExpPS+Rfoil	857	5
1.4	Ceiling R4	890	3
2.4	Ceiling R5	903	4
3.1	Foil batts in ceiling (over battens)	690	60
3.1	Extra ceiling R1.8 insulation + Rfoil and battens	854	54
3.2	Extra ceiling R3 + corrugated foil batts and battens	892	61
3.3	Ultra sealed with no ERV	399	70
3.5	Underfloor 90mm gap & 1500 bubble Insulation with dbl-sided Rfoil	471	16
3.7	Polystyrene cube cavity insulation to ext. West wall only	134	73
4.4	Foil batts in roof under battens	364	59
4.8	R2.5 polystyrene batts under timber floor	507	18
4.8	Foil batts stapled under floorboards	330	62
4.9	Polystyrene cubes insulation to cavity of ext. wall	405	72
6.2	Ultra sealed with ERV system	399	46
6.9	Corrugated galv. iron sheeting as ext wall cladding (not garage)	263	65
8.2	500 dble-foil backed polyethlene foam under floor with 90mm gap	474	15
10.8	R0.6 polystyrene batts under timber floor	363	17
12.4	Add carpet to timber floor	296	67
13.6	500 dble-foil backed polyethlene foam to roof	205	58
14.4	Roof R1 insulation + double-sided Rfoil	389	53
18.1	Roof white paint	112	7
18.8	Roof reflective and high-e paint2	118	6

Source: Shiel

Figure 2 - The carbon savings by payback period for individual DIY retrofits of a 1950s weatherboard timber floor house for the Adelaide 2050 Extreme Climate Change scenario.

Thermal mass is very beneficial for moderating temperatures without air conditioning in temperate or subtropical climates where there are diurnal temperature swings (Barrios et al. 2011). So thermal mass retrofits were trialled, even those with zero cost such as liquids in hobby aquariums and in wine racks.



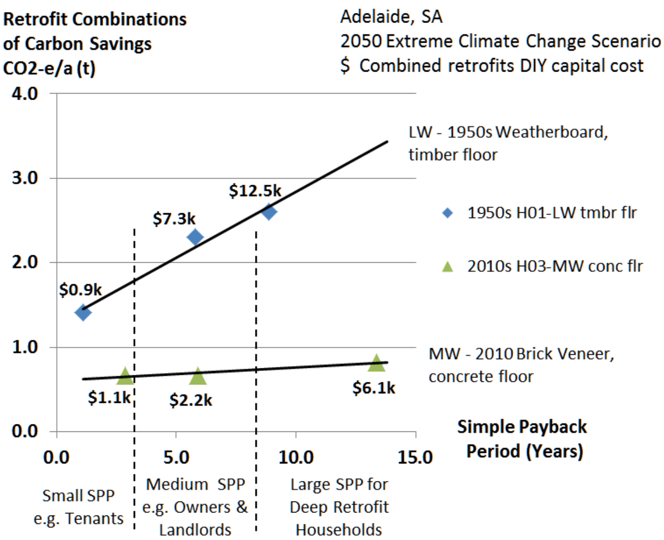
SPP (yrs)	Description	Carbon Savings CO2-e/a (kg/a)	Retrofit
0.0	Partial air-conditioning (partitioned)	552	56
0.0	Parasol roof in N and W (PV panels)	34	35
0.0	8 wine racks (564 bottles) in living room	10	42
0.0	2 large Aquariums in Liv Rm	35	44
0.0	1 large Aquarium in Liv Rm	22	45
1.2	Optimum sealed with no ERV (Lstiburek 10ACH50)	365	76
3.2	Ultra sealed with no ERV	437	70
5.8	Ultra sealed with ERV system	437	46
6.0	Ceiling R3	217	2
6.0	Ceiling R4	254	3
6.2	Ceiling R5	277	4
8.3	Ceiling R2	149	1
10.6	Liv/Garage wall R1.5 insulation & Ceiling R2 (not garage)	190	10
12.4	Liv/Garage wall R2.5 insulation & Ceiling R2 (not garage)	195	11
15.6	Extra ceiling R1.8 insulation + Rfoil and battens	243	54
16.9	Polystyrene cubes insulation to full 140mm cavity of ext. wall	126	74
19.4	Extra ceiling R3 + corrugated foil batts and battens	282	61
35.7	Foil batts in ceiling (over battens)	120	60

Source: Shiel

Figure 3 - The carbon savings by payback period for individual DIY retrofits of a 2010s brick veneer concrete floor house for the Adelaide 2050 Extreme Climate Change scenario.

4.1.3 Rapid decarbonisation with retrofit combinations

Table 1 shows the list of retrofits that make up the large SPP combination for each house type, at a DIY cost of $12,500 and $6,100 for the 1950s and 2010s house types respectively. The table includes single retrofits with carbon savings too low to be effective for the tables in the Figures they have low or zero DIY cost. Partition retrofits were ignored due to their different conditioned area, making ranking more difficult.



Source: Shiel

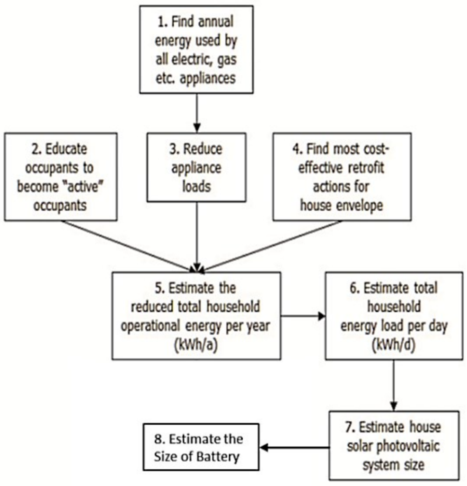
Figure 4 – Combined retrofit carbon savings by payback period with DIY costings for a 1950's weatherboard wall and timber floor house, and a 2010's brick veneer wall with concrete slab on ground.

By interpolating the trends of carbon savings in Figure 4, around 2 tonnes of CO_2-e/a could be saved for the 1950's house for a combined retrofit costing around $6,000. This contrasts with around 1 tonne of CO_2-e/a could be saved for the 1950's house for a combined retrofit costing around the same amount. Further, the slope of the 2010s house line is very shallow which means that it takes longer to payback in conditioned energy cost savings the cost of the retrofit combinations than for the 1950s house, and they are more expensive. This is because the older house has very poor thermal performance, and the most affordable retrofits were very effective, whereas the 2010s house already had a very effective cost-effective ceiling insulation retrofit.

Assuming the trends in Figure 4 holds for other retrofits of these types of houses, decarbonisation of the existing stock could be achieved by showing households with weatherboard and brick veneer houses estimated costs, payback periods and carbon saving impacts of selected retrofit combinations. Rapid decarbonisation could then be achieved if the large renovation network was involved, and if governments promoted schemes with rebates to lower capital costs further since these schemes would help the government climate change goals.

4.1.4 Resilient zero-carbon retrofit method

A resilient zero carbon retrofit method is shown in Figure 5, based on retrofitting a house after an energy audit, and improving appliance energy efficiency and occupant behaviour. A solar photovoltaic (PV) system and battery can be sized from estimated energy consumption, and resilience can be added if an additional inverter is added to the battery to maintain essential services on grid outages.



Source: Shiel

Figure 5 – A resilient operational zero-carbon retrofit method, which includes a battery system which can have its own inverter for essential services

4.1.5 The reliability of the retrofit approach

Since actual houses that have been built were modelled, the AccuRate models are realistic and they are also representative of two of the three main types of wall construction in Australia (DEWHA 2008). DIY costings were used because of the significant renovation movement in Australia. The combination of retrofits also provides a robust approach by adding retrofits that are ranked most cost-effective for each component e.g. for the 2010s house external walls, both polystyrene cube insulation and corrugated galvanised iron sheeting were both used.

While the Simple Payback Period is a reliable cost benefit metric to provide an estimate of the payback period for short terms, various factors are usually not taken into account, such as future energy price rises; inflation; or costs of retrofit replacement, repair or refinishing. However, the longevity of the retrofits was considered, and replacement cost was included in this analysis.

These results are from AccuRate simulations and so adjustments are needed for carbon and cost savings and payback periods, once actual conditioned volumes and occupancy levels are compared with the heavy assumptions in NatHERS.

4.2. Conclusion

Affordable carbon-reducing single retrofits were found for modern brick veneer housing with a concrete floor, and many more were found for weatherboard older style housing with timber floors, due to their poorer thermal performance. Two key retrofits were additional optimal thermal mass to stabilise internal temperatures without the need for air conditioning, and a healthy minimum infiltration level of $10ACH_{50}$ rather than relying on an ERV system due to possible power supply issues in the future.

This research has shown that households can invest in combinations of thermal performance retrofits to upgrade the existing stock of weatherboard and brick veneer houses using a DIY simple payback period approach, and has shown how long it will take for the energy savings to pay for the retrofits. For example, if tenants negotiated a 3 year lease without a rental increase and invested around $1,000 in weatherboard or brick veneer house retrofit combinations, there would be no net cost over 3 years. They would then enjoy the social, environmental and economic benefits that accrue from retrofitting older dwellings (Shalekoff 2017). Deeper retrofits would also be possible if the landlord contributed as well, and Mandatory Residential Disclosure would encourage this to happen with regulation incentives. Both these mechanisms would help to overcome the split incentives problem

Government retrofit subsidies and rebate schemes should be considered for certain household categories to assist both the federal government to meet its greenhouse gas target, and the state government to reduce its peak power loads.

So, weatherboard and brick veneer housing can be rapidly decarbonised if the deep retrofit combinations identified are implemented, and State and Federal government programs should be implemented for occupant categories such as the elderly and those suffering energy deprivation.

4.3 Acknowledgements

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