

# Zero Net Carbon Homes Research Report

ZNC Homes Research Report | April 2021

Shannon Best, Director  
Nycole Wood, Building and Data Analyst  
April 2021



BEST ENVIRONMENTS



# Table of Contents

<b>Table of Contents</b>	<b>i</b>
List of Figures	ii
<b>Executive summary</b>	<b>1</b>
<b>Introduction</b>	<b>10</b>
Background	10
<b>Methodology</b>	<b>12</b>
Overview	12
NatHERS modelling (FirstRate5)	13
Accubatch	14
ZNC extractor	15
ZNC tool	16
Assumptions	16
Zoning and Occupancy	17
Greenhouse Co-efficients	17
Energy Tariffs	17
Data fields	18
Data collation	18
Data analysis and visualisation	19
Capital Improvement Cost Assumptions	19
The homes	21
<b>Results</b>	<b>22</b>
1. NatHERS star rating by orientation	22
2. Building fabric upgrades – 6 Stars to 7 Stars	24
Insulation	26
3. Solar PV and home size	28
4. Capital improvement costs	30
5. Capital improvement cost and standard build cost	33
6. Net costs	34
7. Solar PV size and proportion of roof area	37
8. Solar PV and ghg coefficients	40

Solar PV sizing for Zero Net Energy _____	41
9. Hours outside comfortable temperatures (free running) _____	43
10. Peak demand _____	47
11. Energy cost savings _____	50
12. Energy cost savings and improvement costs by feature _____	53
Fuel mix contribution and energy efficiency _____	55
13. GHG emission reduction by feature _____	57
14. Energy reduction by feature _____	60
15. Net energy to 2050 _____	64
16. Operational energy costs to 2050 _____	67
17. GHG emissions to 2050 _____	70
<b>Areas for Further Research _____</b>	<b>74</b>
<b>Conclusion _____</b>	<b>75</b>
<b>Appendix A _____</b>	<b>77</b>
<b>Appendix B _____</b>	<b>78</b>
<b>Appendix C _____</b>	<b>80</b>

## List of Figures

Figure 1 Simple methodology flowchart.....	13
Figure 2: Thermostat settings and hours of heating and cooling for each profile .....	15
Figure 3: The homes.....	21
Figure 4: NatHERS star ratings for BAU homes for orientations modelled.....	23
Figure 5: NatHERS star ratings for ZNC homes for orientations modelled .....	23
Figure 6: Improvements to meet 7 stars.....	25
Figure 7. Additional insulation to meet 7 stars .....	26
Figure 8. Additional insulation to meet 7 stars (stacked) .....	27
Figure 9: Solar PV size to meet ZNC by home size.....	28
Figure 10: Annual greenhouse emissions from heating and cooling for ZNC home .....	29
Figure 11: Improvement costs by item.....	30
Figure 12: Improvement costs per home to achieve ZNC.....	31
Figure 13: Improvement cost to reach ZNC per sqm of floor area .....	31

Figure 14: Average improvement cost to reach ZNC by improvement type.....	32
Figure 15: Standard build cost and improvement cost to meet ZNC .....	33
Figure 16: Net annual savings .....	34
Figure 17: Net present value to 2050 .....	34
Figure 18: Simple payback period for 15 homes.....	36
Figure 19: Solar PV size to meet ZNC compared with maximum solar PV size .....	37
Figure 20: Solar PV area required to meet ZNC as a proportion of available roof area .....	38
Figure 21: Solar PV size to meet ZNC compared with maximum solar PV size (370W panels).....	39
Figure 22: Solar PV area to meet ZNC for 370W panels and 315W panels and as a proportion of available roof area.....	39
Figure 23: Solar PV size to meet ZNC under various greenhouse co-efficients .....	40
Figure 24: Solar PV size to meet Zero Net Energy.....	41
Figure 26: ZNC Percentage of hours outside comfort temperature range without conditioning .....	43
Figure 26: Percentage of hours of living and non-living areas below 18 degrees and above 26 degrees without conditioning.....	44
Figure 27: Percentage of hours outside comfort temperature range without conditioning .....	45
Figure 28: Reduction of annual hours in uncomfortable temperatures (above 26 or below 18 degrees) without conditioning - ZNC improvement.....	46
Figure 29: Building envelope improvement on Home E temperatures on hottest and coldest days and nights.....	46
Figure 30: Average summer and winter peak demand for BAU and ZNC .....	47
Figure 31: Average ZNC summer and winter peak demand by fuel mix.....	48
Figure 32: Average ZNC winter peak demand by heating system type .....	49
Figure 33: Average ZNC winter peak demand by hot water system type .....	49
Figure 34: Annual energy cost savings by home and typology.....	50
Figure 35: Annual energy cost savings (excluding solar) by home and typology.....	51
Figure 36: Annual operating energy cost saving by fuel mix .....	52
Figure 37: Annual operating energy efficiency cost saving by fuel mix (excluding solar) .....	52
Figure 38: Annual operating energy cost savings split by improvement type .....	53
Figure 39: Annual operating energy cost savings from efficiency .....	54
Figure 40: Heating and cooling operating costs savings contributions.....	54
Figure 41: Improvement cost and operating cost savings by feature.....	55
Figure 42: Annual operating cost savings by use.....	55
Figure 43: Annual operating cost savings by home and fuel type .....	56
Figure 44: Annual emissions reduction split by improvement type .....	57

Figure 45: Annual emissions of BAU and ZNC homes – solar PV not included .....	58
Figure 46: Annual emissions reduction per home – energy efficiency .....	58
Figure 47: Annual emissions savings from efficiency .....	59
Figure 48: Average annual energy consumption by fuel mix – BAU and ZNC.....	60
Figure 49: Average annual energy consumption by end use and fuel mix – BAU and ZNC.....	60
Figure 50: Annual energy reduction by improvement type.....	61
Figure 51: Annual energy consumption of ZNC by end use.....	62
Figure 52: Annual energy consumption of ZNC by end use and heating type.....	63
Figure 53: Cumulative Net Energy Use over 30 years, 6 star BAU compared with 7 star ZNC home.....	64
Figure 54: Cumulative net energy use (GJ) over 30 years, 6 star BAU compared with 7 star ZNC home.....	65
Figure 55: Cumulative net energy ZNC to 2050 – Average of All Electric Homes.....	65
Figure 56: Cumulative net energy ZNC to 2050 – Average of Mixed Fuel Homes.....	66
Figure 57: Cumulative Cost over 30 years, 6 star BAU compared with 7 star ZNC home.....	67
Figure 58: Cumulative Discounted Cost over 30 years, 6 star BAU compared with 7 star ZNC home .....	68
Figure 59: Cumulative Discounted Cost, with ZNC improvements mortgaged over 30 years, 6 star BAU compared with 7 star ZNC home.....	68
Figure 60: Cumulative Greenhouse Emissions (‘Constant ghg coefficient’) for 6 star BAU compared to 7 star ZNC – all homes (blue), all electric only (orange) and mixed fuel only (pink) .....	70
Figure 61: Cumulative Greenhouse Emissions (‘Policy Setting coefficient’) for 6 star BAU compared to 7 star ZNC - all homes (blue), all electric only (orange) and mixed fuel only (pink) .....	71
Figure 62: Cumulative Greenhouse Emissions (‘Policy Setting + 2050 zero coefficient’) for 6 star BAU compared to 7 star ZNC - all homes (blue), all electric only (orange) and mixed fuel only (pink) .....	71
Figure 63: Cumulative greenhouse emissions by year and GHG coefficient scenario .....	72
Figure 64: Marginal cost of abatement (improvements not mortgaged) for three ghg co-efficients.....	73
Figure 65: NatHERS star rating by orientation BAU .....	78
Figure 66: NatHERS star rating by orientation ZNC.....	79

Revision	Description	prepared by	date
0.1	First draft for SV review	SBest & NWood	17.12.2020
0.2	Full draft for SV review	SBest & NWood	23.12.2020
0.3	SV comments and responses	SBest & NWood	27.01.2021
0.4	Final review	SBest & NWood	09.04.2021
0.5	Minor changes and Alt tags	SBest	04.06.2021

# Executive summary

The Victorian Government has legislated a target of a Zero Net Carbon (ZNC) Emission economy by 2050 in the Climate Change Act (2017). An integral part of reaching that target is the transition to high efficiency, low emission buildings as set out in the [climate change framework](#) and the [energy efficiency and productivity strategy](#).

Sustainability Victoria’s Zero Net Carbon Homes Pilot Program delivered 39 homes. These homes had improved thermal performance and improved fixed appliance efficiency to reduce energy consumption, and Solar PV systems installed to offset emissions generated by the home.

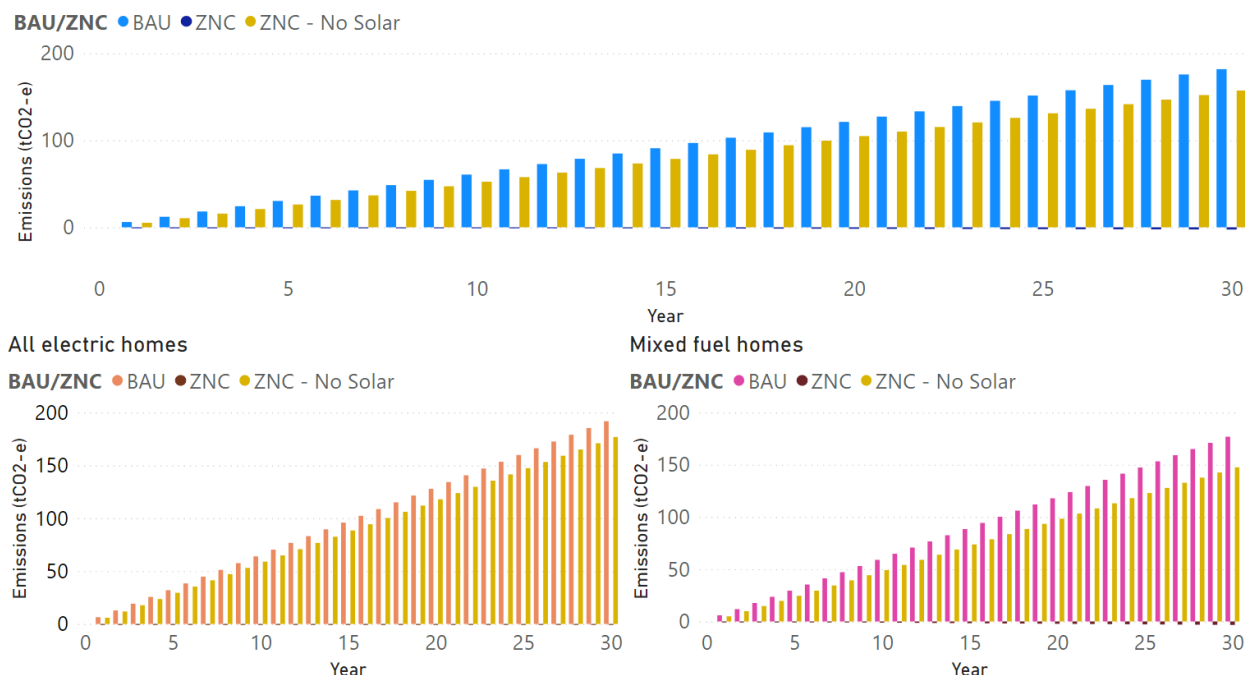
Fifteen of these homes were examined in further detail in order to better understand the program costs, benefits and outcomes under a range of scenarios. The homes are all Class 1 residential buildings and represent a mix of typology, size, fixed appliance types and fuel mix (all electric and mixed fuel – natural gas and electric).

In this study, for each home, a 6 star NatHERS ‘business as usual’ version of the home with market average fixed appliances was compared to a 7 Star thermally improved version of the home with more efficient fixed appliances, and Solar PV sized to meet ZNC.

## What is the overall impact of a ZNC home built today?

The homes we build today will be standing in 40 years or more, and so the design choices made today ‘lock in’ energy use and greenhouse emissions over many decades.

Figure 60: Cumulative Greenhouse Emissions (‘Constant ghg coefficient’) for 6 star BAU compared to 7 star ZNC – all homes (blue), all electric only (orange) and mixed fuel only (pink)



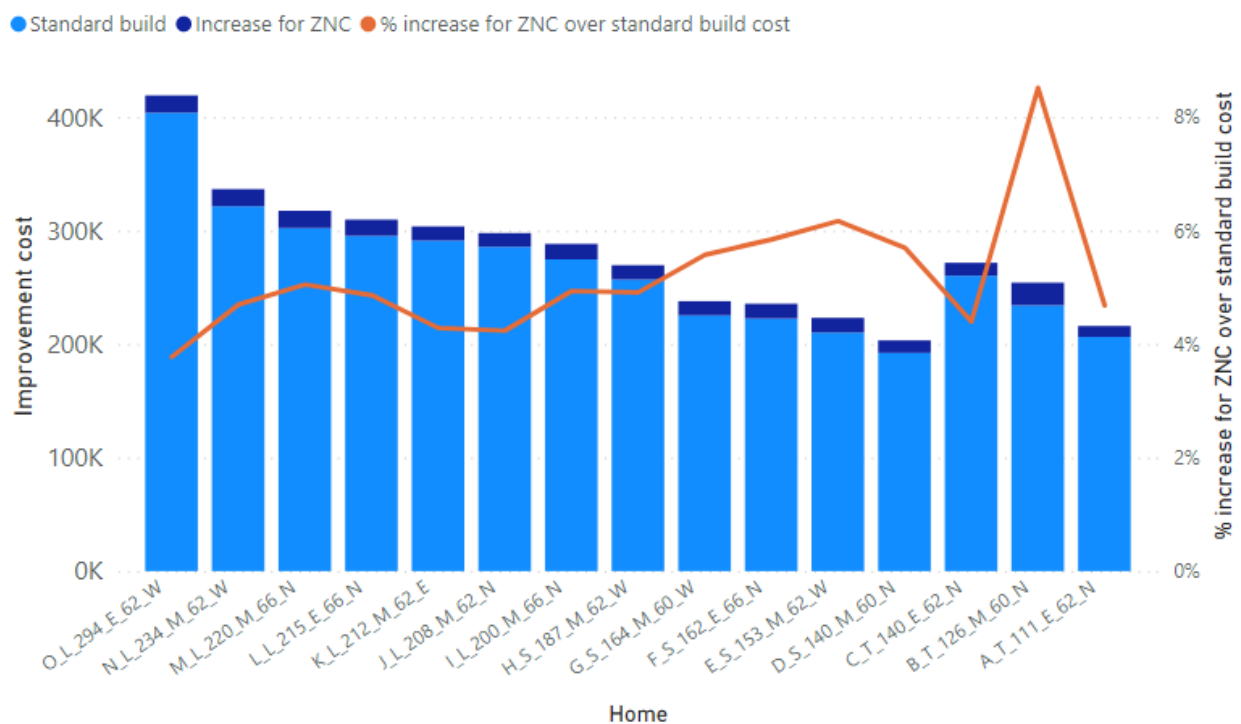
In the decarbonising grid scenario (discussed later in this summary, also refer section 17) all electric ZNC homes deliver 100% emissions savings for the entire 30 years, whereas for mixed fuel ZNC homes the solar PV size originally installed to meet ZNC is not sufficient to meet ZNC in later years. This is because each kW of solar energy generated offsets less emissions in a decarbonising grid, while the emissions generated from gas consumption remains constant.

### How much does it cost to build a ZNC home?

The percentage increase on a standard build is in the range of 4% to 7%, excluding Home B which is an outlier. Home B had the highest calculated percentage at 8.5% due to a high cost shading device that was larger and more complex than necessary.

All homes are well under the often quoted 10% or more premium for low carbon homes.

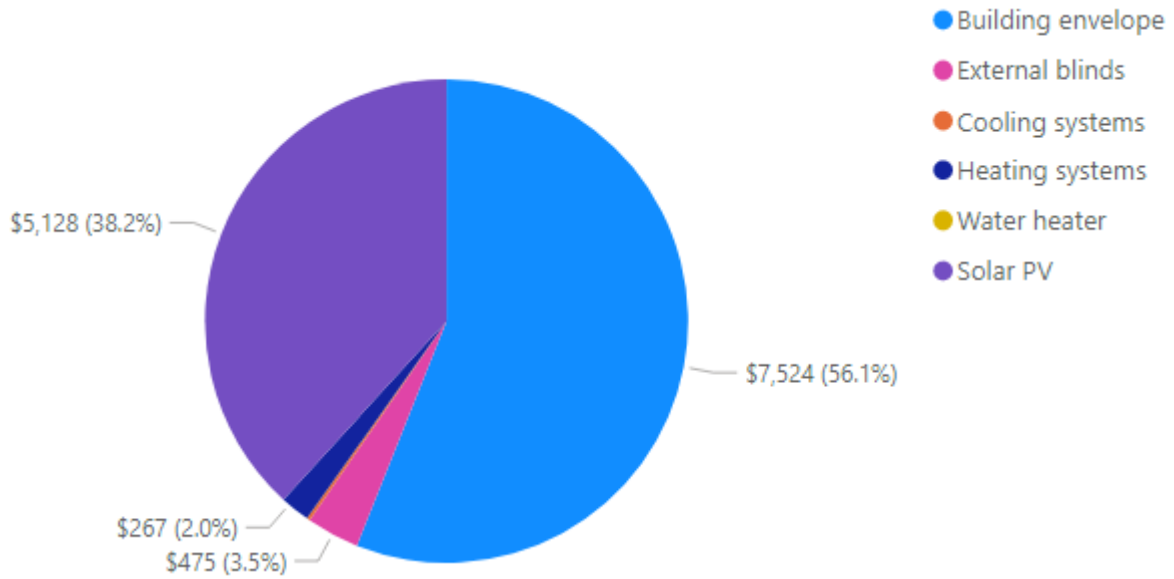
Figure 15: Standard build cost and improvement cost to meet ZNC



### What are the relative costs and benefits of different upgrade features required to meet ZNC – building fabric, appliance efficiency and Solar PV?

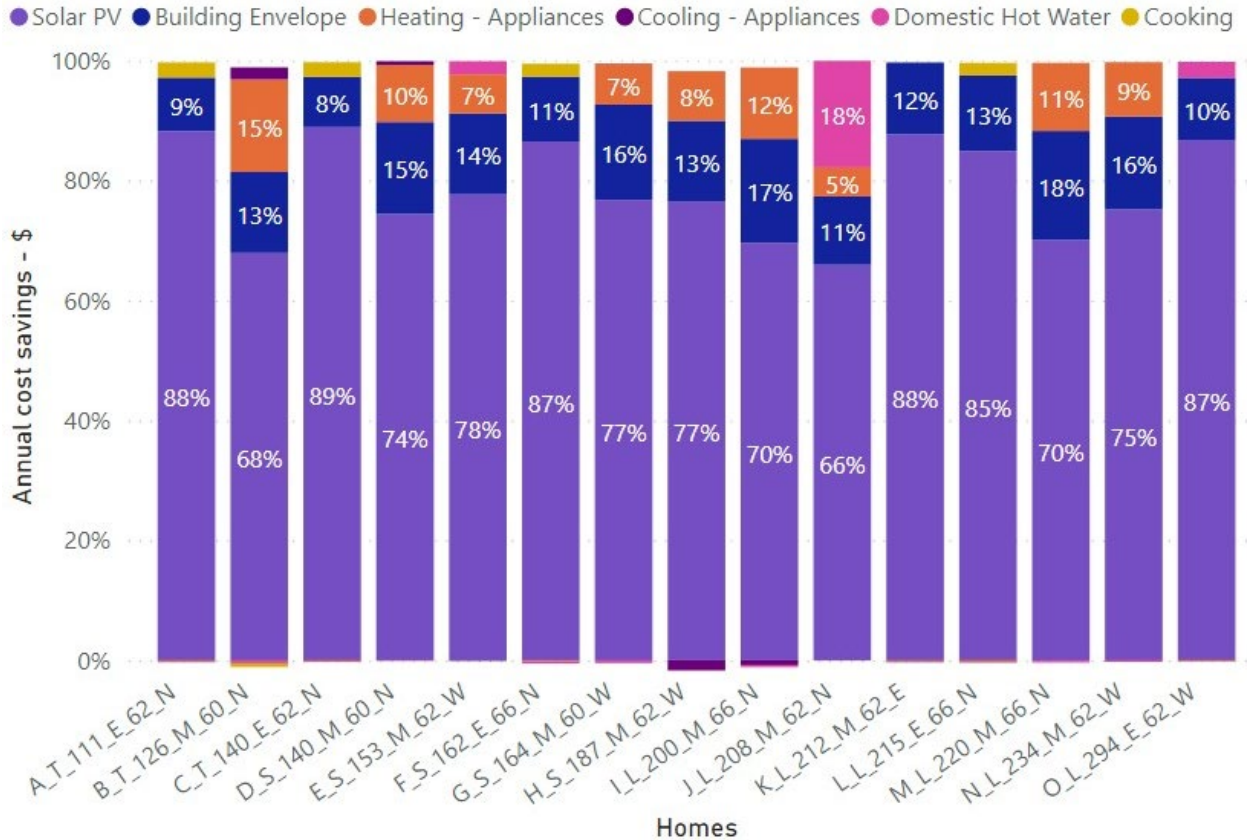
Building envelope improvements represent the highest proportion of improvement costs, followed by Solar PV. The average improvement cost of the combined heating systems, cooling systems, water heating systems represents only 5.7% of the overall improvement cost.

Figure 14: Average improvement cost to reach ZNC by improvement type



For annual operating cost savings, Solar PV operating cost benefits accounted for between 66% and 89% of total cost savings. Improvements to building envelope and heating appliances accounted for another 8% to 28%. When viewed in purely financial terms, Solar PV delivers a strong return on investment compared with building fabric improvements. However, building fabric improvements remain an important part of reducing energy consumption and improving the comfort of homes.

Figure 38: Annual operating energy cost savings split by improvement type



Appliance choices, particularly for heating, also remain significant. Heating and hot water system choices are more important than the choice of cooling system for the homes studied. This is expected in Victorian climate zones which are heating dominated.

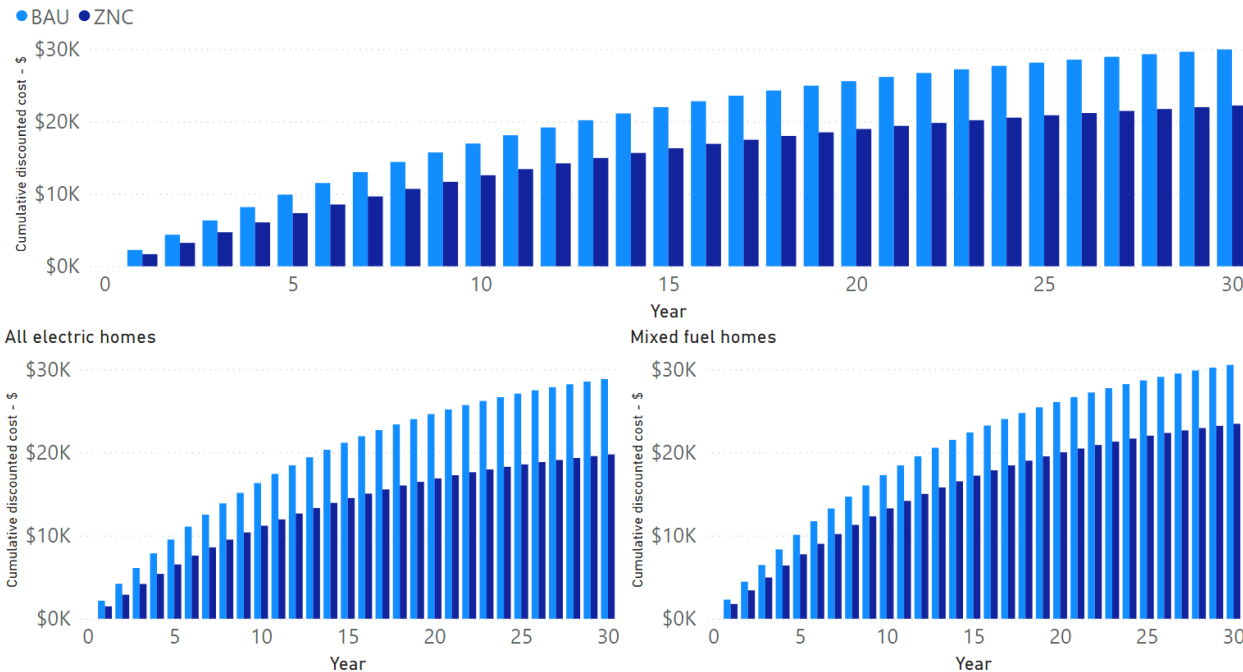
**What is the payback period of ZNC homes? How long do these homes take to recoup the initial investment in efficiency and renewable energy via energy cost savings?**

Net cost savings calculated for each home using current tariffs show that net savings start at occupancy for all ZNC homes when improvement costs are included on the mortgage (at 2.48%<sup>1</sup> over 30 years). The payback is zero years. This is due to energy savings being greater than the additional mortgage payments.

Net annual savings ranged from \$79 to \$882 with all homes except Home B showing net annual savings over \$400. Over 30 years, an average discounted saving of \$7,742 was shown, with all electric homes realising higher average savings of \$9,064.

While there are many factors that may influence the use and cost of energy within a home, including behaviour, energy price changes and climate change, the ZNC home is likely to deliver a significant cost saving over a 6 Star BAU home over a 30 year period. The ZNC home also delivers associated benefits including greater comfort from an improved thermal envelope and improved indoor environment quality when less mechanical heating and cooling is needed.

**Figure 59: Cumulative Discounted Cost, with ZNC improvements mortgaged over 30 years, 6 star BAU compared with 7 star ZNC home**



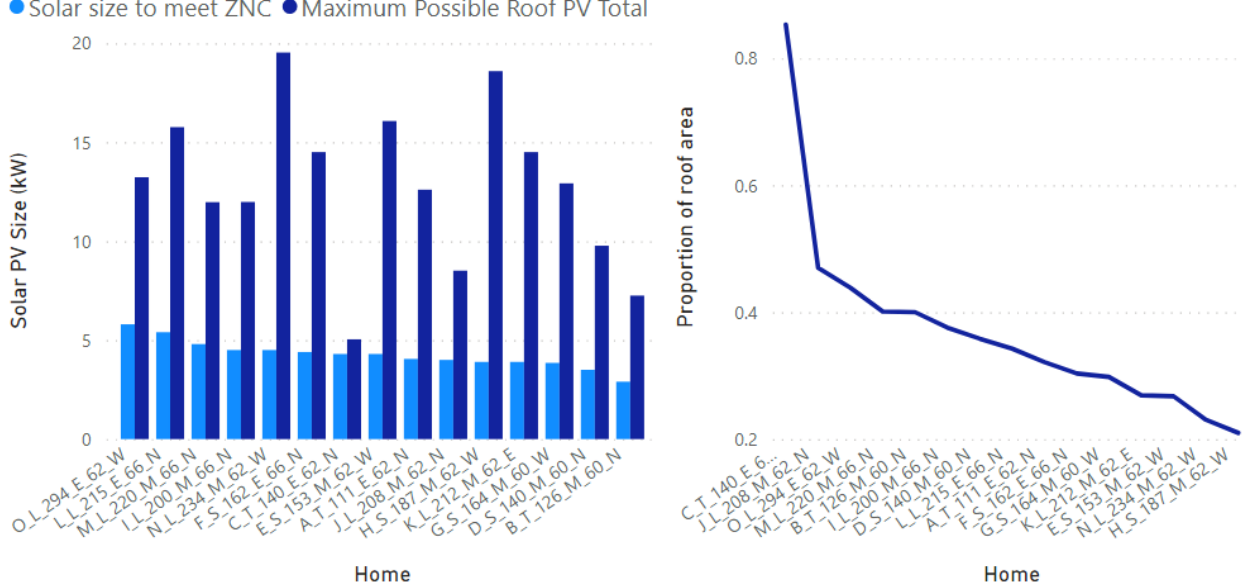
<sup>1</sup> moneysmart.gov.au – accessed 1 March 2021

**Can ZNC be achieved on site? What Solar PV sizes are needed? Is the roof area a limiting factor?**

One concern has been that ZNC homes will not have sufficient roof area available for Solar PV systems to offset the emissions generated by the home. Of the 15 homes in this study, 100% were able to install the required Solar PV size system on their roof. Thirteen required less than half the roof area they had available for Solar PV. Improvements in panel technology (W/sqm) only improve this result.

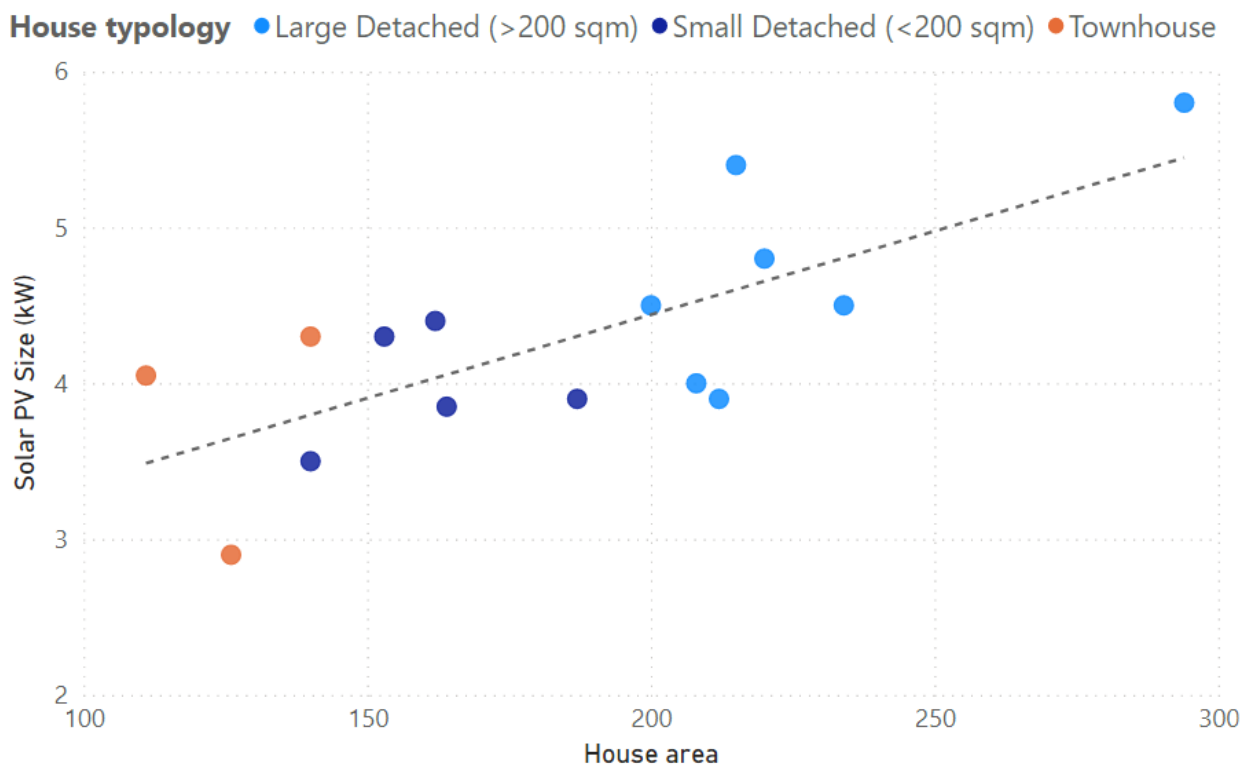
It is possible but unlikely that there will be inadequate roof area available for the required Solar PV system. Where this does occur, it is likely to be for more constrained sites such as townhouses where design to avoid overshadowing of neighbours may limit the roof design options. Sites with significant shading (by neighbouring buildings or large trees) may also be limiting.

**Figures 19 and 20: Solar PV size to meet ZNC compared with maximum solar PV size, and as a proportion of available roof area**



All but three of the 7 Star homes required a Solar PV size between 3.5kW and 4.5kW to achieve ZNC. In the ZNC Homes program, builders almost universally installed 5kW systems – likely demonstrating that a standardised product offering is preferred by the volume build industry.

Figure 9: Solar PV size to meet ZNC by home size



### How much more ‘comfortable’ are 7 Star homes compared with 6 Star BAU?

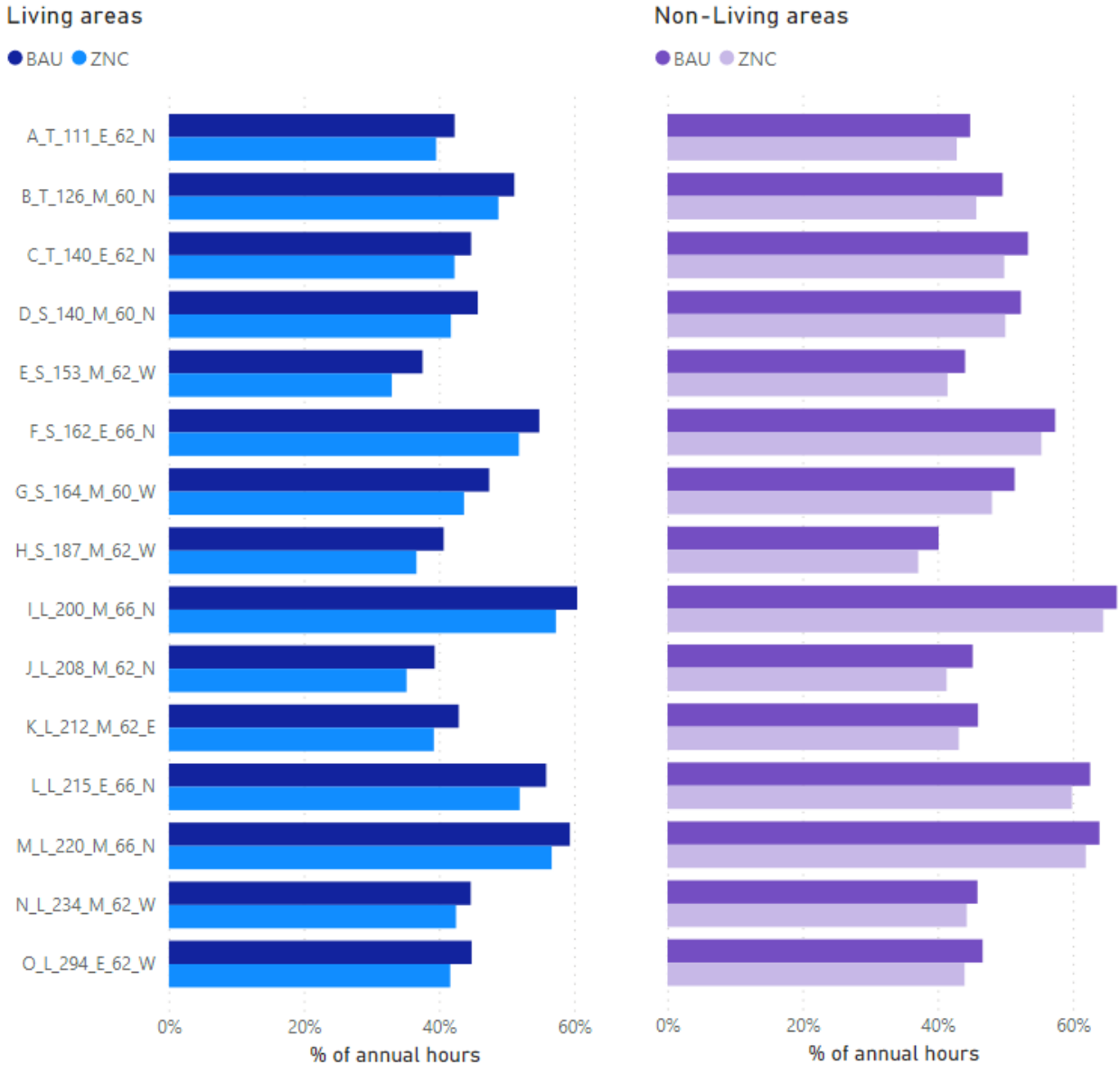
An important consideration for policy makers is how successfully homes can maintain a comfortable temperature range without mechanical heating and cooling. This is an emerging area of research that is important for climate change risk and vulnerability assessment and the concept of ‘thermal safety’. More work is required in this area.

Knowing more about this will not only help homes to be more resilient to a changing climate, but also demonstrate how more thermally efficient homes make a tangible difference to those in the community who cannot afford the cost of running heating and cooling to maintain comfortable temperatures within their homes<sup>2</sup>.

Without heating and cooling, and based on the current NatHERS climate files, the modelling showed that most homes would be spending upwards of a third of hours (sometimes over half) below 18 degrees Celsius, and under 5% of hours above 26 degrees.

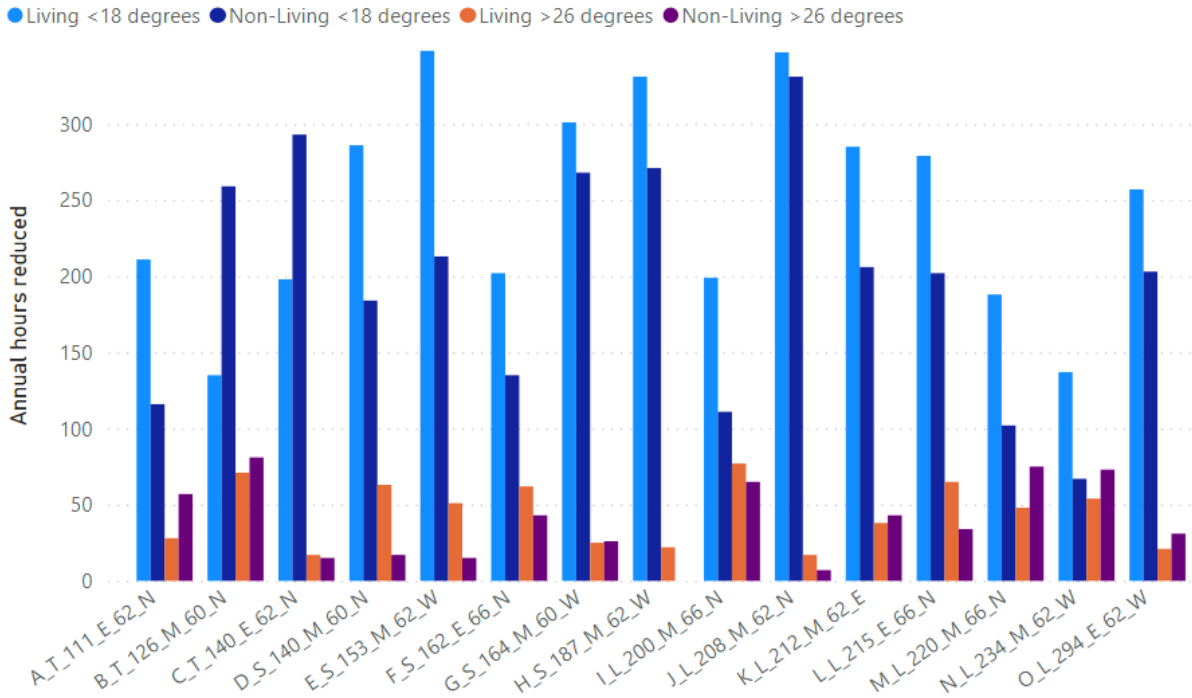
<sup>2</sup> The Department of Health and Human Services has recognised this by setting a 7 Star NatHERS rating in its Housing Design Guidelines (2018)

**Figure 27: Percentage of hours of living and non-living areas below 18 degrees and above 26 degrees without conditioning**



Thermal improvements to 7 star reduced the number of uncomfortable hours, however the homes still spend a significant proportion of the day outside a comfortable temperature range without mechanical heating and cooling. To better understand the impacts on residents, it would be useful to interrogate this further including looking at day / night hours and consecutive hours.

**Figure 28: Reduction of annual hours in uncomfortable temperatures (above 26 or below 18 degrees) without conditioning - ZNC improvement**



For one home (Home E), results for the hottest summer and coldest winter days and nights were examined. The severity of the coldest and hottest hours in the living and non-living areas was reduced by between 0.4 and 1.1 degree.

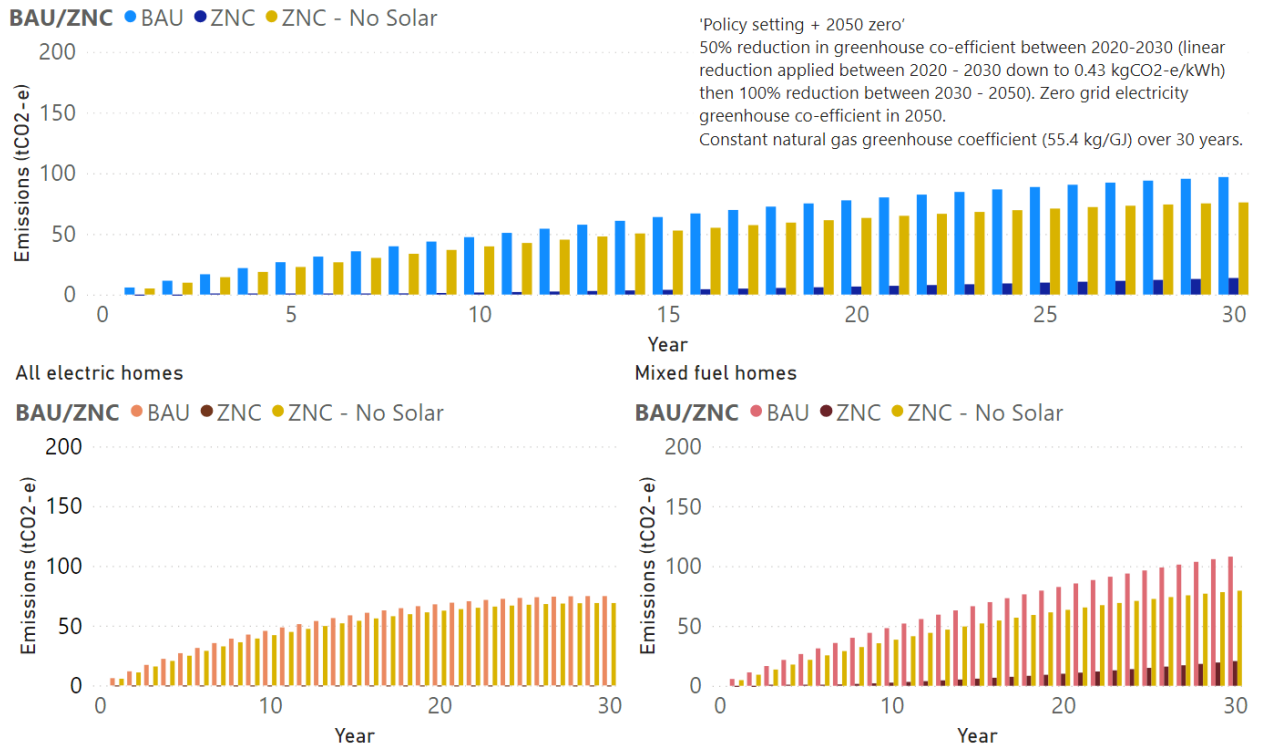
**How do mixed fuel (natural gas and electric homes) compare with all electric homes? What is the impact of a decarbonising grid on the delivery of ZNC homes?**

Using today’s emission factors, whether a home is all electric or mixed fuel had no material impact on the cost of appliance upgrades nor the Solar PV size required to achieve ZNC for the modelled homes.

Where the difference becomes apparent is in a decarbonising grid scenario. Here the emissions intensity of grid electricity is reduced; so the emissions offset by every kWh generated by an on-site Solar PV system is reduced. For an all-electric home this is immaterial, but for homes using natural gas there is an impact. A mixed fuel ZNC home built today with solar sized accordingly would lose its ZNC status as the grid decarbonises. Similarly, the same home built in several years’ time would require a larger Solar PV system to achieve ZNC.

Looking at cumulative greenhouse emissions for the BAU home, we see the impact of the decarbonising grid; cumulative emissions flatten as the grid decarbonises. We also see the ZNC mixed fuel homes showing some cumulative emissions in the decarbonised grid scenario.

**Figure 62: Cumulative Greenhouse Emissions ('Policy Setting + 2050 zero coefficient') for 6 star BAU compared to 7 star ZNC - all homes (blue), all electric only (orange) and mixed fuel only (pink)**



# Introduction

## Background

The Victorian Government has legislated a target of a Net Zero Carbon (ZNC) Emission economy by 2050 in the Climate Change Act (2017). An integral part of reaching that target is the transition to high efficiency low emission buildings as set out in the [climate change framework](#) and the [energy efficiency and productivity strategy](#).

With the lifespan of most homes being 40 years or more, the homes we build today will still be standing in 2050 and beyond; therefore how we build today will have an impact on our carbon emissions in 2050. Achieving a net zero carbon emission economy therefore requires market transformations today.

Sustainability Victoria (SV) has delivered the Zero Net Carbon Homes pilot program in collaboration with two volume home builders and a land developer to identify how the Victorian State could deliver homes that meet the requirements of an emission free future.

The objectives of the program were to:

- improve the supply of zero net carbon homes<sup>3</sup> by volume home builders
- increase consumer demand for zero net carbon homes
- pilot as-built verification methodologies, standards and skills development through a collaborative approach with industry.

The program delivered 39 ZNC homes. These homes were designed and modelled to produce enough renewable energy to off-set the annual greenhouse gas emissions of their estimated energy use.

Sustainability Victoria produced a net zero carbon design guide, which included information on energy efficient thermal building envelope, efficient fixed appliances and a solar energy system to help reduce running costs, increase comfort and curb carbon emissions.

This research project involved detailed modelling of 15 of the ZNC pilot program homes in order to better understand the program costs, benefits and outcomes, and to test a range of scenarios.

The research project had two key objectives:

1. to analyse the impact of building ZNC homes compared to current building standards
2. to inform decisions related to building design and construction towards ZNC homes e.g. relating to cost and benefit

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<sup>3</sup> zero net carbon is based on operational energy emissions and does not include embodied energy of building materials, waste or the use of water.

Sustainability Victoria engaged Best Environment to complete this work in collaboration with Filter ESD.

In order to compare current building practice to a ZNC home, a 6 star NatHERS model of each home was compared with a 7 star NatHERS model<sup>4</sup>. Fixed appliances were specified as market average for the business as usual scenario, and improved efficiency appliances for the ZNC home were as specified by the builder during the ZNC pilot.

Sustainability Victoria's Zero Net Carbon Homes modelling tool was used to calculate the Solar PV system size required to offset the carbon emissions generated by the home.

The following research questions were investigated:

1. What are the common building fabric changes to upgrade a home from 6 Star to 7 Star NatHERS and what do these cost?
2. What appliance efficiency upgrades were utilised in the ZNC Homes program, what did these cost and how did they contribute to achieving zero net carbon?
3. What Solar PV system sizes are needed to achieve zero net carbon for the homes? Is the roof area available for Solar PV a limiting factor in the realisation of ZNC homes?
4. What are the additional capital costs required to achieve a ZNC home, what are the energy costs savings and what is the payback period?
5. What are the relative costs and benefits of the different upgrade features – building fabric, appliance efficiency and Solar PV?
6. How do the results vary depending on fuel mix - all electric homes compared with mixed fuel homes?
7. What is the impact of a decarbonising grid on the delivery of ZNC homes?
8. What is the cumulative impact on energy, greenhouse and cost for ZNC homes to 2050?

This report outlines the process and results of modelling using SV's ZNC Homes tool and analysis by Best Environments on ZNC Homes for SV.

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<sup>4</sup> Actual homes in the ZNC Homes Pilot were required to meet a 6.5 Star NatHERS rating. This research tests a ZNC building fabric standard of 7 Stars NatHERS.

# Methodology

The data used in this report was created over a four-month period (June to September 2020) by multiple consultants engaged by Sustainability Victoria (SV).

This section outlines the modelling undertaken and the process of data collation and analysis used in this research project.

The 15 homes used to produce this data are Zero Net Carbon homes under Sustainability Victoria's Zero Net Carbon (ZNC) Homes pilot program. These homes were slightly modified for use in the project and have been anonymised for reporting.

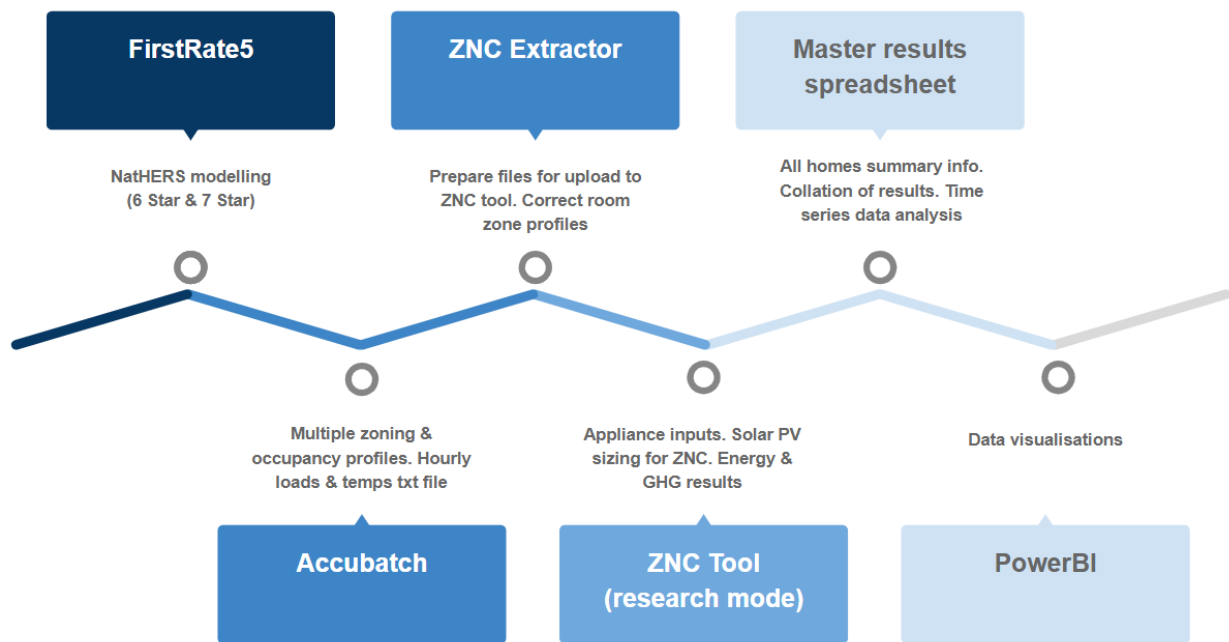
## Overview

The analysis required multiple steps:

1. NatHERS modelling of the 15 homes to provide a BAU 6 star NatHERS version and a 7 star NatHERS version of each home (this work was completed by Filter ESD)
2. Identifying the market standard appliances for the BAU homes and the fixed appliances installed in the ZNC homes
3. Modelling 15 homes (BAU and ZNC) using the research version of the ZNC tool (completed by Best Environments and SolarRate). The modelling process involved multiple consultants, a chain of tools, modification to existing tools and creation of new scripts, data processing files and QA tools.
  - a. FR5 files run through Accubatch to simulate different zoning and occupancy profiles
  - b. Use of the ZNC extractor tool to prepare Accubatch files for importation into the ZNC tool
  - c. ZNC tool (research mode) – for calculation of energy and greenhouse results and solar PV size needed to meet ZNC.
4. Modelling each home under a range of future scenarios for the greenhouse gas coefficient.
5. Collating results in a custom designed spreadsheet to enable efficient analysis and interrogation, including the consideration of potential future research questions.
6. Detailed aggregate results analysis using PowerBI, to assess the costs, benefits and outcomes of delivering ZNC homes compared with BAU homes.

The ZNC Homes tool facilitates the comparison of energy consumption, greenhouse gas emissions and energy bills required by volume home builders to transform standard homes to 'zero net carbon'.

Figure 1 Simple methodology flowchart



## NatHERS modelling (FirstRate5)

Filter ESD (Erika Bartak) undertook NatHERS modelling using FirstRate5 version 5.2.11 (FR5). This work was undertaken under a separate contract; Filter ESD's report is included here as Appendix A, and the NatHERS modelling process is described below.

Note that the ZNC program required a minimum 6.5 Star NatHERS rating and the NatHERS files were provided accordingly - the actual homes varied from 6.5 to 7.5 stars. As this project aimed to compare current building standard (6 Star) with the proposed NCC 2022<sup>5</sup> increase to 7 Star, the NatHERS files were modified to create two new files – a 6 Star 'business as usual rating' and a 7 Star rating.

The modelling process was:

- NatHERS files from 15 homes in the ZNC Homes Pilot Program were modified to generate pairs of files for each home - a 6 Star 'Business as Usual' (BAU) rating, and a 7 Star rating.
- The homes were modelled in their original site orientation, altered slightly to the closest compass point (e.g. north, north-east).
- All homes were modelled in Victorian climate zones (60, 62, or 66); 4 homes originally located in climate zones 22 and 64 were modelled in climate zone 66.
- Program builders' standard construction specifications were used for the 6 Star BAU rating.
- Practical, cost-effective and industry-typical specification upgrades were made to achieve the 7 Star ratings.

<sup>5</sup> [Energy efficiency: NCC 2022 and beyond - Scoping study, ABCB 2019](#)

- The original designs of the 15 homes were left largely unchanged; in just a few instances, modest design or construction changes were made to suit the needs of the study (e.g. amending atypical construction materials to more standard choices; altering window dimensions).
- Some homes achieved slightly above the benchmarks (maximum 6.2 or 7.2 stars respectively). Where possible, the insulation and glazing specifications of the actual homes were used for the research.
- To align with proposed changes, new NatHERS climate files and star bands were used to generate all ratings in this study. These were supplied by the NatHERS administrator.
- The energy rating scores and specification changes for the 6 and 7 Star file pairs were recorded in spreadsheets (along with any relevant design or construction changes).
- An orientation sensitivity analysis was also conducted, to compare the performance of the 6 and 7 Star file pairs as they were located in 8 different orientations (i.e. 45 degree compass points).
- The 15 NatHERS file pairs were provided to SV for further ZNC calculations and cost comparisons.

## Accubatch

Using the NatHERS (FR5) scratch files<sup>6</sup> as input, Accubatch (developed by CSIRO) was used to simulate each file across a range of zoning and occupancy profiles so that these profiles can be used in the ZNC tool as needed. These were:

- All Day, Zoned (1-Z)
- All Day, Unzoned (1-U)
- Work Day, Zoned (2-Z)
- Work Day, Unzoned (2-U)
- Free running (assumes no heating or cooling)

The output of the Accubatch simulation is a txt file for each profile (1-Z, 1-U etc) with hourly heating and cooling loads, and hourly temperatures for the free running simulation.

Thermostat settings and hours of heating and cooling for each profile are shown in Figure 2. Thermostat temperatures are set at:

- Cooling: 23°C for both living and non-living
- Heating: 20°C for living, 18°C for non-living

The unzoned profile applies any heating or cooling for each hour of the zoned profile to all spaces (living and non-living).

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<sup>6</sup> A scratch file is a temporary output created by the NatHERS software each time a simulation is run.

**Figure 2: Thermostat settings and hours of heating and cooling for each profile**

Occupancy 1-Z (All Day Zoned)		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 Spaces	Heating							20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
	Cooling							23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	
Spaces other than living	Heating							18	18	18										18	18	18	18	18	
	Cooling	23	23	23	23	23	23	23	23	23										23	23	23	23	23	23

Occupancy 1-U (All Day Unzoned)		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 Spaces	Heating							20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
	Cooling	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
Spaces other than living	Heating							18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	
	Cooling	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23

Occupancy 2-Z (Work Day Zoned)		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 Spaces	Heating							20	20										20	20	20	20	20	20	
	Cooling							23	23										23	23	23	23	23	23	
Spaces other than living	Heating							18	18										18	18	18	18	18	18	
	Cooling	23	23	23	23	23	23	23	23										23	23	23	23	23	23	23

Occupancy 2-U (Work Day Unzoned)		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 Spaces	Heating							20	20										20	20	20	20	20	20	
	Cooling	23	23	23	23	23	23	23	23										23	23	23	23	23	23	23
Spaces other than living	Heating							18	18										18	18	18	18	18	18	
	Cooling	23	23	23	23	23	23	23	23										23	23	23	23	23	23	23

## ZNC extractor

The Accubatch output txt files were imported into the ZNC extractor tool and from here into the ZNC tool. The ZNC extractor aggregates and compiles the Accubatch files for importing into the ZNC tool.

The outcome of this step is two ZNC extractor files (xls) for each home - a 6 Star (BAU) file and a 7 Star file.

## ZNC tool

The online version of the ZNC tool links directly to a NatHERS file and can be used in an iterative process to calculate the Solar PV size required to achieve zero net carbon. The tool calculates the net emissions and indicates when a ZNC status has been achieved. The online version uses Rating mode and is based on a set of standard assumptions. The excel based version of the ZNC tool in Research mode was used in this research project as it allows these assumptions to be modified.

To provide the breadth of results sought, the research version of the ZNC tool was modified to complete the modelling in this project.

### Assumptions

For this research, the background assumptions held constant are:

PARAMETER	ASSUMPTION
ENERGY TARIFFS	Refer
ZONING	Unzoned
OCCUPANCY	Home All Day
LIGHTING ENERGY DENSITY	5 W/sqm
PLUG IN APPLIANCES	Market average
POOL OR SPA	None
ELECTRIC VEHICLES	None

Inputs specific to each model include:

- home area and layout
- 6 star and 7 star NatHERS related data including climate zone
- heating and cooling zoning for living and non-living spaces
- household size - number of residents
- heating and cooling system type/s and efficiencies
- domestic hot water system type and efficiency
- stovetop and oven types
- solar PV system size.

Extractor files for both 6 star and 7 star were imported and other inputs added manually and through macros. The output is a single ZNC tool file for each home.

Heating, cooling, hot water and cooking systems were specified according to advice from each builder, for both base case systems (BAU) and the actual specification for the ZNC models.

The ZNC tool was modified for this project in the following ways:

- Calculations added to provide Solar PV sizing to achieve:
  - Zero Net Carbon (ZNC)
  - ZNC for proposed regulated services only (under NCC2022)
  - Zero net energy (ZNE)
  - ZNE for proposed regulated services only (under NCC2022).
- Defined names added (over 400) to facilitate macros allowing collation of results into master results spreadsheet.

### *Zoning and Occupancy*

Initial modelling runs of four of the homes included an analysis of the four zoning / occupancy combinations shown in Figure 2 (1-Z, 1-U, 2-Z, 2-U). The results showed less than 2% variation in total energy use, total greenhouse emissions and total energy costs between all four models for any home.

Given the small impact of these parameters to the results, the most conservative scenario of 'home all day' occupancy profile and unzoned heating/cooling was used for this research.

### **Greenhouse Co-efficients**

The greenhouse gas (GHG) co-efficients used in this research, as provided by SV were:

GHG CO-EFFICIENT	TYPE and SOURCE
<b>0.9 kgCO<sub>2</sub>-E/kWh</b>	Current emissions scenario based on Australian Building Codes Board NCC2022 modelling
<b>0.58 kgCO<sub>2</sub>-E/kWh</b>	Medium emissions scenario based on Electricity – Victorian Energy Upgrades Target Setting Regulatory Impact Statement 2019 <sup>7</sup>
<b>0.08 kgCO<sub>2</sub>-E/kWh</b>	Low emissions scenario
<b>55.4 kg/GJ</b>	Natural Gas (Scope 1 + 3)

### **Energy Tariffs**

The following energy tariffs supplied by SV have been used in this research:

FUEL	ENERGY TARIFF	NOTE
Peak Electricity	\$0.3707 /KWH	7 - 9am and 4 - 8pm
Shoulder Electricity	\$0.2383 /KWH	9am - 4pm and 8 - 10pm
Off-Peak Electricity	\$0.1854 /KWH	10pm - 7am
Daily Electricity Supply	\$0.9 /DAY	
Peak Natural Gas Block 1	\$0.0198 /MJ	June – September <6000 MJ / 2months

<sup>7</sup> Victorian Energy Upgrades Regulatory Impact Statement – supporting modelling by Jacobs.

Peak Natural Gas Block 2	\$0.0196 /MJ	June – September 6000 - 12000 MJ / 2months
Peak Natural Gas Block 3	\$0.0163 /MJ	June – September >12000 MJ / 2months
Off-Peak Natural Gas Block 1	\$0.0182 /MJ	October – May <6000 MJ / 2months
Off-Peak Natural Gas Block 2	\$0.0151 /MJ	October – May 6000 – 12000 MJ / 2months
Off-Peak Natural Gas Block 3	\$0.0141 /MJ	October – May >12000 MJ / 2months
Daily Natural Gas Supply	\$0.8 /DAY	

## Data fields

The modified ZNC tool modelling provided the following data for the BAU and ZNC model of each home:

- hourly energy consumption by use
- hourly greenhouse gas emissions from energy consumption
- hourly energy costs
- solar PV size required to achieve ZNC or zero net energy
- hourly solar PV on-site consumption and export to grid
- filtering of hourly heating loads, cooling loads and internal temperature of living and non-living areas from Accubatch

## Data collation

The previous modelling step produced 76 large ZNC tool files (over 150MB). Due to the size of these files, Microsoft Excel was used for focussed data collation before the data was imported into PowerBI for analysis and visualisations.

This step compiled results in a single Excel file (the master results spreadsheet) that is digestible and familiar to many. This provides maximum flexibility for any ongoing data analysis needed by SV.

The master results spreadsheet is designed to import results from a defined set of source data (in this case the ZNC tool files for each of the 15 homes). Where there is any change in the source data files, the master results file can be easily updated.

Modifications to the ZNC tool also improved the flexibility and usefulness of the ZNC tool in future research projects. Approximately 400 defined names were added; this allows the importation of data from multiple files into the results spreadsheet, and for revisions to those files.

Excel visualisations of key data early in the project provided useful direction (refer to occupancy and zoning decisions discussed in ZNC modelling section) and allowed for the ZNC tool files, parameters and input values to be adapted to suit the objectives of SV.

For portability, an embedded (static) version of the master results spreadsheet was provided - with no links to source data. This allows sharing of a relatively small file of key results across devices / organisations as needed.

In summary, this approach allowed for flexibility and ease of coordination between Best Environments / Solar Rate and SV. The nature of the project required an agile approach, choice of tools where existing knowledge was strong, and flexibility for ongoing data analysis by SV.

## Data analysis and visualisation

Microsoft PowerBI was chosen due to the relationship to Excel (the ZNC tool) and availability within SV and other government departments and agencies.

Due to the intended mobility of the data across organisations, departments and teams, a single source file was used - the embedded version of the master results spreadsheet.

The visualisations shown in this report are from the PowerBI file.

As the 15 homes included in the research are real homes, the data has been anonymised for use in this report. To provide useful project markers for easy recall and some context, de-identification included the following:

- simple site identifier from A to O for ease of discussion (e.g. Home A, Home B)
- typology: T = Townhouse, S = Small detached <200sqm, L = Large detached >200sqm
- home area in square meters (sqm)
- fuel mix of the ZNC model: A=all electric, M= Mixed fuel (gas and electric)
- NatHERS Climate zone
- solar PV orientation of the as-built ZNC model (to the closest cardinal point): N=North, E=East, W=West.

**Example:** A\_T\_111\_E\_62\_N is Home A, a townhouse (T), Home area = 111 sqm, all electric improved case (E), in climate zone 62, and north (N) facing solar PV to meet ZNC.

## Capital Improvement Cost Assumptions

The improvement costs are based on the following methodology/assumptions provided by Sustainability Victoria:

1. Insulation and glazing cost upgrades were applied at \$/sqm rates, which were based on the cost of upgrading to a better insulation collected through builder information and internet search of the products used.
2. A more conservative installation cost is included where the item would not normally be installed e.g. anti-con blankets.
3. For insulation costs, in cases where builder costs were higher than retail, retail is used but rounded up due to the additional handling required for thicker insulation.
4. Where glazing upgrade costs were provided by the builder, this was used in lieu of assumed \$/sqm rates (e.g. Home B – increased the cost, Home G – reduced the cost).

5. Heating upgrades for gas were approximately \$500 for a better performing (more efficient) system.
6. Where the BAU is more expensive than the ZNC solution, \$0 is used. Some builders found better performing (more efficient) appliances for less cost than others.
7. Solar PV systems were costed at a conservative \$1.2/W installed.

Given this approach, the financial results overall are considered conservative. Real costs are likely to be lower.

## The homes

Fifteen homes were chosen by Sustainability Victoria for this research. These homes represent a mix of typology, floor area, climate zone, primary living area orientation, solar PV orientation, fuel mix (all electric or mixed fuel) and appliances. Solar PV orientation refers to the primary solar PV panels, to the nearest cardinal point.

Home area excludes garages.

More information on each home is detailed in Appendix C, including building fabric improvements to upgrade from 6 Star to 7 Star, and appliances for the BAU and ZNC scenarios.

**Figure 3: The homes**

HOME	TYPOLOGY	HOME AREA	CLIMATE ZONE	SOLAR PV ORIENTATION	FUEL MIX	REFERENCE
A	Townhouse	111	62	N	All Electric	A_T_111_E_62_N
B	Townhouse	126	60	N	Mixed Fuel	B_T_126_M_60_N
C	Townhouse	140	62	N	All Electric	C_T_140_E_62_N
D	Small detached	140	60	N	Mixed Fuel	D_S_140_M_60_N
E	Small detached	153	62	W	Mixed Fuel	E_S_153_M_62_W
F	Small detached	162	66	N	All Electric	F_S_162_E_66_N
G	Small detached	164	60	W	Mixed Fuel	G_S_164_M_60_W
H	Small detached	187	62	W	Mixed Fuel	H_S_187_M_62_W
I	Large detached	200	66	N	Mixed Fuel	I_L_200_M_66_N
J	Large detached	208	62	N	Mixed Fuel	J_L_208_M_62_N
K	Large detached	212	62	E	Mixed Fuel	K_L_212_M_62_E
L	Large detached	215	66	N	All Electric	L_L_215_E_66_N
M	Large detached	220	66	N	Mixed Fuel	M_L_220_M_66_N
N	Large detached	234	62	W	Mixed Fuel	N_L_234_M_62_W
O	Large detached	294	62	W	All Electric	O_L_294_E_62_W

# Results

## 1. NatHERS star rating by orientation

This section includes analysis of the star rating differentiation for potential orientations of the homes modelled.

An orientation sensitivity analysis was conducted by Filter ESD in order to compare the performance of the 6 star and 7 Star homes in eight different orientations (45 degree compass points).

The best and worst orientations related to NatHERS star ratings for each home plus the rating for the as-built orientation are shown in Figure 4 (BAU) and Figure 5 (ZNC). Refer to Appendix B for results of all orientations modelled.

Per the summary report by Filter ESD (included at Appendix A) and as shown in Figure 4 and Figure 5:

- The average variation between the best and worst orientation was 0.5 Stars across all homes.
  - Some homes demonstrated a significant difference in energy performance between their best and worst orientation, while others changed very little.
  - The greatest variation was 1.2 Stars (Home A), while the smallest variation was 0.2 Stars (Home G).
  - The largest variations tended to occur in the smaller footprint homes, but the results were mixed across the 15 homes.
- Approximately one third of the 15 homes studied (5 of the 6 Star homes, and 4 of the 7 Star homes) were constructed with the best / optimal orientation.
- No homes were constructed with the worst orientation.
- Many of the home designs did not achieve the relevant 6 or 7 Star benchmark when tested in other orientations:
  - Only 6 out of the 15 homes met (or exceeded) the relevant 6 or 7 Star benchmark for the majority of their orientations.
  - 9 out of the 15 homes performed below the relevant 6 or 7 Star benchmark for half (or more) of their orientations.
  - For 2 homes (Home A and Home F) the true site was the optimal orientation, and all other orientations failed to meet the relevant 6 or 7 Star benchmark.

When reoriented south or south-east, only three of the 15 homes met the 6 and 7 star benchmarks. When reoriented south-west this increased to four of 15.

The results reconfirm the design principle that each home should be designed specific to each site to ensure that the targeted performance is achieved.

Figure 4: NatHERS star ratings for BAU homes for orientations modelled

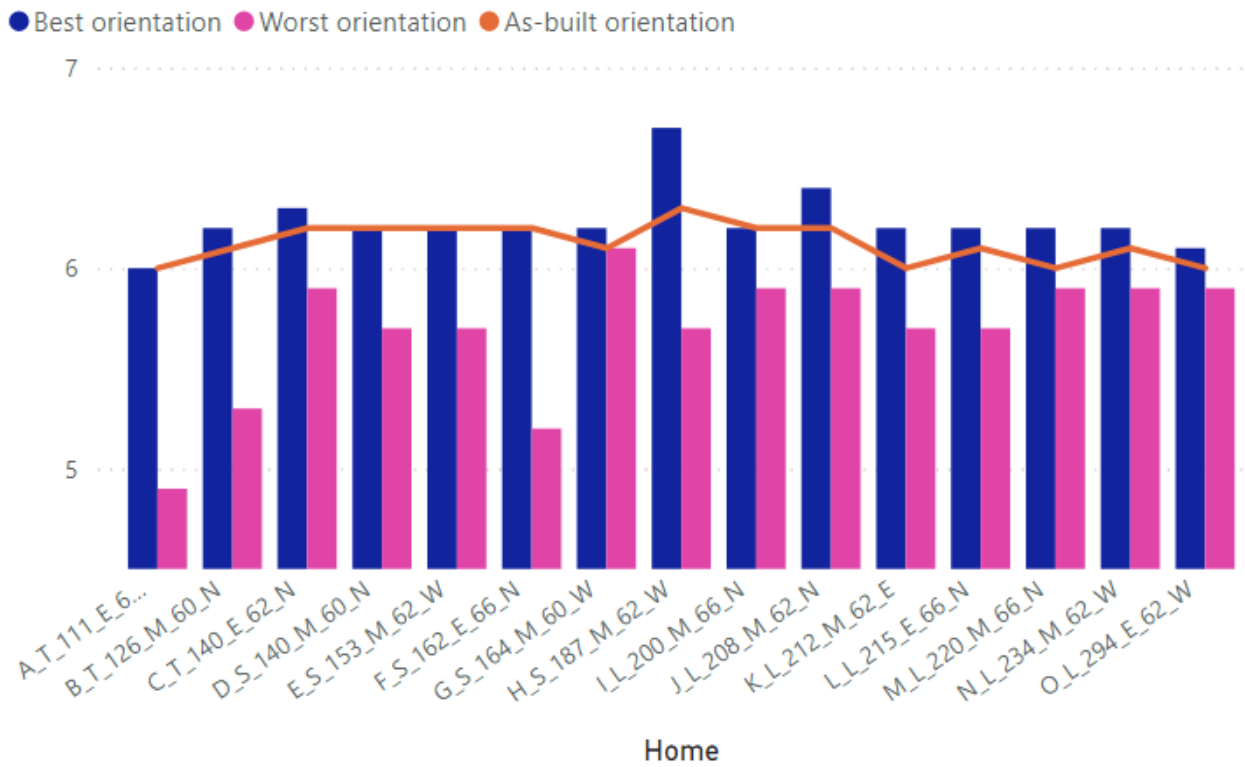
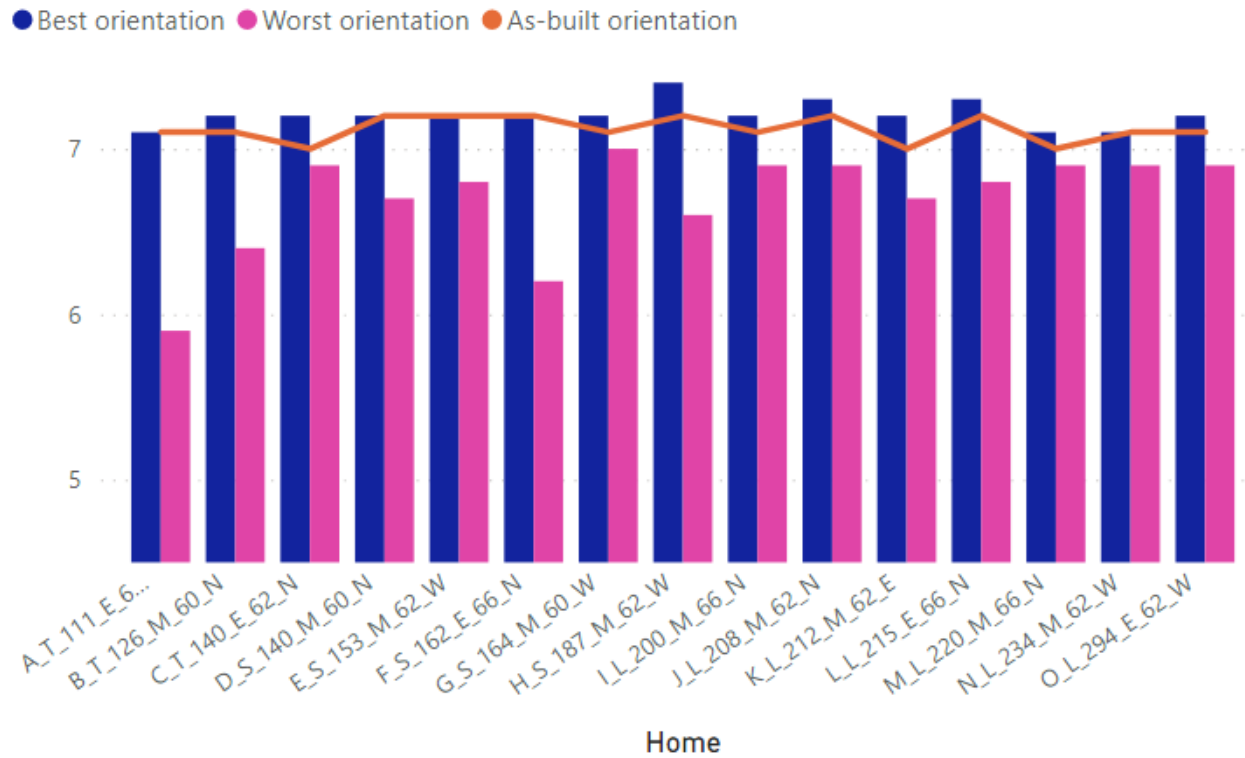


Figure 5: NatHERS star ratings for ZNC homes for orientations modelled



## 2. Building fabric upgrades – 6 Stars to 7 Stars

Per the summary report by Filter ESD (included at Appendix A), specification changes to increase the NatHERS ratings from 6 to 7 Stars were concentrated in the following areas, reflecting typical industry practice:

- external wall insulation (increased R value)
- internal wall insulation (increased R value, and location)
- roof and ceiling insulation (increased R value, and varied product type)
- windows and glazed doors (typically glass type, e.g. single to double glazing).

One-off changes to external shading, or window frame type, were also noted.

The NatHERS modelling showed that (Filter ESD, refer Appendix A):

- Insulation specifications to achieve 6 or 7 Stars varied depending on the design, orientation and climate zone of each home.
- Many homes achieved 6 Stars with single glazing in standard aluminium frames to most, if not all, windows and glazed doors: 12 out of 15 homes required no double glazing to achieve 6 Stars.
- All homes needed some double glazing to achieve 7 Stars; in some cases this was to all windows and glazed doors, in other cases this was limited to glazing in primary living areas.
- The orientation of the home, and the passive solar opportunity of each home design, influenced the specifications required to achieve the 6 and 7 Star ratings.

Figure 6: Improvements to meet 7 stars

Site Reference	Insulation - roof	Insulation - external wall	Insulation - internal garage wall	Insulation - internal bathroom/ laundry wall	Roof sarking	Glazing - kitchen/living	Glazing - other rooms	Shading to glazing
A_T_111_E_62_N	-	-	1	2.5	-	argon-filled double	argon-filled double	-
B_T_126_M_60_N	1.3	0.5	0.5	-	-	argon, low-e	argon-filled low-e double	Retractable horizontal awning (1.5m) to main Living wall / glazing (north)
C_T_140_E_62_N	-	0.5	0.5	0.5	foil	low-e	argon-filled double	-
D_S_140_M_60_N	1.5	1	-	1.5	foil	air-filled double	-	-
E_S_153_M_62_W	1.5	1	-	1.5	foil	air-filled double	-	-
F_S_162_E_66_N	1.5	0.5	0.5	-	-	air-filled double	-	-
G_S_164_M_60_W	1	0.5	-	2	foil	-	argon-filled double	-
H_S_187_M_62_W	1.5	1	0.5	2	foil	air-filled double	-	-
I_L_200_M_22_N	1.5	1	0.5	2	foil	air-filled double	-	-
J_L_208_M_62_N	1.5	0.5	0.5	2	-	argon-filled double	-	-
K_L_212_M_62_E	-	-	-	-	foil	argon-filled double	argon-filled double	-
L_L_215_E_22_N	1.5	1	0.5	-	-	argon-filled double	-	-
M_L_220_M_22_N	1.3	0.5	0.5	0.5	-	argon-filled double	argon-filled double	-
N_L_234_M_62_W	1.3	-	-	-	-	argon, low-e double	argon-filled double	-
O_L_294_E_62_W	-	-	-	-	-	argon, low-e double	argon-filled double	-

## Insulation

Twelve homes improved external wall and/or roof insulation. All roof insulation was an added R1 to R1.5, while for walls the added insulation was between R0.5 and R1.0.

Homes K and O did not require additional insulation to reach a 7 star rating. Home A added only internal wall insulation.

Additional internal wall insulation to garages and/or laundries/bathrooms was included to nine homes; almost exclusively an added R0.5 was added to internal garage walls, while for internal walls to bathrooms and laundries the range was R0.5 - R2.5 with an additional R2.0 most common.

Four homes (H, I, J and M) required additional insulation to external walls, roof, internal bathroom/laundry and garage walls.

Only Home B required additional shading to achieve 7 stars. This was to exposed north facing glazing to living areas.

**Figure 7. Additional insulation to meet 7 stars**

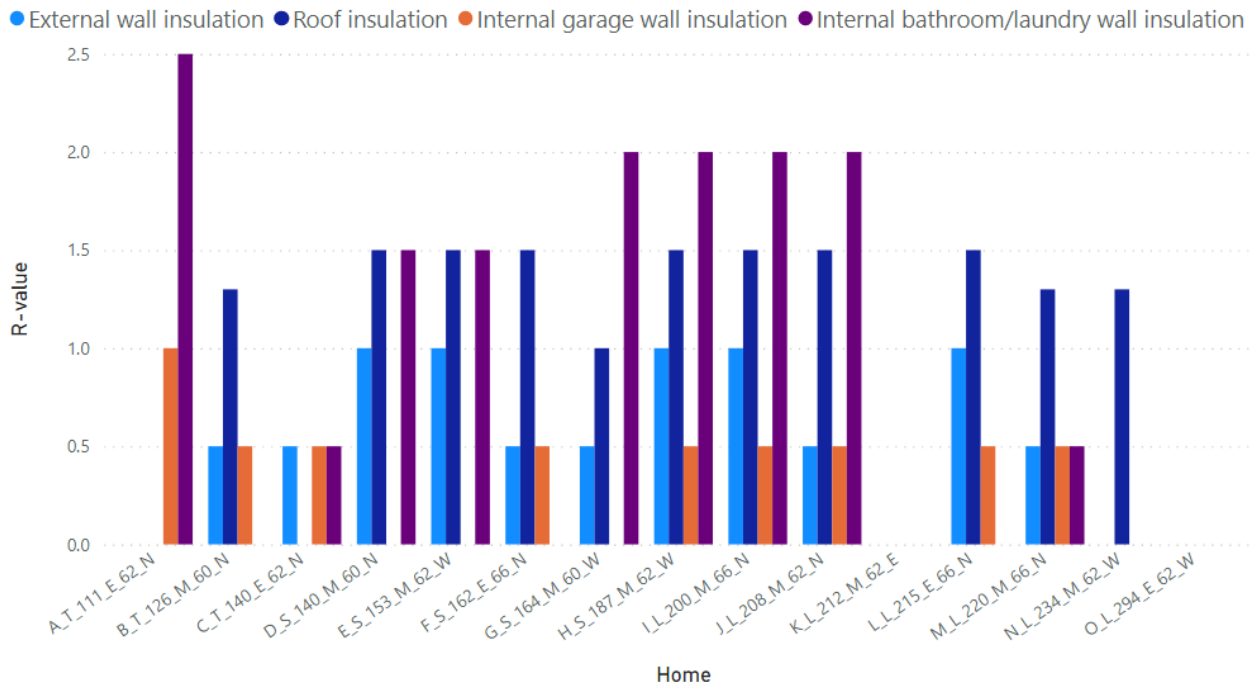
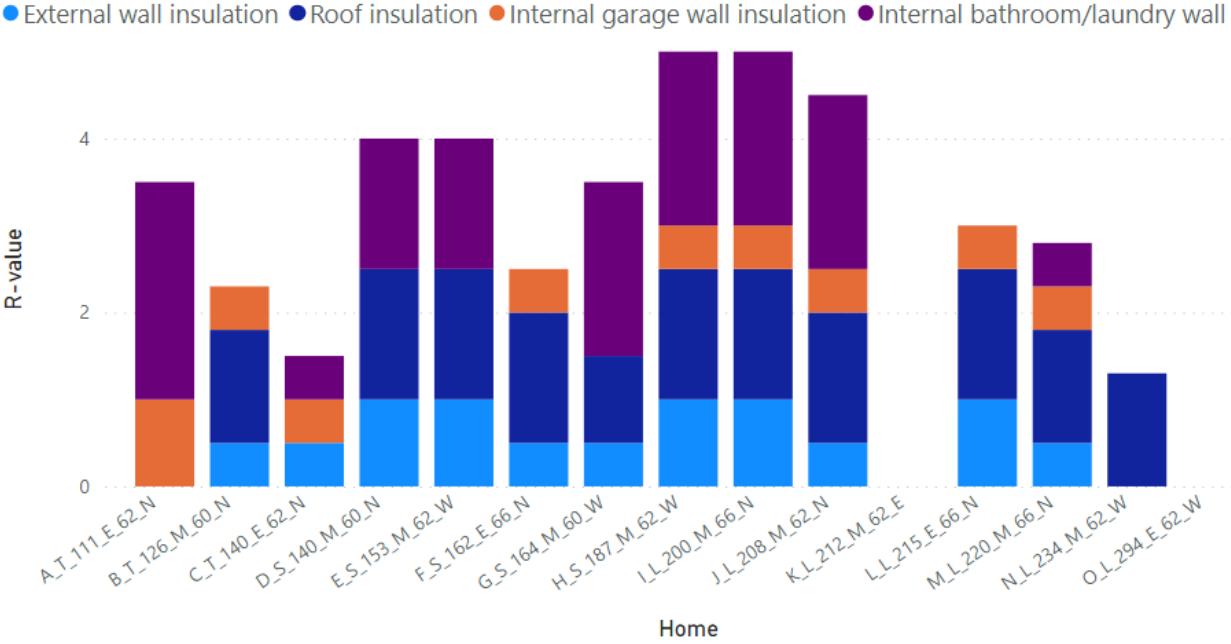


Figure 8. Additional insulation to meet 7 stars (stacked)



### 3. Solar PV and home size

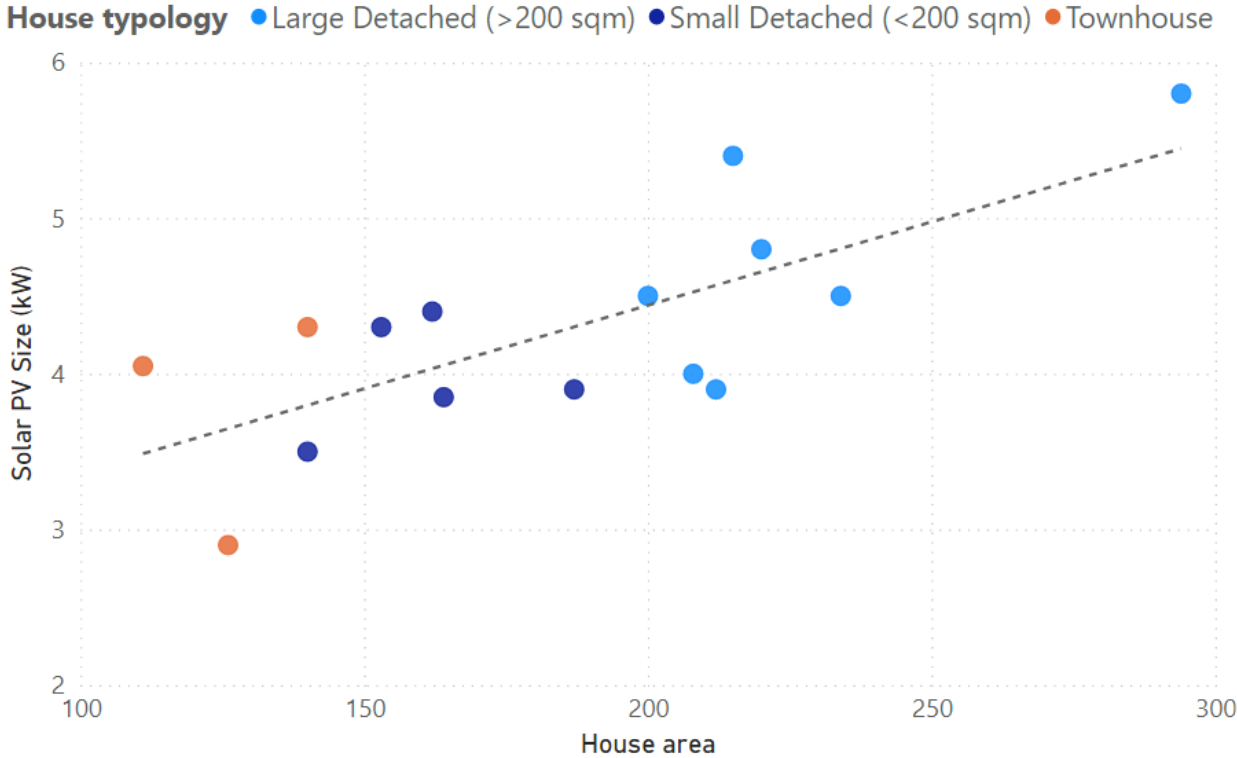
Solar PV size was plotted against home area and home typology. A moderate positive correlation was shown between home area and the Solar PV system size needed to achieve ZNC.

Very generally, the larger a home, the greater the emissions and the larger the Solar PV system needed to meet ZNC, but not always. Fixed appliance choices also play an important role. For example, the largest four homes required the largest Solar PV systems, however, Home K, a large detached dwelling (212 sqm) requires a similar size Solar PV system to meet ZNC as House A, which is almost half the size (111 sqm).

The correlation coefficient is 0.56, meaning that around 56% of the variation in Solar PV to achieve ZNC can be explained by the home size.

The homes plotted in the graph below are all 7 Stars – the impact of building fabric improvements are not included in this analysis.

Figure 9: Solar PV size to meet ZNC by home size



All but four of the homes required a Solar PV size between 3.5kW and 4.5kW. While this represents approximately 25% difference in capacity, the difference in price would be much lower as the panels are only a portion of the installed cost. This played out in the ZNC Homes Pilot where the builders almost universally installed 5kW systems – the assumption is that bulk pricing outweighed any savings of installing smaller systems.

The solar PV size required to meet ZNC is calculated directly from the emissions of each home, so to understand this in more detail requires an understanding of the correlation between each emission source and home area.

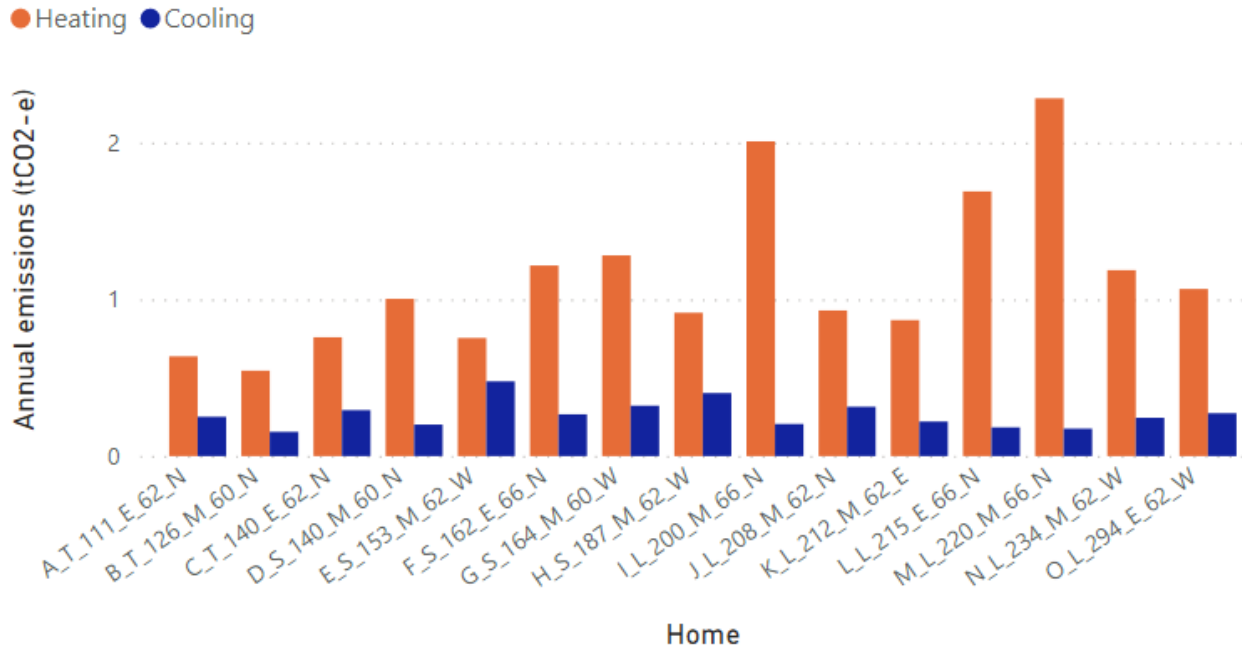
Of the emission sources, lighting is most strongly correlated to home area. This makes sense as building legislation dictates lighting energy consumption by area (W/sqm). Lighting is also from a single fuel source (electricity), and lighting emissions are not impacted by other factors such as building fabric (which does impact heating and cooling emissions).

In comparison, domestic hot water (DHW) emissions are more strongly correlated to system type than home area. Home area does impact occupancy, which in turn impacts how much hot water is used, but this is less a factor than the type and efficiency of the hot water system, which vary widely.

Heating and cooling emissions are correlated to home area, although also to other factors including fuel source, system type and building fabric. As shown in Figure 10, Home O (294sqm), which has 'room heat pumps' (non-centralised, single reverse cycle systems throughout the home), has lower heating emissions compared with other large detached homes using central heating systems.

Figure 10: Annual greenhouse emissions from heating and cooling for ZNC home

Total Annual Emissions



Home size is therefore one, but not the only factor that influences the solar PV size needed to meet ZNC. With efficient choices for lighting and fixed appliances, large homes can produce less emissions than smaller homes that choose less efficient options. Also, the ZNC Homes Pilot showed that in practice it is more straightforward (and likely more cost effective) for volume builders to oversize the Solar PV in order to use standardised construction methods.

## 4. Capital improvement costs

The costs to achieve ZNC status were modelled as additional costs above BAU.

These were separated into building envelope changes to meet a minimum 7 star NatHERS rating, external shading (discussed separately), heating systems, cooling systems, water heating systems and solar PV systems.

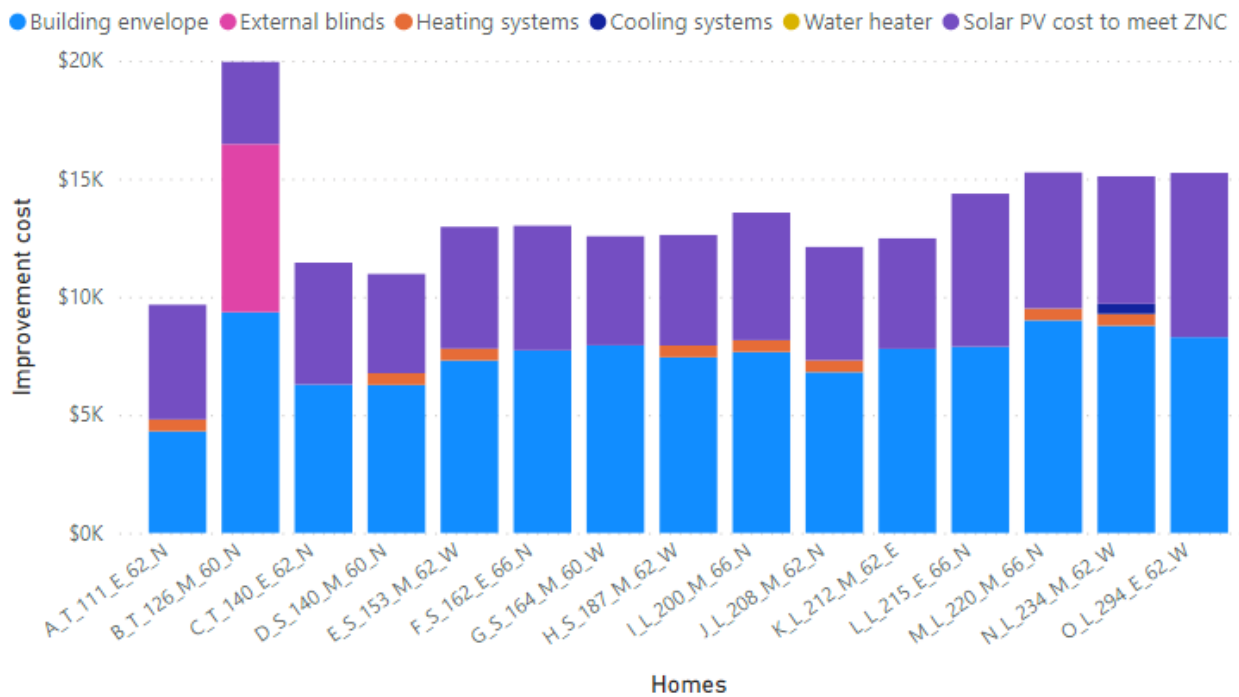
All costs are based on construction in 2020, with STCs claimed for Solar PV Systems.

*Figure 11: Improvement costs by item*

Site Reference	Building envelope	Cooling systems	External blinds	Heating systems	Water heater	Solar PV	Total
A_T_111_E_62_N	\$4,306	-	-	\$500	-	\$4,860	\$9,666
B_T_126_M_60_N	\$9,349	-	\$7,122	-	-	\$3,480	\$19,951
C_T_140_E_62_N	\$6,286	-	-	-	-	\$5,160	\$11,446
D_S_140_M_60_N	\$6,268	-	-	\$500	-	\$4,200	\$10,968
E_S_153_M_62_W	\$7,306	-	-	\$500	-	\$5,160	\$12,966
F_S_162_E_66_N	\$7,732	-	-	-	-	\$5,280	\$13,012
G_S_164_M_60_W	\$7,945	-	-	-	-	\$4,620	\$12,565
H_S_187_M_62_W	\$7,439	-	-	\$500	-	\$4,680	\$12,619
I_L_200_M_22_N	\$7,665	-	-	\$500	-	\$5,400	\$13,565
J_L_208_M_62_N	\$6,812	-	-	\$500	-	\$4,800	\$12,112
K_L_212_M_62_E	\$7,798	-	-	-	-	\$4,680	\$12,478
L_L_215_E_22_N	\$7,888	-	-	-	-	\$6,480	\$14,368
M_L_220_M_22_N	\$9,007	-	-	\$500	-	\$5,760	\$15,267
N_L_234_M_62_W	\$8,776	\$430	-	\$500	-	\$5,400	\$15,106
O_L_294_E_62_W	\$8,290	-	-	-	-	\$6,960	\$15,250

The average improvement cost was \$13,423 and ranged from \$9,666 to \$19,951.

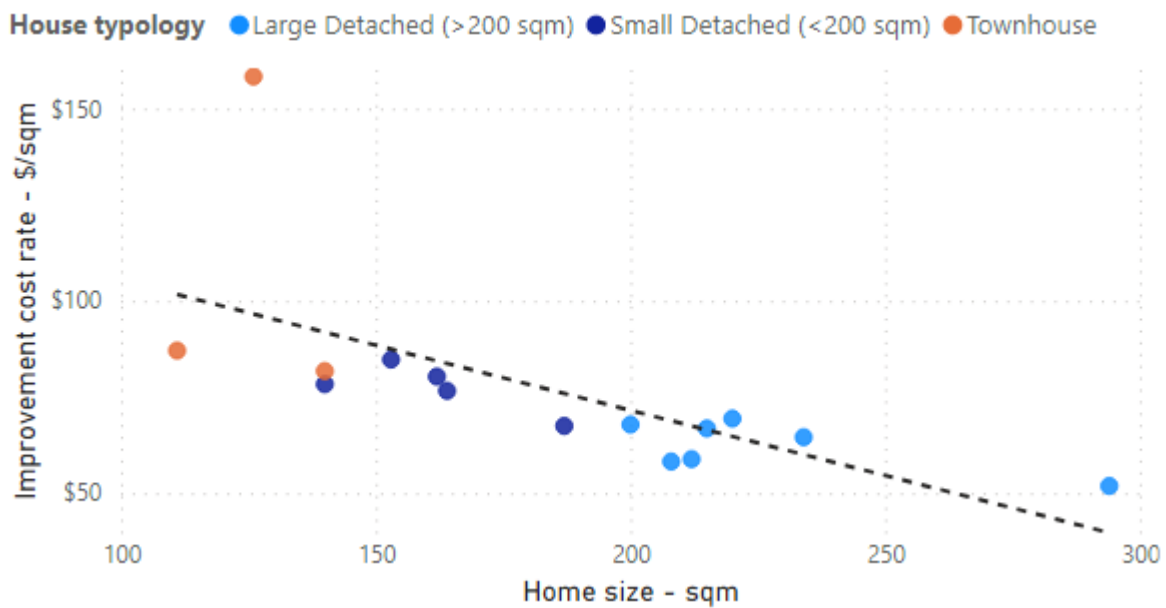
**Figure 12: Improvement costs per home to achieve ZNC**



Excluding Home B which is an outlier, the total improvement cost increases with home area. However, there is a clear negative correlation (excluding Home B) between cost per sqm and home area.

Improvement costs per sqm ranged between \$50/sqm and \$100/sqm, except Home B (\$158/sqm).

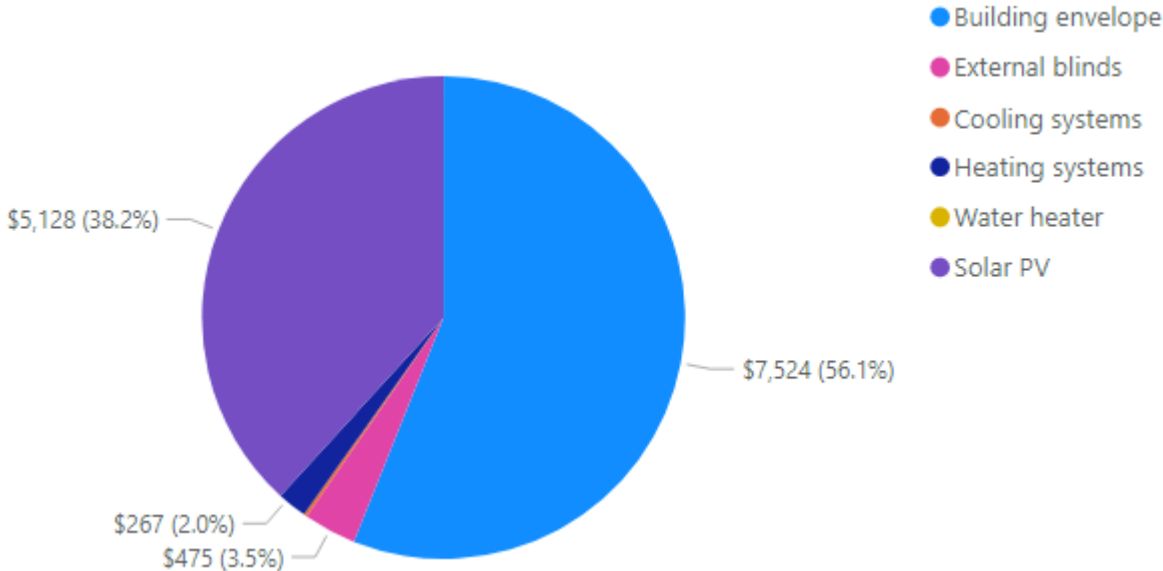
**Figure 13: Improvement cost to reach ZNC per sqm of floor area**



Building envelope improvements represent the highest proportion of improvement costs for all homes modelled except Home A. On average building envelope improvements account for over 56% of total improvement costs.

Solar PV was the second highest improvement cost for all homes except Home A (highest) and B (third). On average Solar PV accounts for over 38% of improvement costs.

Figure 14: Average improvement cost to reach ZNC by improvement type



The average improvement cost of the combined heating systems, cooling systems, and water heating systems is \$295 or 2.2% of the improvement costs.

Building envelope and solar PV improvements accounted for over 90% of improvement costs for all homes other than Home B.

Home B is an outlier from an improvement cost perspective due to the inclusion of a large automated shading device over north glazing to the living areas. This \$7000 item accounts for over 35% of the improvement cost of the home, making it the home with the highest improvement cost, even though it is the second smallest home.

The higher improvement cost for Home B was also impacted by the project timing. Construction had already commenced when the design was altered to achieve ZNC which limited the options for improvements. This was reflected in the costs for building fabric which were double the cost due to not considering these measures from an early stage. This was likely intensified by the home being a part of a mass-produced product, where altering a single design is less cost efficient.

The impact of these higher cost items can be seen in the analysis in sections 5, 5 and 16.

According to the NatHERS modelling, a much smaller, non-automated shading device could have been specified to achieve the 7 star rating, however it was included by the builder and so was included in the research project.

## 5. Capital improvement cost and standard build cost

This section discusses the cost of upgrade per home as compared to a standard build. The improvement costs included were per those discussed in section 2. Standard build costs were calculated from published Australian Bureau of Statistics (ABS, <https://www.abs.gov.au/>) data on building activity and average floor areas of new homes.

From the Building Activity, Australia report, June 2020 and December 2019, the following rates for standard building costs in Victoria were determined:

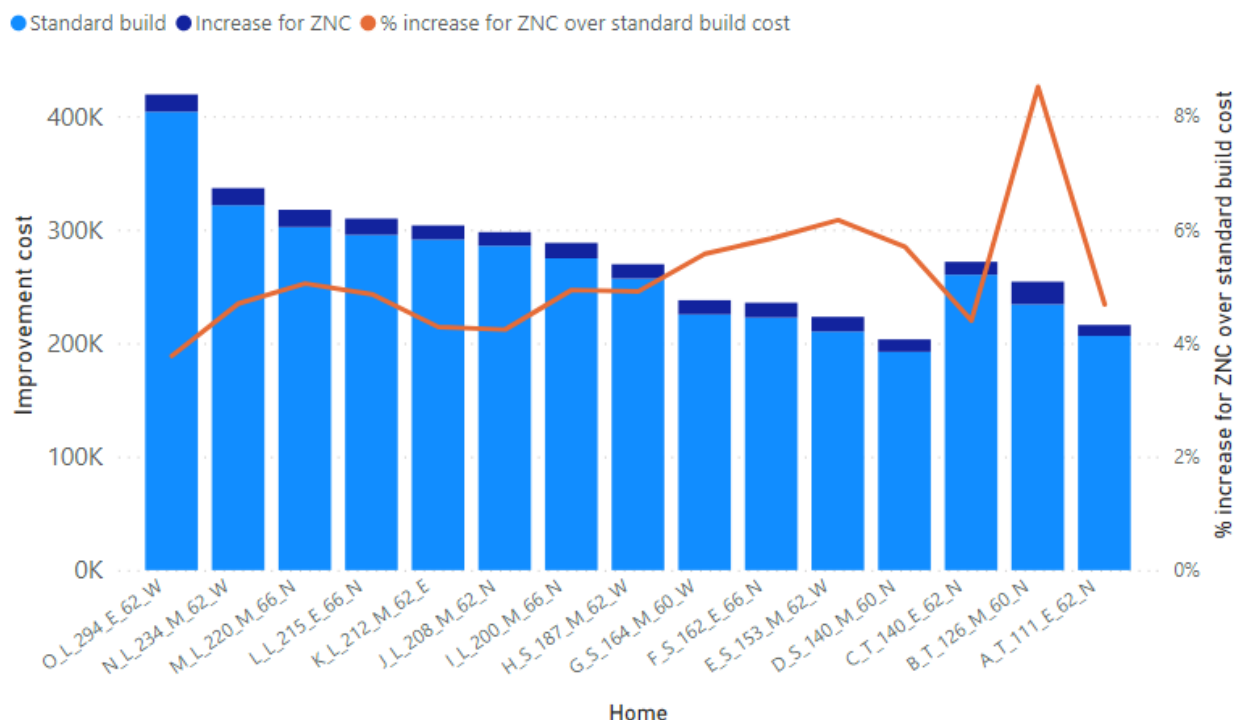
- townhouses - \$1859 per sqm
- detached dwellings - \$1374 per sqm.

These rates were used to determine a standard construction cost for each modelled home. The standard build cost ranged from \$206,000 to \$260,000 for townhouses and from \$192,000 to \$404,000 for the detached homes.

As shown in Figure 15, the percentage increase on a standard build is in the range of 4% to 7%, excluding Home B which is an outlier. Home B had the highest calculated percentage at 8.5%.

All homes are well under the often quoted 10% or more premium for low carbon homes.

**Figure 15: Standard build cost and improvement cost to meet ZNC**



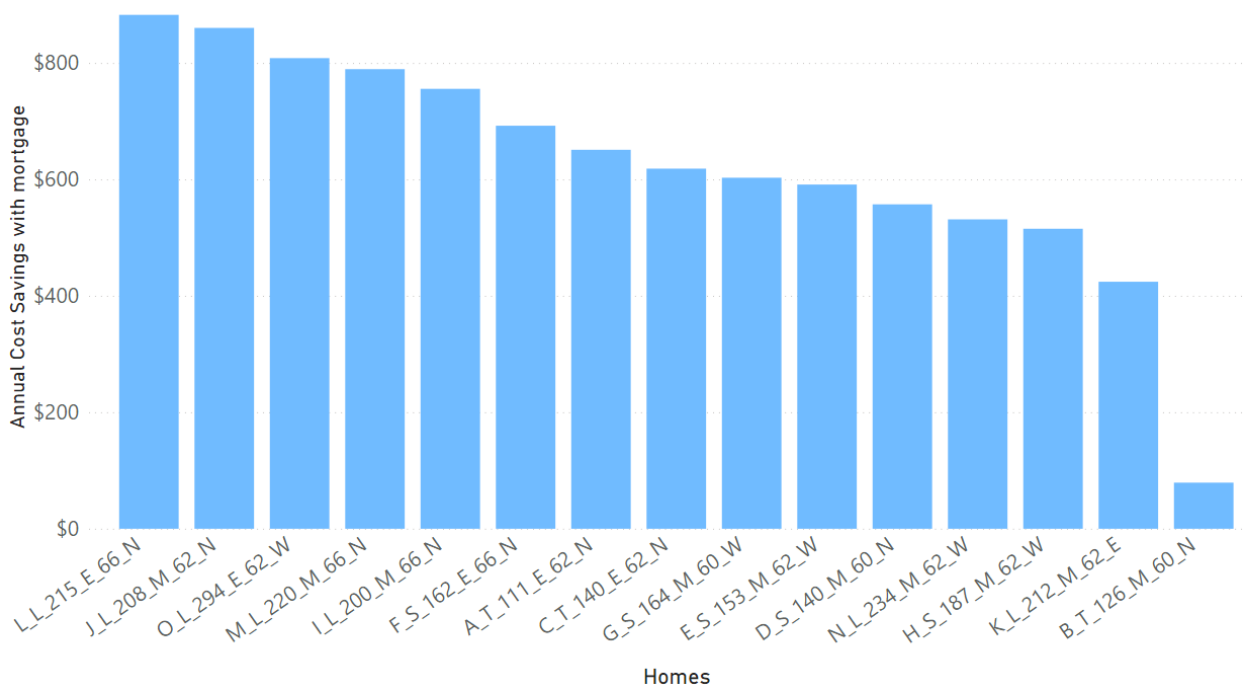
Given these homes were first builds as a part of a pilot, the improvement cost is expected to reduce with larger volumes of homes being built. As more are built, “learning effects” would be expected as well as supply chain improvements which reduce the cost of building the upgraded houses, for example due to the larger volume of double-glazing required.

## 6. Net costs

Net cost savings were calculated for each home using current tariffs. When improvement costs are included on the mortgage (at 2.48%<sup>8</sup> over 30 years), net savings start at occupancy for all ZNC homes. This is due to energy savings being greater than the additional mortgage payments.

Net annual savings ranged from \$79 to \$882 with all homes except Home B showing net annual savings over \$400.

**Figure 16: Net annual savings**



The net present values (NPV) were calculated with a discount rate of 7% to 2050 (over 30 years). When improvement costs were mortgaged, the NPV was positive for all homes. When directly funded (not mortgaged), all homes showed a positive NPV other than Home B. As discussed in section 4 and section 5, Home B is an outlier with higher improvement costs than other homes.

**Figure 17: Net present value to 2050**

NPV	Lowest - Home B	Highest - Home L
not mortgaged	- \$6,969	\$5,187
mortgaged	\$918	\$10,235

<sup>8</sup> moneysmart.gov.au – accessed 1 March 2021

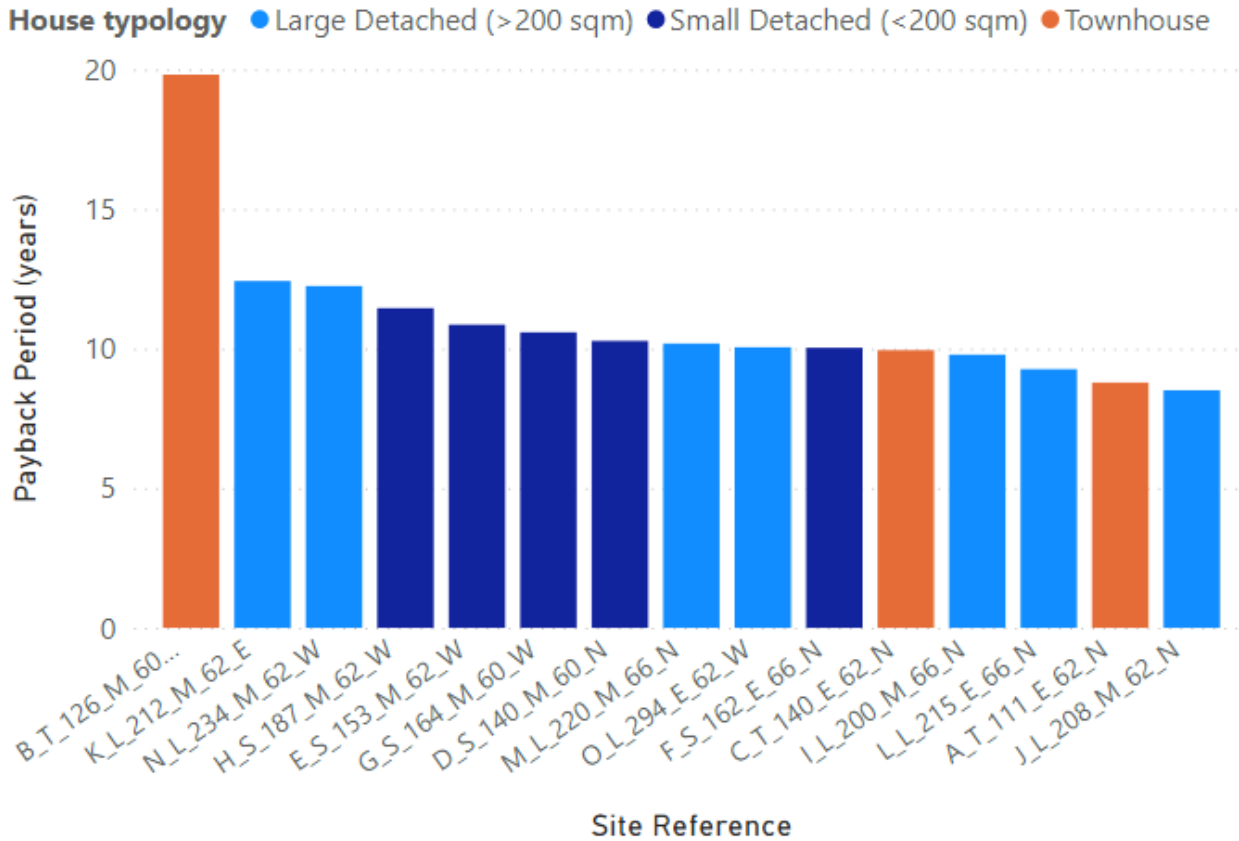
To account for homes where improvement costs are funded directly by the homeowner (i.e not mortgaged), simple payback periods were also calculated for each home using current tariffs. The simple payback is also represented in section 16, as an average across the homes. The average payback period, that is when the initial investment is recouped in energy cost savings is between 10 and 11 years when improvement costs to achieve ZNC are not included on the mortgage.

The simple payback period based on the energy bill savings for each home is shown in Figure 18. The following is observed:

- The overall range is between 8.5 – 19.8 years
- The range for small detached is 9.8 - 11.5 years
- The range for large detached is 8.5 - 12.4 years
- The range for townhouses is 8.8 – 19.8 years

Improvement costs and energy bill savings only were included. There may be some additional financial benefits that are not accounted for. These can include cost savings on smaller heating and cooling equipment, reduced maintenance due to less systems wear and fewer lighting changes due to LED longevity. Additional maintenance costs including those associated with the Solar PV systems were not included.

Figure 18: Simple payback period for 15 homes



From this sample, the following inferences are made:

- In general (although not always), the payback period for improvements to large detached homes is shorter than the other typologies. This suggests there may be more ‘lower hanging fruit’ available for investment in larger homes.
- For small detached homes, the narrow range in payback period suggests the improvements used for these homes were reasonably consistent across the typology.
- The large range in payback periods for townhouses suggests that improvements for this typology were less standardised and were more tailored for a specific home. This would be expected for semi-detached or row houses where party walls create design constraints compared with free standing houses. Further, compared to detached houses, townhouses could offer greater scope for improvements where these homes are mass produced. For example, if you build 200 town houses as a 7 star ZNC home and put them out to tender, costs are likely to be optimised.

The homes included in the report were first builds as a part of the pilot program. As these homes become standard offers, “learning effects” are expected to reduce the improvement cost, for example due to the larger volume of double-glazing required.

# 7. Solar PV size and proportion of roof area

The solar PV size to achieve ZNC has been compared with the maximum solar PV size for each home. The maximum solar PV size is the total kW able to be installed on north, east and west facing roof areas.

Thirteen of the 15 homes achieve ZNC using less than half of the roof area available for solar PV.

Of the other two homes, one (Home J) requires just over 50% of the available roof area and the other (Home C) is an outlier - this uses 85% of the available roof area. Home C is a double storey townhouse with the primary roof area facing south. It is understood the roof for Home C is designed in such a way to minimise overshadowing of the private open space of the neighbouring single storey dwelling.

These results indicate that in most cases the available roof area is not a constraining factor in houses achieving ZNC. There is no indication that houses in the pilot program have needed to modify roof designs in order to accommodate the required solar PV system to meet ZNC.

However, in particular cases where there are other constraints on roof design, the solar PV size required for ZNC does approach the available roof area.

Figure 19: Solar PV size to meet ZNC compared with maximum solar PV size

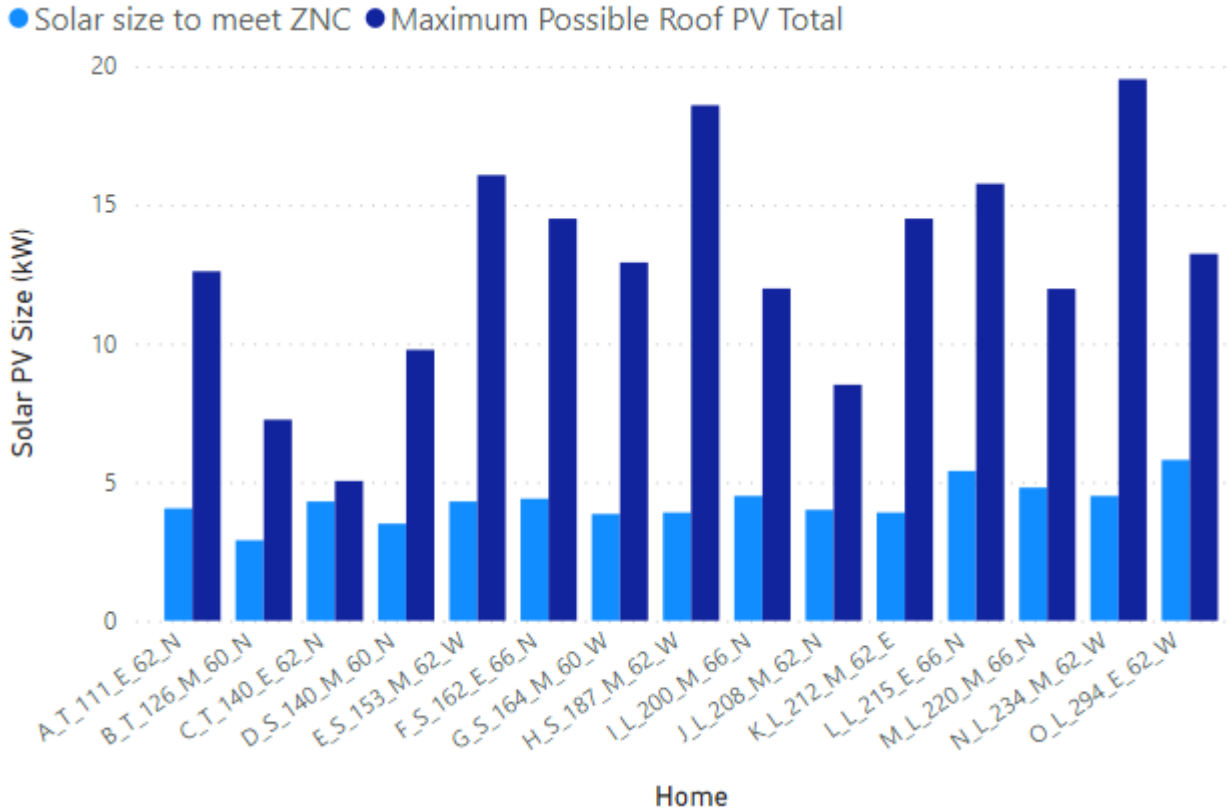
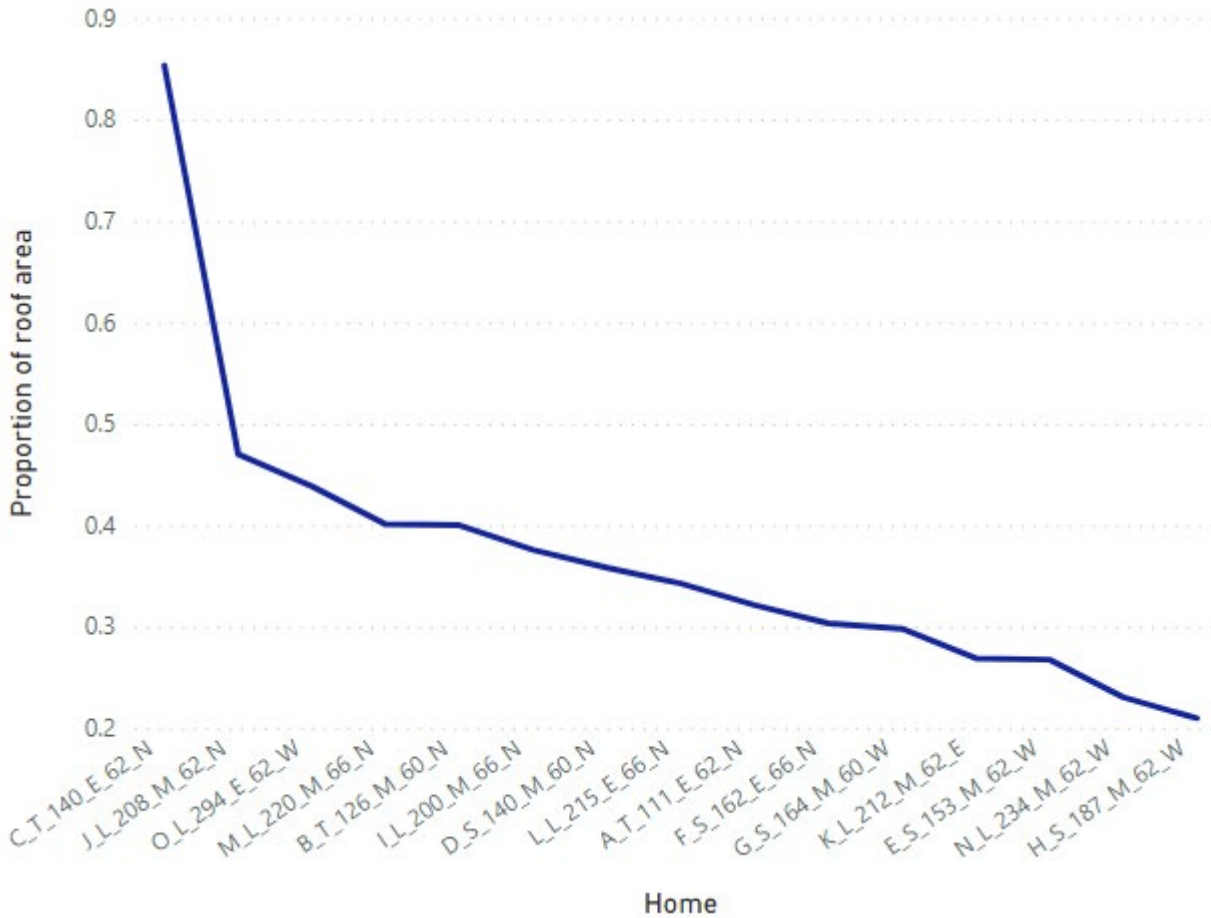


Figure 20: Solar PV area required to meet ZNC as a proportion of available roof area



It should be noted that this analysis is based on 315W solar PV panels that are 1.1m x 1.9m in physical size. As of the time of publishing, solar panels of 370-380W are becoming readily available in the market in similar physical sizes.

If the analysis is repeated using 370W panels, the maximum solar PV size for each home and the proportion of the available roof area that is needed to achieve ZNC can be seen (refer Figure 21 and Figure 22).

In this case, thirteen of 15 homes now use less than 40% of the available roof area to achieve ZNC.

Using 370W panels, 85% of the homes could fit Solar PV systems over 10kW. Two homes could have over 20kW.

The additional Solar PV capacity based on available roof area suggests that electric vehicle charging could be achieved using at-home Solar PV generation for many ZNC homes.

Figure 21: Solar PV size to meet ZNC compared with maximum solar PV size (370W panels)

● Solar PV size to meet ZNC ● Maximum Possible Roof PV (315W) ● Maximum Possible Roof PV (370W)

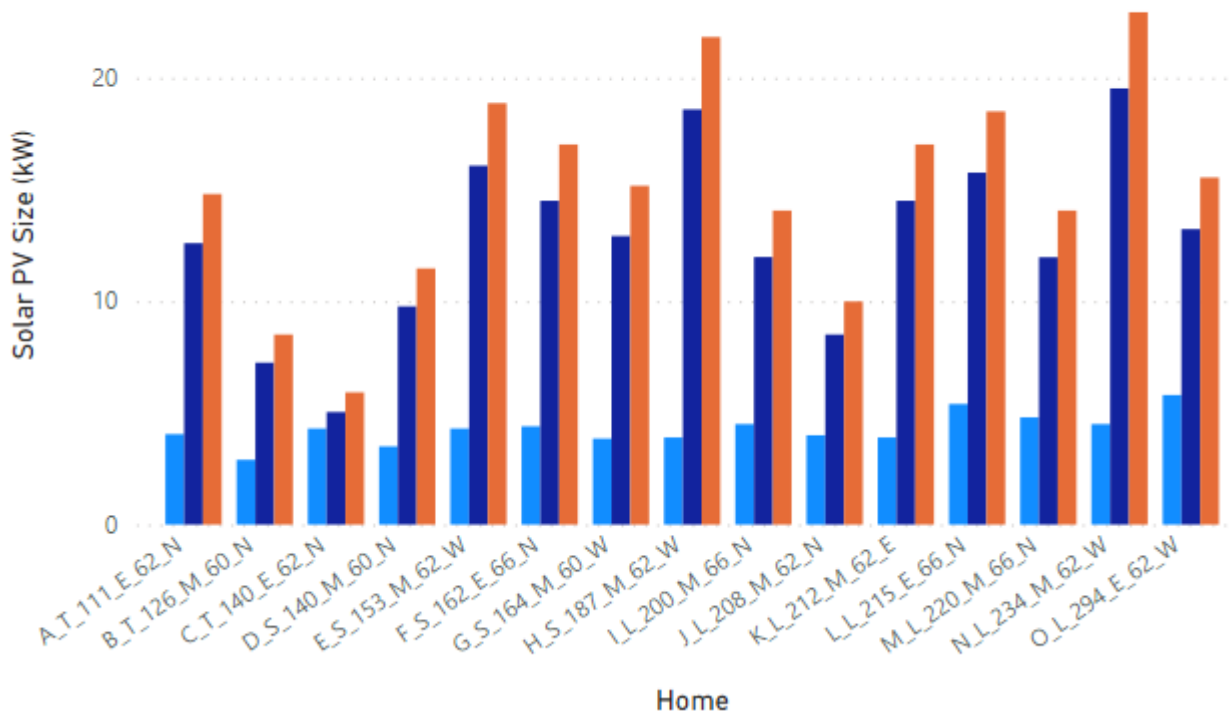
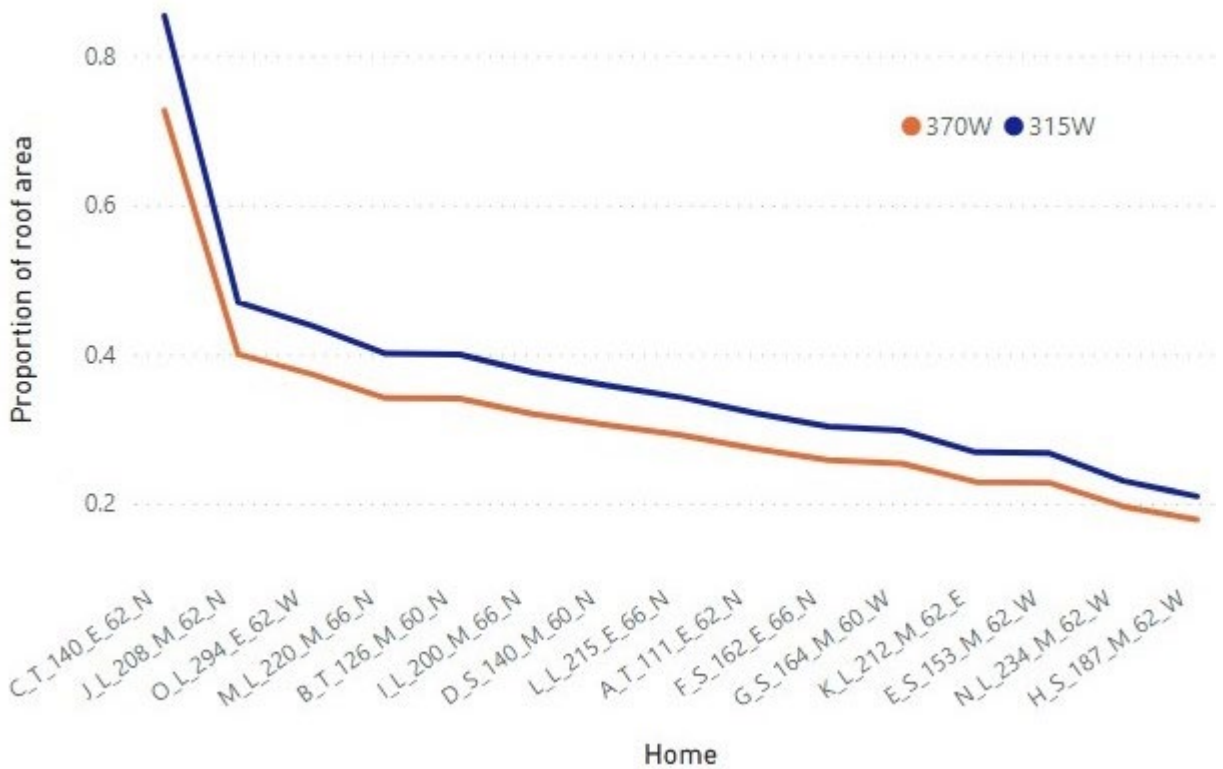


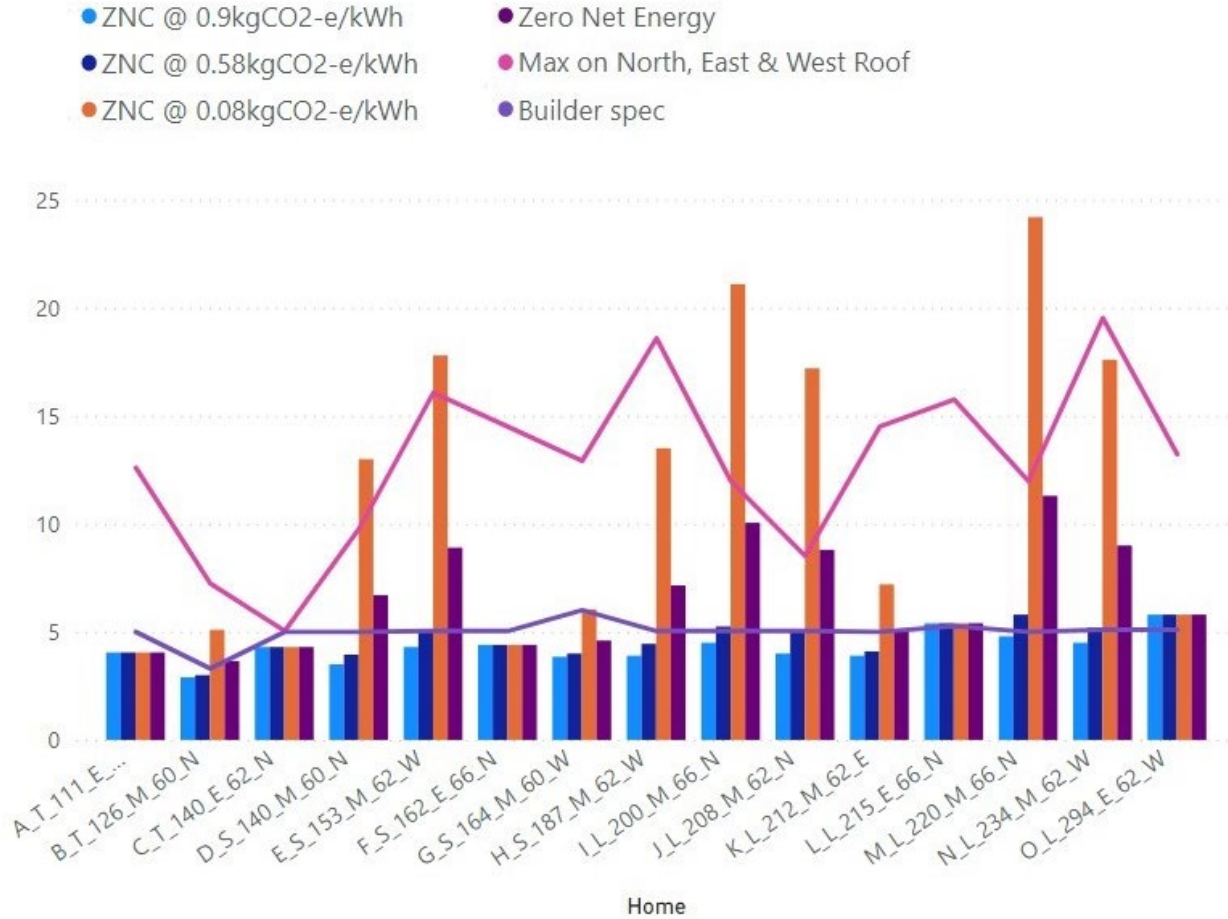
Figure 22: Solar PV area to meet ZNC for 370W panels and 315W panels and as a proportion of available roof area



## 8. Solar PV and ghg coefficients

The solar PV size to achieve ZNC was investigated for each home across three greenhouse co-efficients for grid electricity, as detailed in the methodology. This chart (Figure 23) also shows the solar PV size to achieve zero net energy, maximum solar PV size possible for each home if all north, east and west roof space is utilised (discussed more in section 7), and the as-built solar PV size for each home.

Figure 23: Solar PV size to meet ZNC under various greenhouse co-efficients



The all-electric homes require the same size solar PV to meet ZNC, regardless of greenhouse co-efficient. This is because as the greenhouse co-efficient changes, a home’s emissions and the emissions offset by the solar PV change are in direct proportion to one another. So, for example, if the greenhouse co-efficient fell by 20%, the home’s emissions (in tCO<sub>2</sub>-e) would fall by 20%, but so would the emissions offset by the existing solar PV. Therefore, the home requires the same size solar PV system to achieve ZNC.

For mixed fuel homes, the emissions do not change in direct proportion, because in this case emissions are made up of electricity emissions (which do change as the emission factor changes) and gas emissions (which do not). Therefore, for lower electricity

emission factors, each kW of installed solar PV offsets less emissions. This results in larger solar PV sizes being needed for mixed fuel homes.

For very low greenhouse gas co-efficients, such as the 0.08kgCO<sub>2</sub>-e/kWh shown below, the solar PV required for mixed fuel homes becomes very large.

In all ghg coefficient cases except the most extreme (0.08kgCO<sub>2</sub>-e/kWh) for half of the mixed fuel homes, the solar PV size required to achieve ZNE is below the solar PV size possible on that home.

Solar PV size to meet Zero Net Energy (ZNE) is also shown in Figure 23; this is discussed further in the following section.

### Solar PV sizing for Zero Net Energy

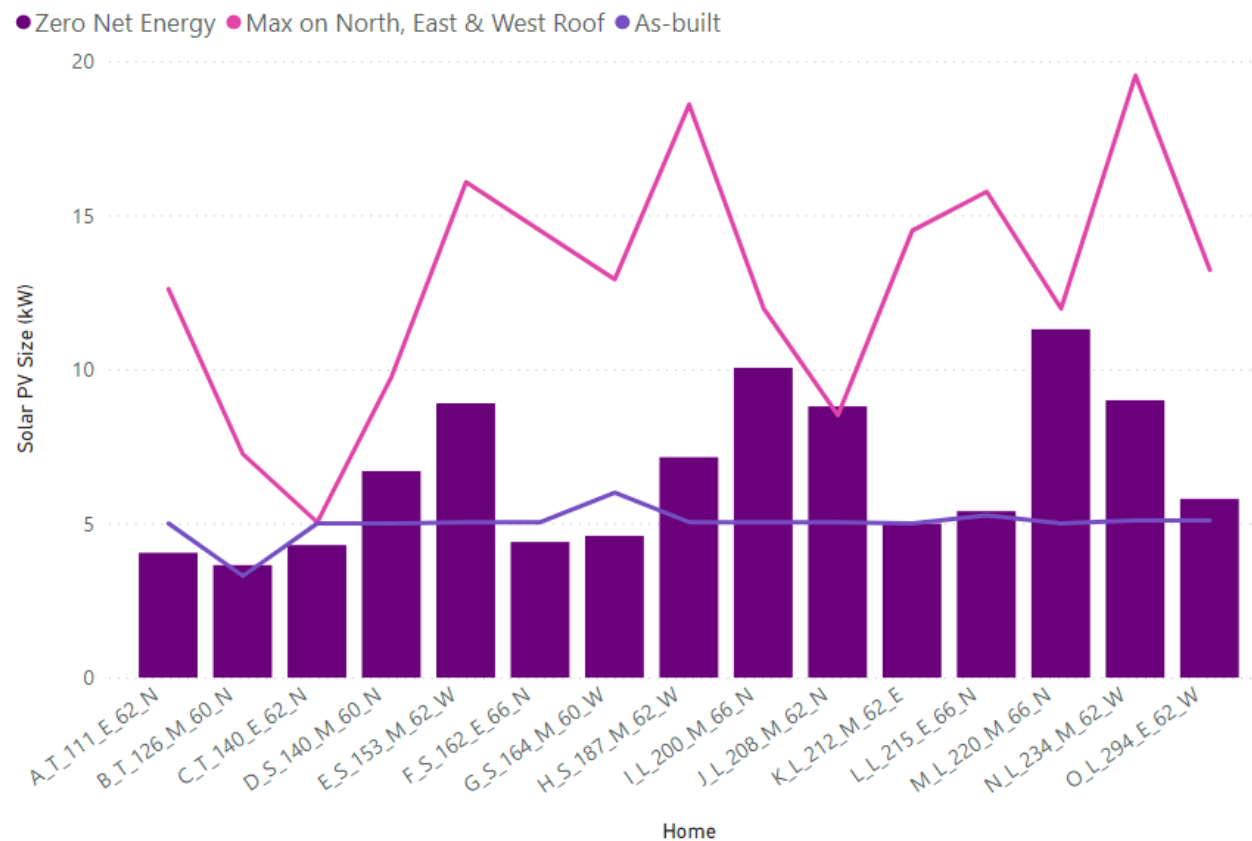
As well as examining the Solar PV size needed to meet ZNE under different ghg coefficients, we can also examine the solar PV size needed to meet Zero Net Energy (ZNE). This is shown in Figure 24.

For all electric homes (as discussed earlier in this section), the solar PV needed to achieve ZNE remains constant regardless of greenhouse co-efficient. For these homes, the same size solar PV is also needed to meet ZNE.

For mixed fuel homes, the solar PV needed to meet ZNE is significantly higher than that needed to meet ZNE (under the ZNE tool ghg coefficient).

Figure 24: Solar PV size to meet Zero Net Energy

Solar PV size for ZNE vs as built size vs max available roof area



The following additional observations can be made:

- Ten of the 15 homes would not achieve ZNE with the as-built solar PV size.
- Fourteen of the 15 homes (all excepting Home J) could achieve ZNE with their available roof area, and Home J would likely achieve this with a higher watt solar panel. The impact of higher wattage panels per sqm is discussed in Section 7.

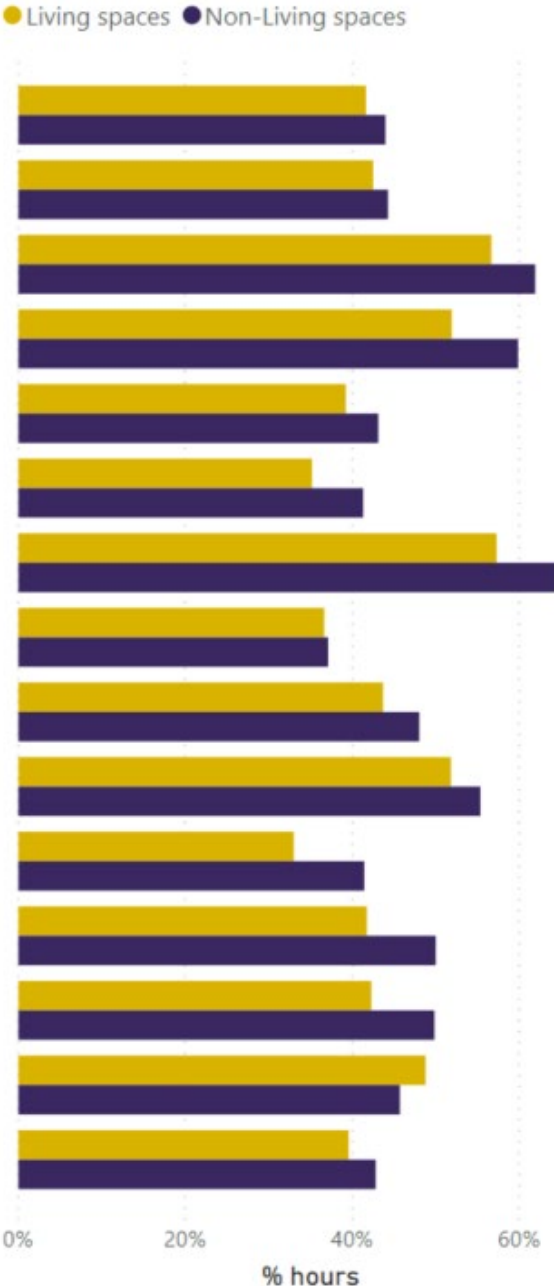
# 9. Hours outside comfortable temperatures (free running)

The data allows investigation of predicted temperatures within the homes when no mechanical heating or cooling is used. From here we can see how many hours the homes spend within and outside a 'comfortable' temperature range - set at 18-26 degrees Celsius. This was modelled using the freerunning mode in Accubatch.

The World Health Organisation comfort temperatures are 18 degrees and 24 degrees. 26 degrees was used in this research to align with other government modelling work.

The modelling provides predicted internal temperatures based on no heating and no cooling.

**Figure 25: ZNC Percentage of hours outside comfort temperature range without conditioning**



Safe and healthy temperatures are important to determine for homes when access to heating and cooling is restricted due to energy poverty and energy grid failure (e.g. blackouts).

Figure 25 shows the percentage of hours in a year that the spaces in the 7 star homes would be either above 26 degrees (too-hot) or below 18 degrees (too-cold) if heating and cooling weren't available.

The best result for a space is for Home E with living areas outside the temperature range for 33% of the year.

The best result across a whole home is Home H with 36% of hours for Living areas and 37% of hours for Non-living areas outside the temperature range.

Home I shows the worst performance for both Living and Non-living with modelled results of 57.3% and 64.5%.

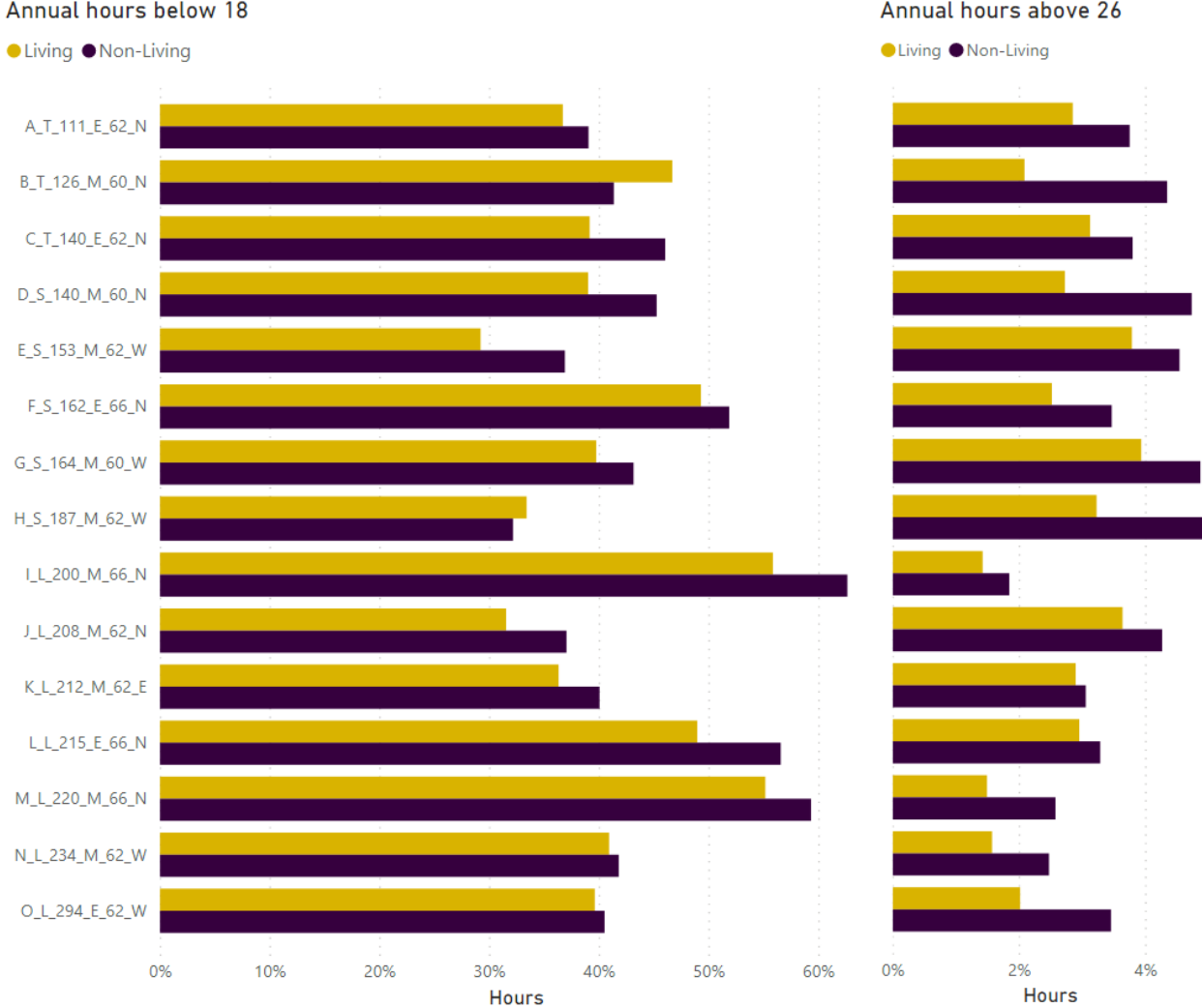
In all the homes, the living areas are within the 'comfortable' temperature ranges for more of the year.

Living and non-living are included separately due to the variety of the composition of residents in homes. For some residents, non-living areas are used frequently and are relied upon as a primary living space. For example bedrooms might be a home office, study space or retreat from communal areas during any time of the day.

For some residents, retreating to living areas to seek comfortable temperatures over extended periods can be a challenge.

For both living and non-living areas, the hours too-cold were significantly greater than hours too-hot in all homes (Figure 26). This is by a minimum factor of 6.5 (Home H) up to a maximum factor of 40 (Home I).

**Figure 26: Percentage of hours of living and non-living areas below 18 degrees and above 26 degrees without conditioning**



Non-living areas show more hours:

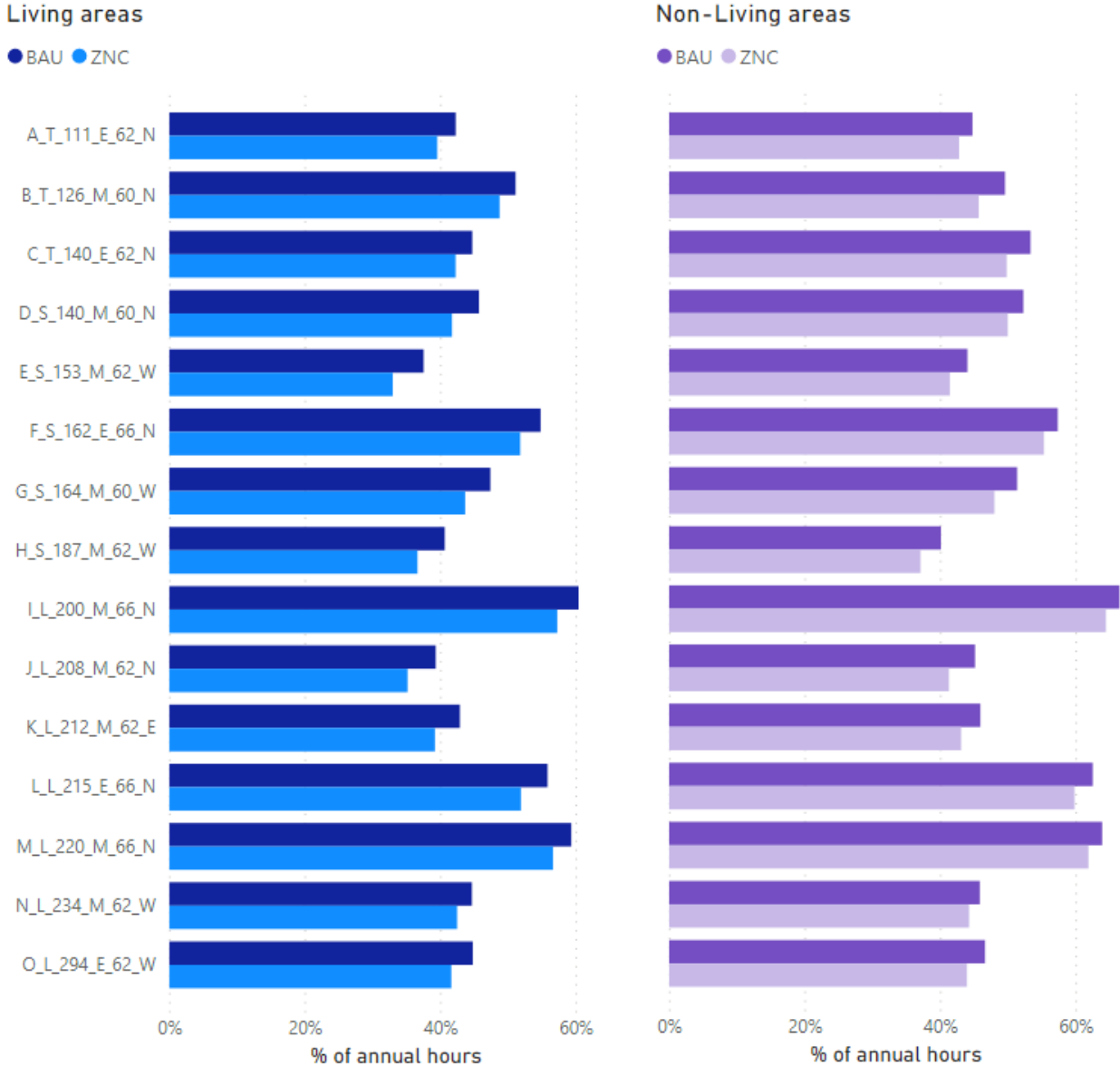
- of uncomfortable temperatures than living areas in all homes.
- too-hot than living areas in all homes.
- too-cold than living areas in all homes except Homes B and H.

The average percentage of annual hours too-cold across the typologies showed large detached as the highest on average at over 44%, 6% higher than small detached for both living and non-living spaces. Townhouses were marginally worse than small detached.

The average percentage of annual hours too-hot for small detached were highest at 4.5% for non-living and 3.2% for living. Large detached homes had the lowest number of hours too-hot on average.

Figure 25 and Figure 26 show the results related to 7 star homes. The percentage reduction in uncomfortable hours from building envelope improvements to the 6 star homes (improvements discussed in section 2) are shown in Figure 27 and Figure 28.

Figure 27: Percentage of hours outside comfort temperature range without conditioning

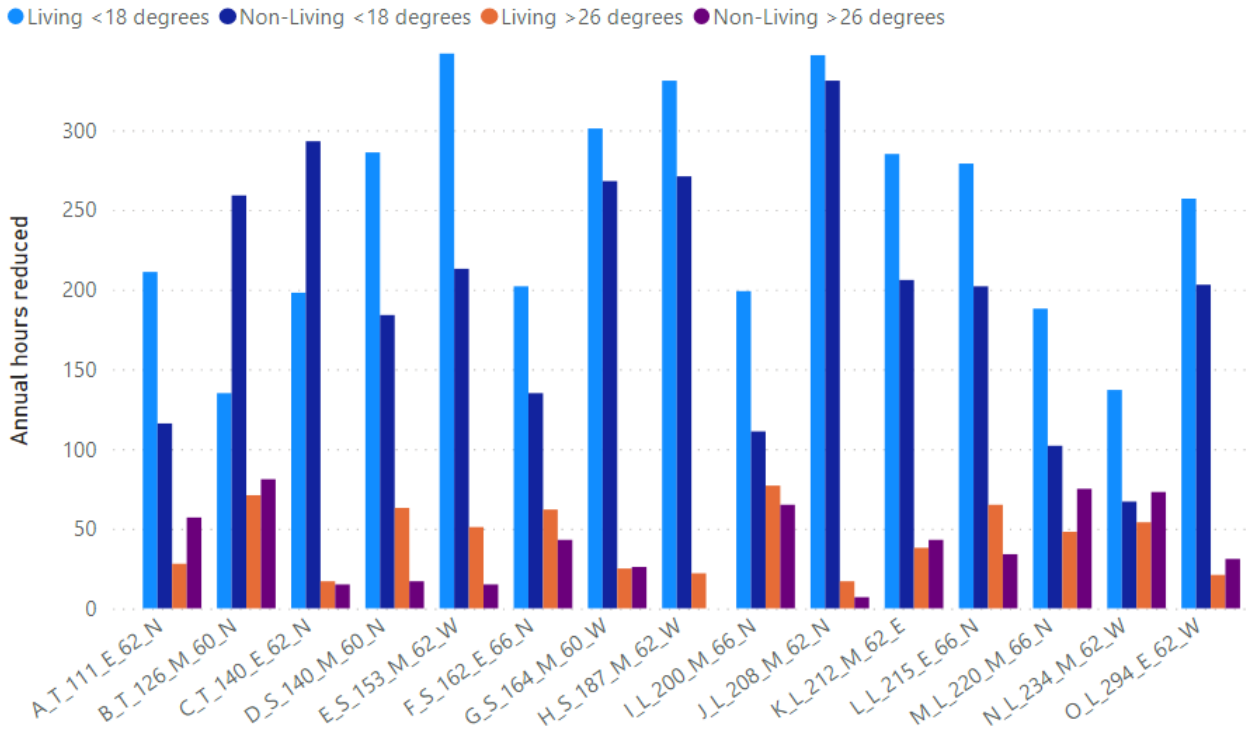


All ZNC homes were within the comfortable temperature range for more hours per year. This was found for both living areas and non-living areas.

The reduction of annual hours too-cold for both living and non-living were largest for all homes. Living area reductions were the largest in all homes except Homes B and C.

The reduction of hours in uncomfortable temperatures correlates well with the relative improvements to heating and cooling. This is discussed in section 14 where building envelope improvements showed greater impacts on thermal performance related to heating, than to cooling.

**Figure 28: Reduction of annual hours in uncomfortable temperatures (above 26 or below 18 degrees) without conditioning - ZNC improvement**



For one home (Home E), results for the hottest summer and coldest winter days and nights were examined. The severity of the coldest and hottest hours in the living and non-living areas was reduced by between 0.4 and 1.1 degree.

**Figure 29: Building envelope improvement on Home E temperatures on hottest and coldest days and nights**

	Day	Night
Summer peak	0.4 - 1.0°C cooler	0.5 - 0.9°C cooler
Winter peak	0.8 - 1.1°C warmer	0.8 - 1.1°C warmer

## 10. Peak demand

Summer and winter electrical peak demands were modelled for ZNC homes and BAU homes. Demand was modelled for import from and export to the electricity distribution network. The profiles show solar PV exports to the grid as negative demand.

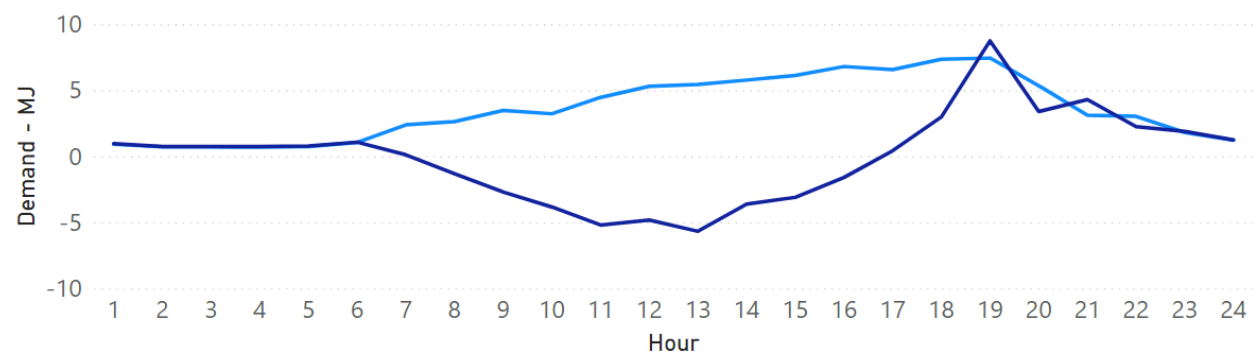
The profiles shown are the daily demand profile for the day of peak hourly demand. The dates of peak hourly demand are different for each home and for BAU and ZNC. For example, Home C summer peak demand for BAU was 7 pm on 14 February and for ZNC was 7pm on 13 January.

The daily profile for the average home shows the clear reduction in demand due to Solar PV on the ZNC homes (Figure 30). The hour of the summer and winter peak demand were unchanged, remaining at 7pm and 7am respectively.

Figure 30: Average summer and winter peak demand for BAU and ZNC

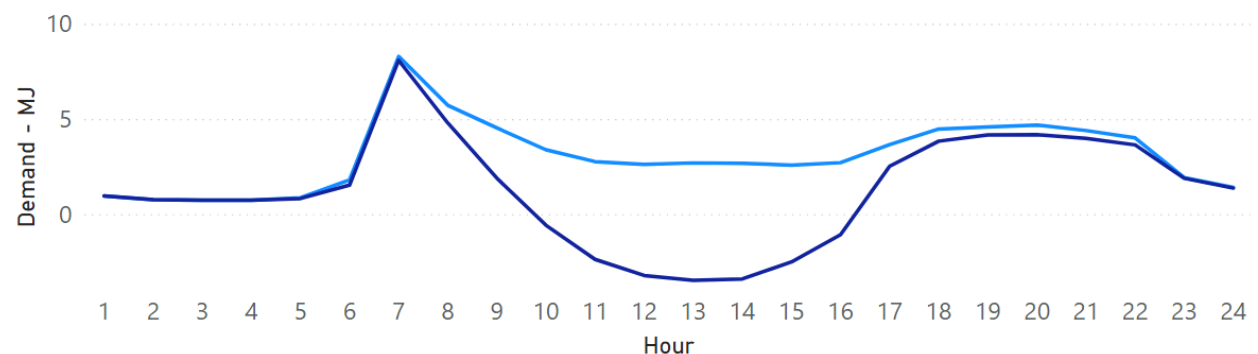
Summer

BAU/ZNC ● BAU ● ZNC



Winter

BAU/ZNC ● BAU ● ZNC



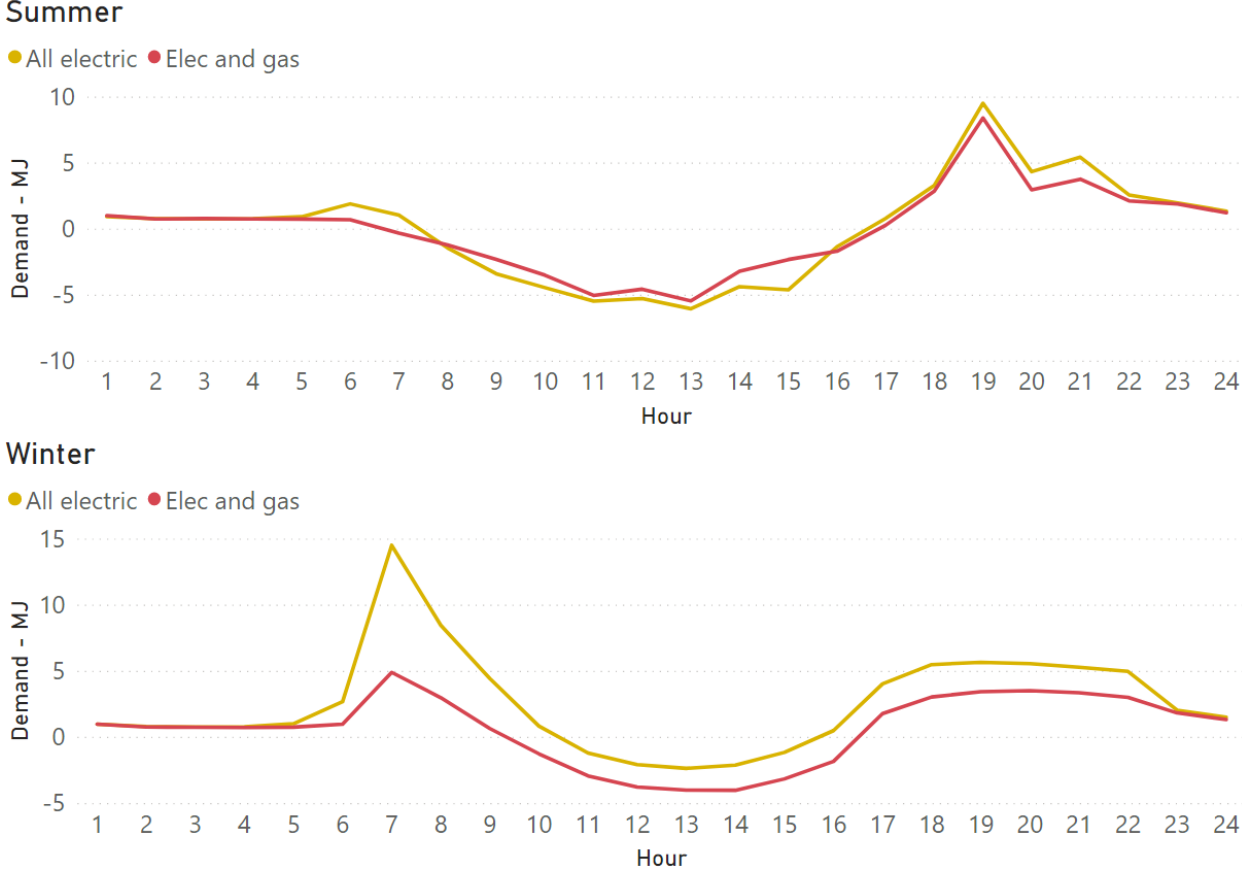
All ZNC homes had a 7pm summer peak demand. This aligns with timing of reduced Solar PV generation, high cooling demand for many homes and increased hot water and cooking demand.

BAU summer peak demand ranged from 7am to 7pm. This indicates that cooling demand largely determined peak demand with the varying orientations of the homes contributing to peak cooling demand not being consistent across the homes.

All ZNC homes had a 7am winter peak demand. This aligns with low Solar PV generation, commonly high heating demand and increased hot water and cooking demand. All BAU all electric homes also had a 7am winter peak demand.

For BAU mixed fuel homes, the winter peak demand ranged from 7am to 8pm.

Figure 31: Average ZNC summer and winter peak demand by fuel mix



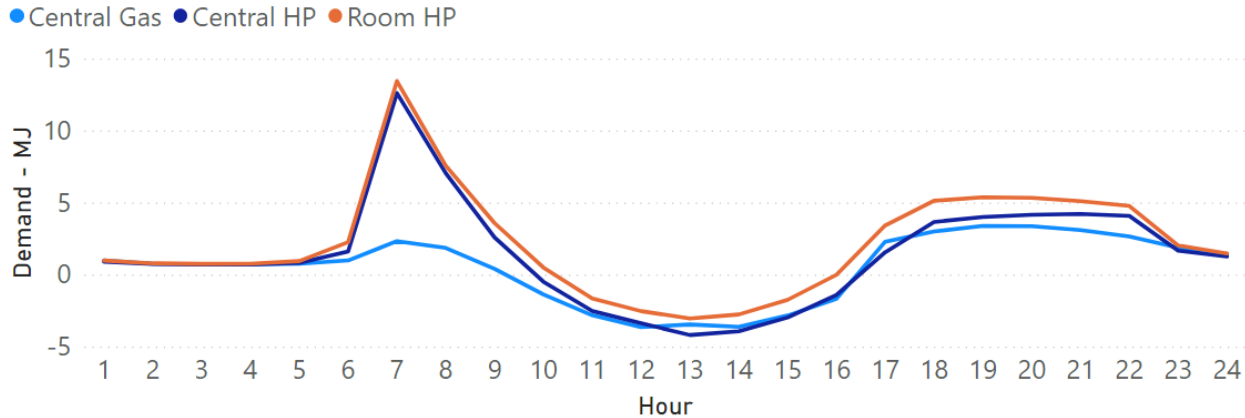
Summer peak demand day profiles for average all electric and average mixed fuel ZNC homes were found to be very similar (Figure 31). However, the 7pm peak was 12% less for the average mixed fuel home than for the average all electric home.

The winter peak demand for the average all electric ZNC home was approximately triple that of the average mixed fuel ZNC home. This is an average 10 MJ (2.78 kWh) increase. The modelling assumptions in the ZNC tool include that use of heating, hot water and cooking all peak around 7am. The implications of this sharp peak on distribution network management are significant. Further analysis of this assumption including comparison with metered data would assist in future winter peak demand modelling and forecasting.

Induction cooktops (0.4 MJ) reduced peak demand by 0.2 MJ when compared with electric cooktops (0.6 MJ). As expected, this indicates that the cooking system type is not a key contributor to peak demand in all electric homes.

Similar to the findings when looking at fuel mix, heating system fuel source was shown to be a key indicator of winter peak electricity demand (Figure 32).

**Figure 32: Average ZNC winter peak demand by heating system type**



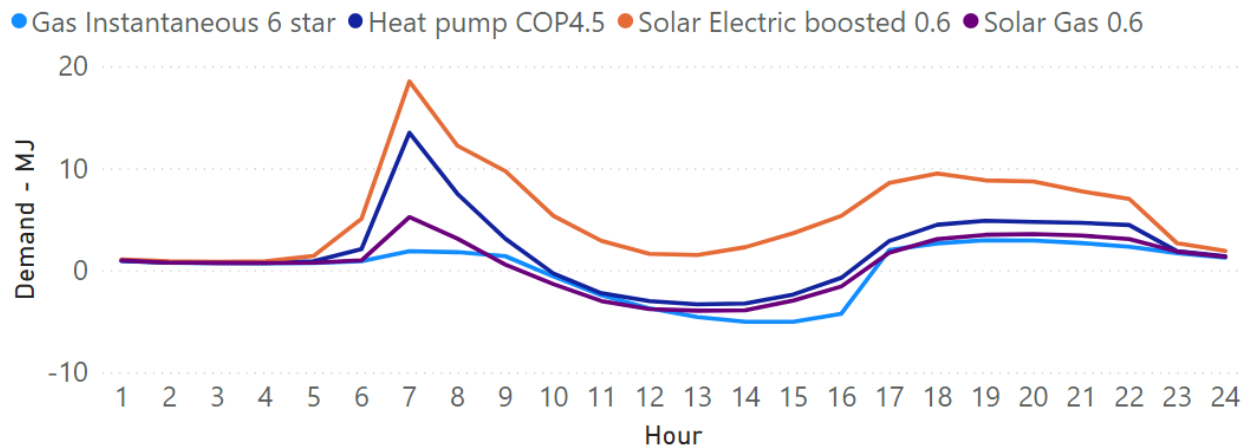
Heat pump system type showed as having little impact on winter peak demand when averaged across the ZNC homes.

Solar electric boosted hot water systems were found to have a significant impact on winter peak demand. Homes F, L and O homes were modelled for BAU with solar electric boosted hot water systems. These homes had the highest BAU winter peak demand. Home L was also modelled for ZNC with a solar electric boosted hot water system. It was the only ZNC home modelled with this system type and it had the highest ZNC winter peak demand.

Homes F and O were modelled for ZNC with heat pump hot water systems. These homes had winter peak demand lower than BAU by 21% (3.5 MJ) and 25% (5.8 MJ).

This showed that electric boost required for hot water supply on winter mornings had a significant impact on winter peak demand. For all electric homes, it indicates that heat pump hot water systems would be a preferred system type for peak demand mitigation.

**Figure 33: Average ZNC winter peak demand by hot water system type**

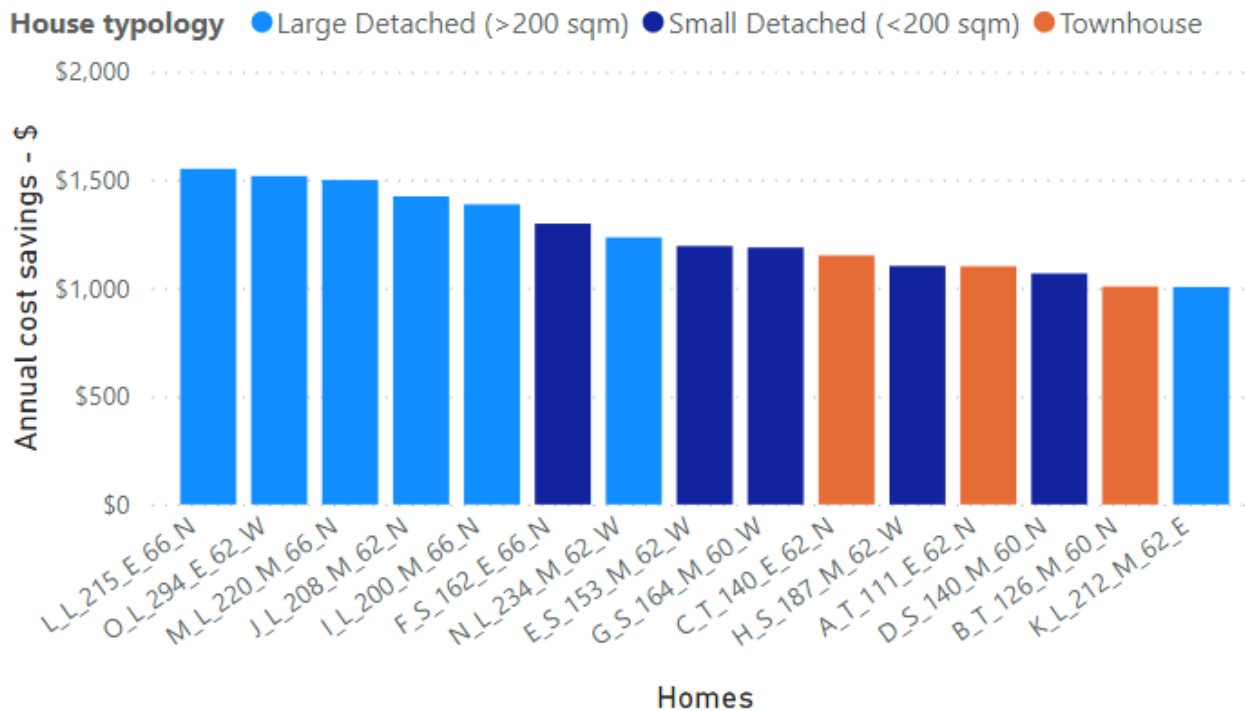


## 11. Energy cost savings

Cost savings were modelled for ZNC homes against BAU homes on the annual energy bill. Energy costs were modelled with current tariffs using time of use for electricity and flat rate for natural gas. None of the modelled homes had wood or LPG appliances.

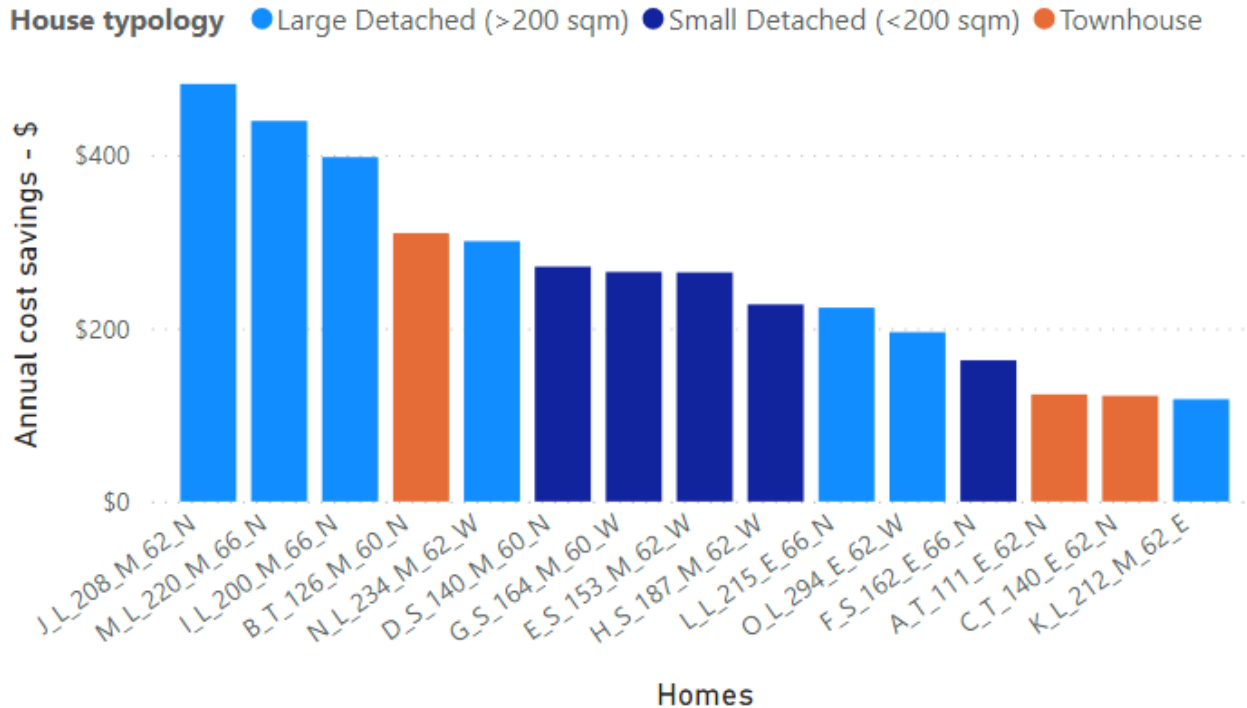
The results show that all ZNC homes have operational energy cost savings compared to BAU homes (Figure 34). The savings range from \$1,004 per year to \$1,550 per year, trending up with increase in home size.

Figure 34: Annual energy cost savings by home and typology



When solar PV related cost savings and income are excluded, the trend of higher savings for larger homes is less evident (Figure 35). Fuel choice (Figure 37) and appliance type and efficiency (refer section 12) then have a larger impact on relative cost savings.

Figure 35: Annual energy cost savings (excluding solar) by home and typology



All electric homes had an average \$110 higher saving on energy costs.

All electric homes had an average 20% lower energy cost compared to mixed fuel homes. However, there was a weak correlation between fuel mix and annual operating savings (Figure 36).

When looking at the same results without the benefit of solar PV (Figure 37), fuel mix is a clear indicator of operating savings. The cost benefit of energy efficiency was greater for mixed fuel homes, whereas the cost benefit of solar PV was greater in all electric homes.

This aligns with the increased cost benefit of solar PV when being consumed onsite and saving on the higher electricity tariff compared to exporting to grid.

Figure 36: Annual operating energy cost saving by fuel mix

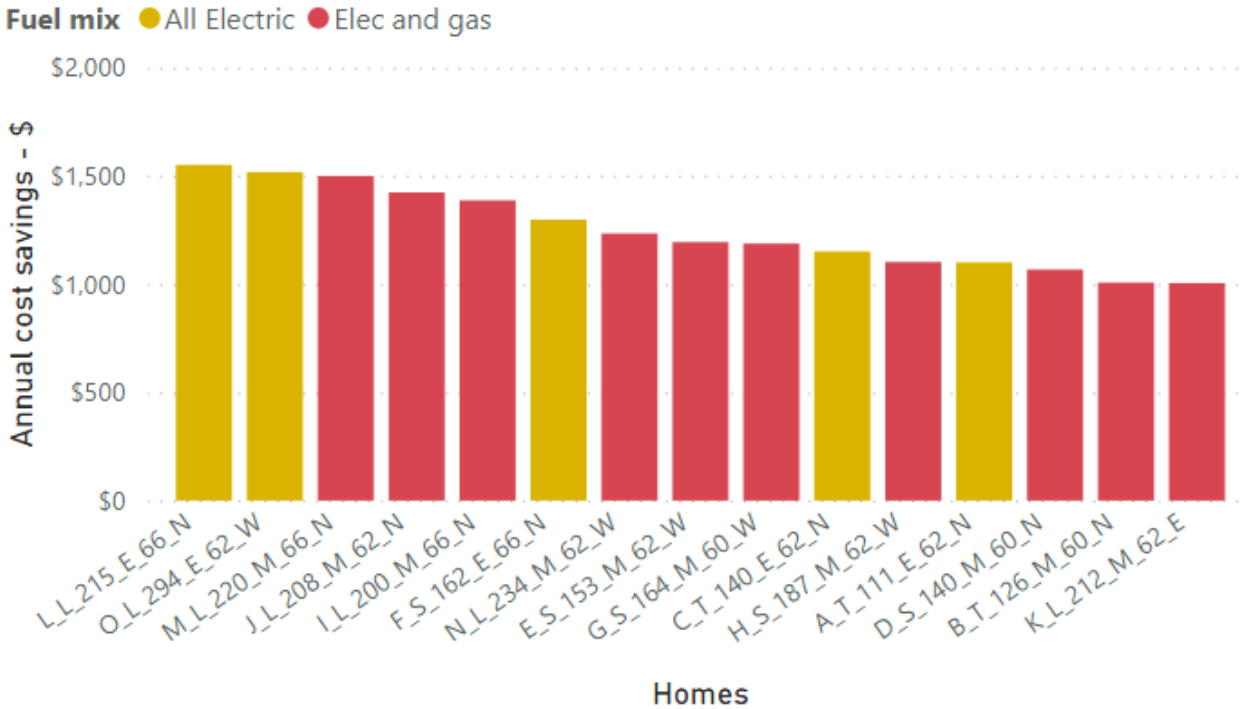
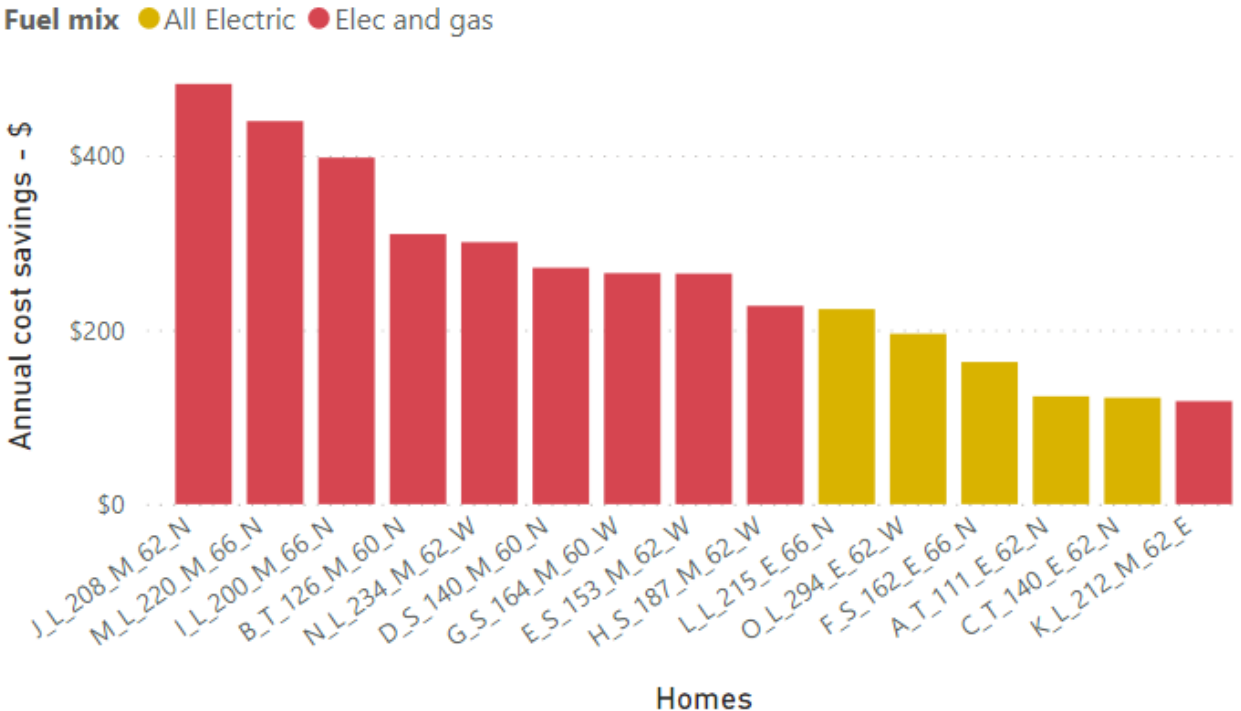


Figure 37: Annual operating energy efficiency cost saving by fuel mix (excluding solar)



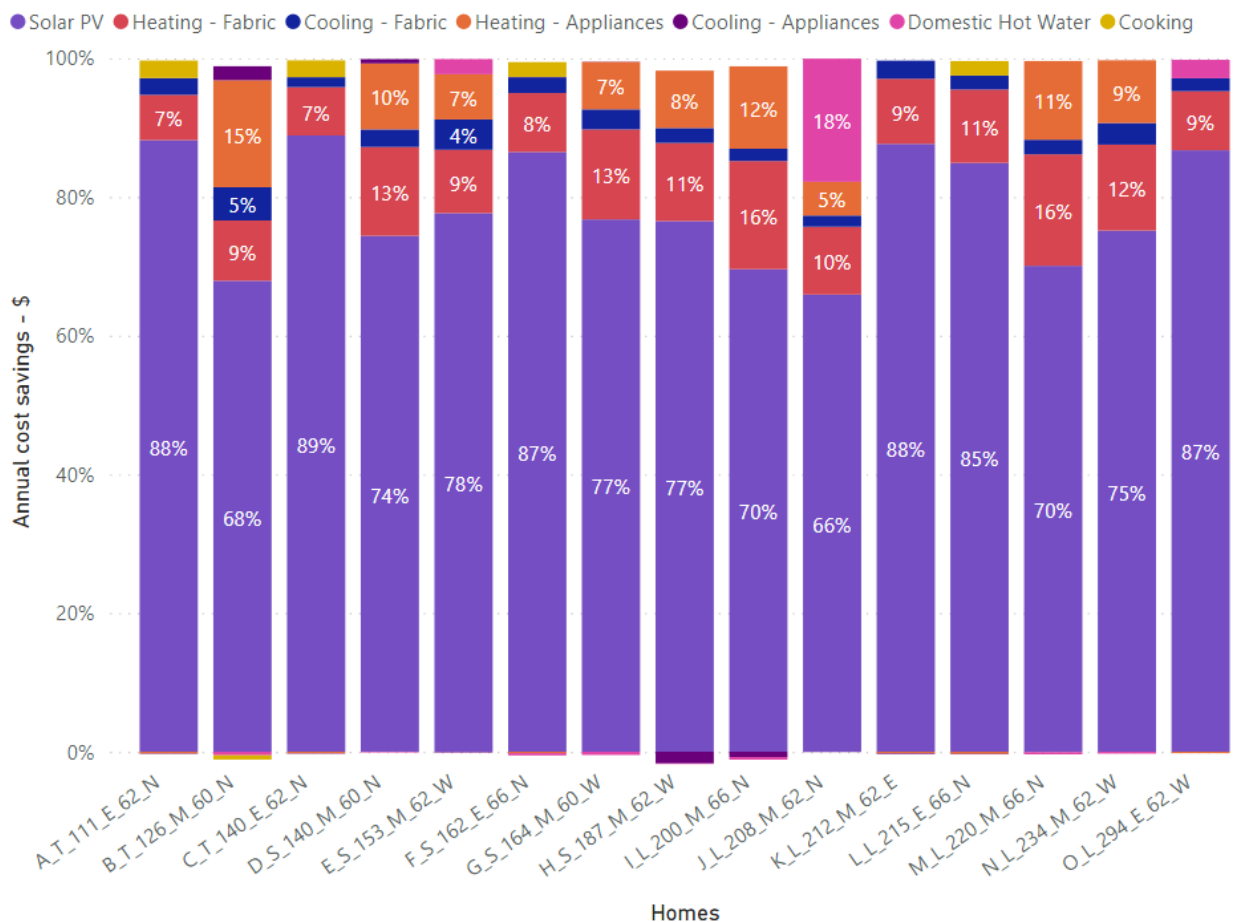
## 12. Energy cost savings and improvement costs by feature

To further explore the impact of specific features of energy cost savings, savings were split into thermal envelope, appliances and solar PV.

As partly indicated in section 11, the cost savings associated with adding the solar PV systems are significant. Solar PV operating cost benefits accounted for between 66% and 89% of total cost savings. For all electric homes, the Solar PV contribution was 86% to 89% of cost savings.

Improvements to building envelope and heating appliances accounted for between 8% and 28% with an average of 23%.

**Figure 38: Annual operating energy cost savings split by improvement type**

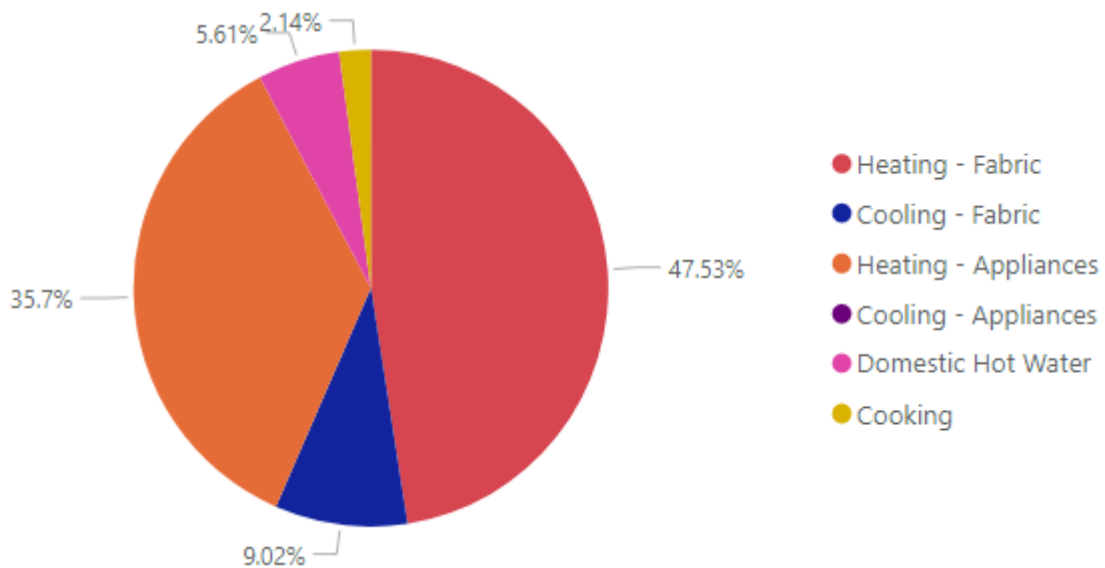


Homes with heating savings over 20% were from improvements to BAU central gas heating. The domestic hot water for Home J was an outlier at 18% contribution. This relates to inclusion of a solar gas hot water system in the ZNC home.

Related to efficiency measures, the greatest cost saving item was thermal envelope improvements related to heating at ~42% (Figure 39). Heating related improvements were 75% of energy efficiency cost savings.

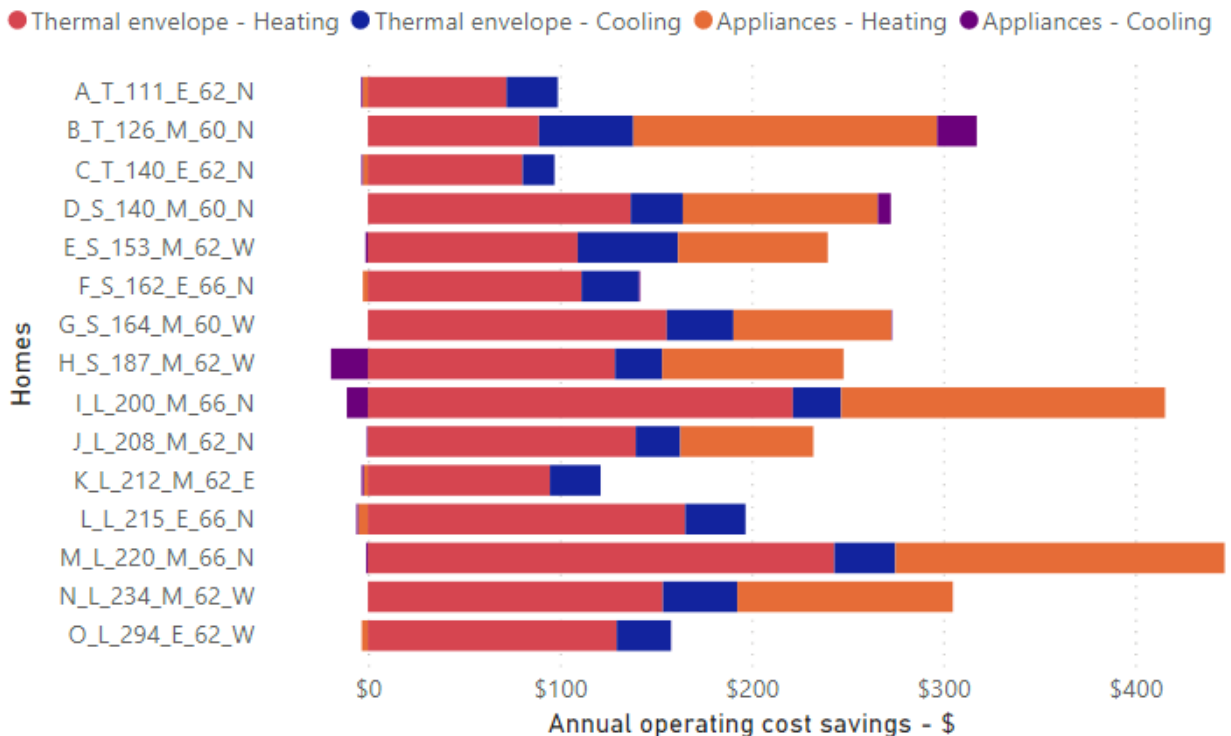
Cooling appliance changes averaged out as being negligible across the homes.

**Figure 39: Annual operating energy cost savings from efficiency**



Cooling improvements are a minor contributor to cost savings. Homes B and D included cost savings from cooling appliances while homes H and I had equivalent cost losses. The home B saving related to a change from central to room heat pump reverse cycle system and the home D saving related to a more efficient reverse cycle heat pump system. Cost losses for homes H and I both related to a change from room to central heat pump systems.

**Figure 40: Heating and cooling operating costs savings contributions**

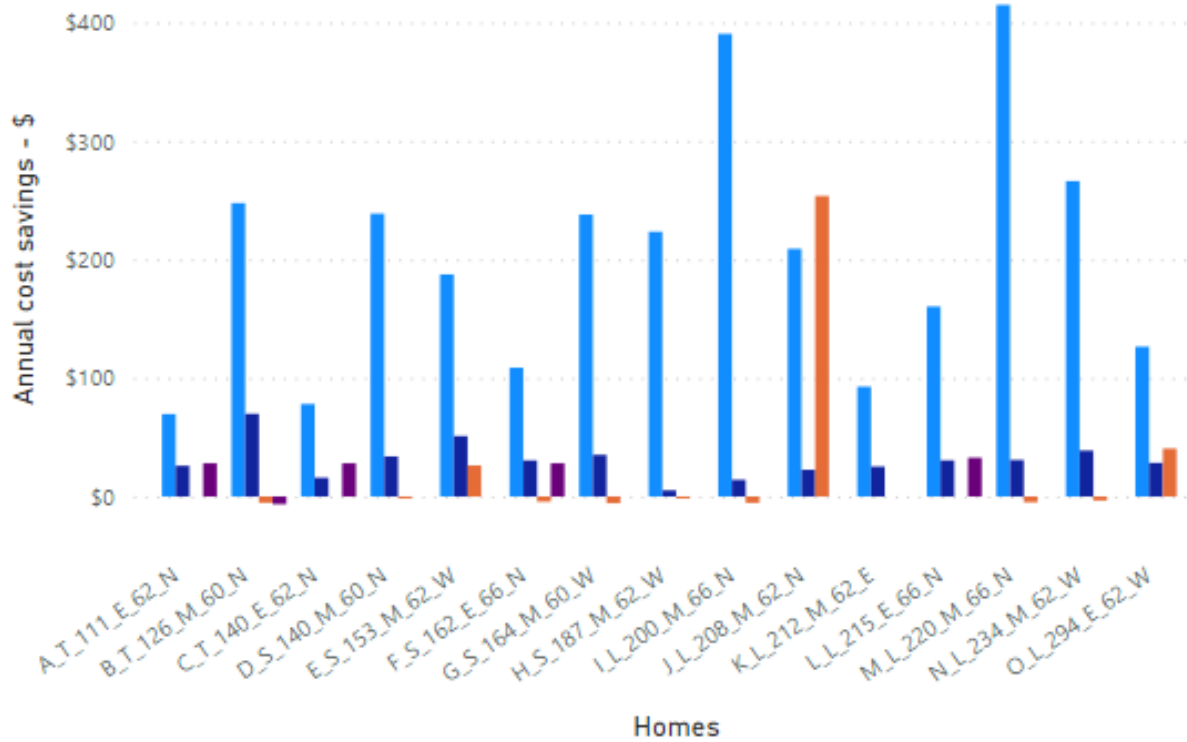


**Figure 41: Improvement cost and operating cost savings by feature**

Site Reference	Improvement cost Building envelope	Improvement cost External blinds	Annual operating costs savings Fabric	Improvement cost Heating systems	Heating annual operating costs savings Appliances	Improvement cost Cooling systems	Cooling annual operating costs savings Appliances	Improvement cost Water heater	DHW annual operating costs savings	Improvement cost Cooking equipment	Cooking annual operating costs savings	Total Improvement Cost
A_T_111_E_62_N	\$4,306	\$0	\$99	\$500	-\$3	\$0	-\$1	\$0	\$0	\$0	\$28	\$9,666
B_T_126_M_60_N	\$9,349	\$7,122	\$138	\$0	\$158	\$0	\$21	\$0	-\$5	\$0	-\$6	\$19,951
C_T_140_E_62_N	\$6,286	\$0	\$97	\$0	-\$3	\$0	-\$1	\$0	\$0	\$0	\$28	\$11,446
D_S_140_M_60_N	\$6,268	\$0	\$164	\$500	\$102	\$0	\$7	\$0	-\$1	\$0	\$0	\$10,968
E_S_153_M_62_W	\$7,306	\$0	\$162	\$500	\$78	\$0	-\$1	\$0	\$26	\$0	\$0	\$12,966
F_S_162_E_66_N	\$7,732	\$0	\$141	\$0	-\$3	\$0	\$1	\$0	-\$4	\$0	\$28	\$13,012
G_S_164_M_60_W	\$7,945	\$0	\$191	\$0	\$82	\$0	\$0	\$0	-\$6	\$0	\$0	\$12,565
H_S_187_M_62_W	\$7,439	\$0	\$153	\$500	\$95	\$0	-\$19	\$0	-\$1	\$0	\$0	\$12,619
I_L_200_M_66_N	\$7,665	\$0	\$247	\$500	\$169	\$0	-\$11	\$0	-\$5	\$0	\$0	\$13,565
J_L_208_M_62_N	\$6,812	\$0	\$163	\$500	\$69	\$0	-\$1	\$0	\$254	\$0	\$0	\$12,112
K_L_212_M_62_E	\$7,798	\$0	\$121	\$0	-\$2	\$0	-\$1	\$0	\$0	\$0	\$0	\$12,478
L_L_215_E_66_N	\$7,888	\$0	\$197	\$0	-\$5	\$0	-\$1	\$0	\$0	\$0	\$33	\$14,368
M_L_220_M_66_N	\$9,007	\$0	\$275	\$500	\$172	\$0	-\$1	\$0	-\$5	\$0	\$0	\$15,267
N_L_234_M_62_W	\$8,776	\$0	\$193	\$500	\$112	\$430	\$0	\$0	-\$3	\$0	\$0	\$15,106
O_L_294_E_62_W	\$8,290	\$0	\$158	\$0	-\$3	\$0	\$0	\$0	\$41	\$0	\$0	\$15,250

**Figure 42: Annual operating cost savings by use**

● Heating ● Cooling ● Domestic Hot Water ● Cooking

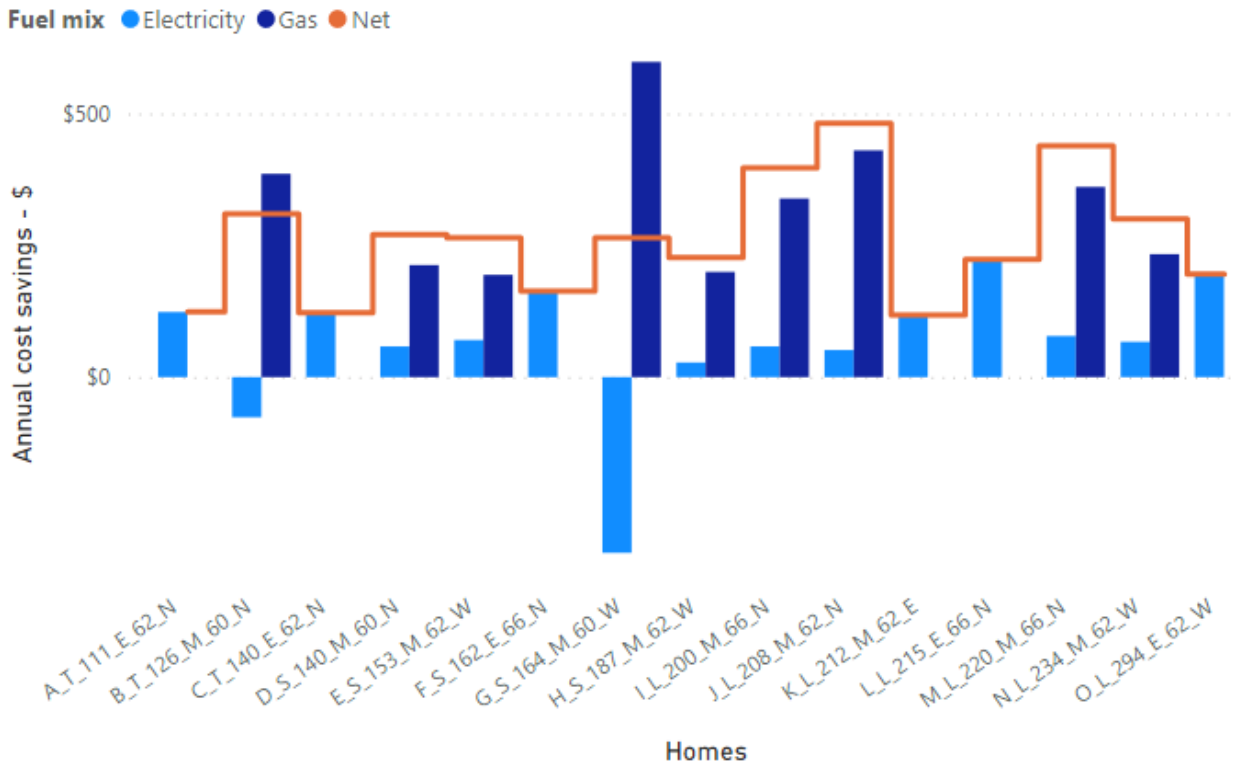


## Fuel mix contribution and energy efficiency

For energy efficiency measures, the results show that natural gas cost savings are greater than electricity cost savings in every home that has both (Figure 43).

Home B and G show an overall cost saving while having a loss on electricity costs. This is due to the BAU homes having gas heating and the ZNC homes having electric heating. The increased electricity costs are compensated by gas savings.

Figure 43: Annual operating cost savings by home and fuel type



### 13. GHG emission reduction by feature

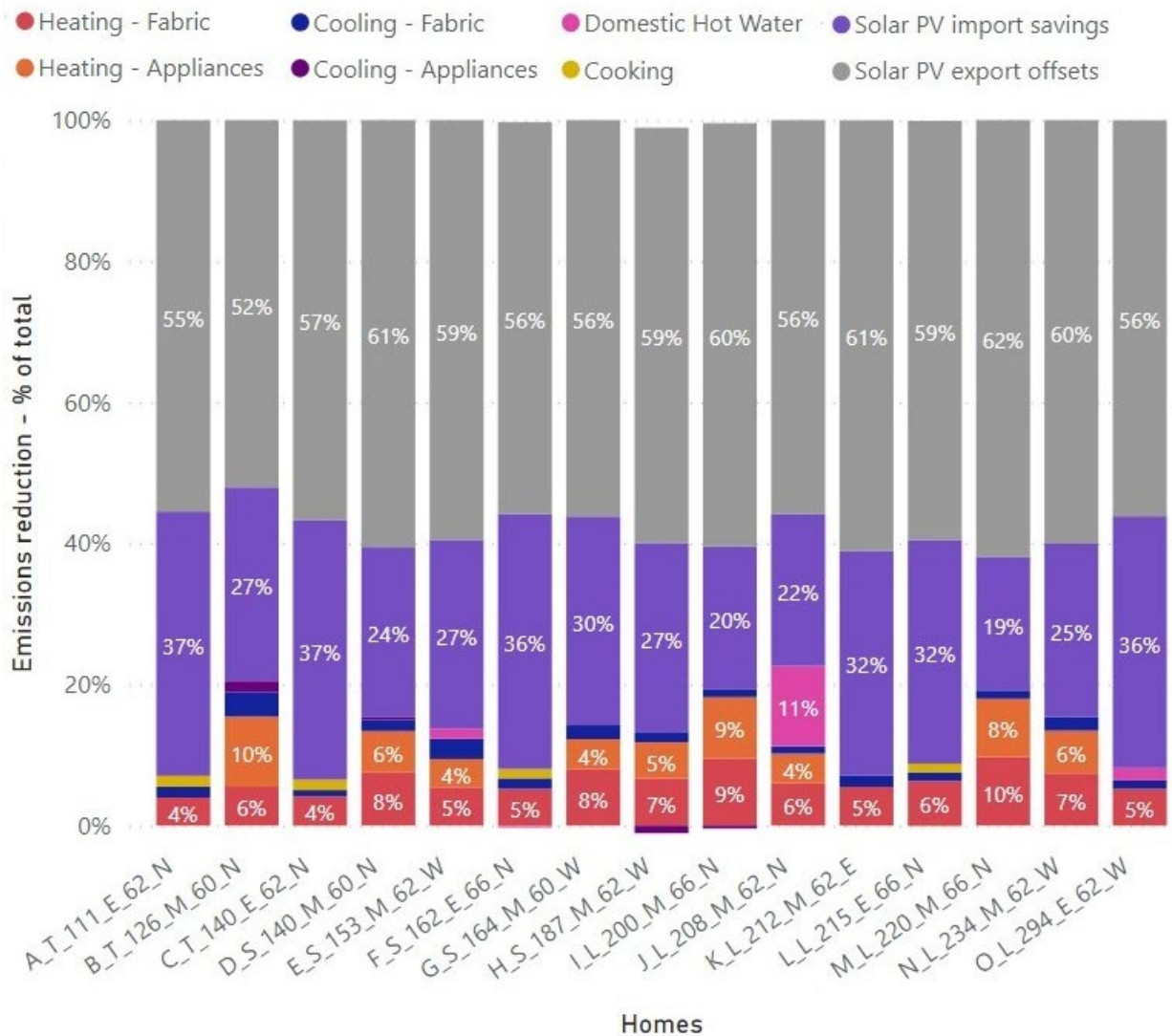
Similar to cost savings (section 12), the impact of specific features on GHG emissions reduction were split into thermal envelope, appliances and solar PV.

The reductions associated with adding the solar PV systems accounted for over 75% of total GHG emission reduction for every home. Solar PV export offsets were over half of emissions reduction for all homes.

Emissions abated from on-site consumption of solar PV generation were over 30% for all electric homes and one mixed fuel home.

Improvements to building envelope and heating appliances contributed 6.5% to 24%.

Figure 44: Annual emissions reduction split by improvement type



Energy efficiency improvements Annual emissions from energy efficiency improvements were reduced for all homes. Energy efficiency improvements reduced annual emissions between 0.3 and 1.6 tCo2-e with an average of a 0.8 tCo2-e reduction.

Figure 45: Annual emissions of BAU and ZNC homes – solar PV not included

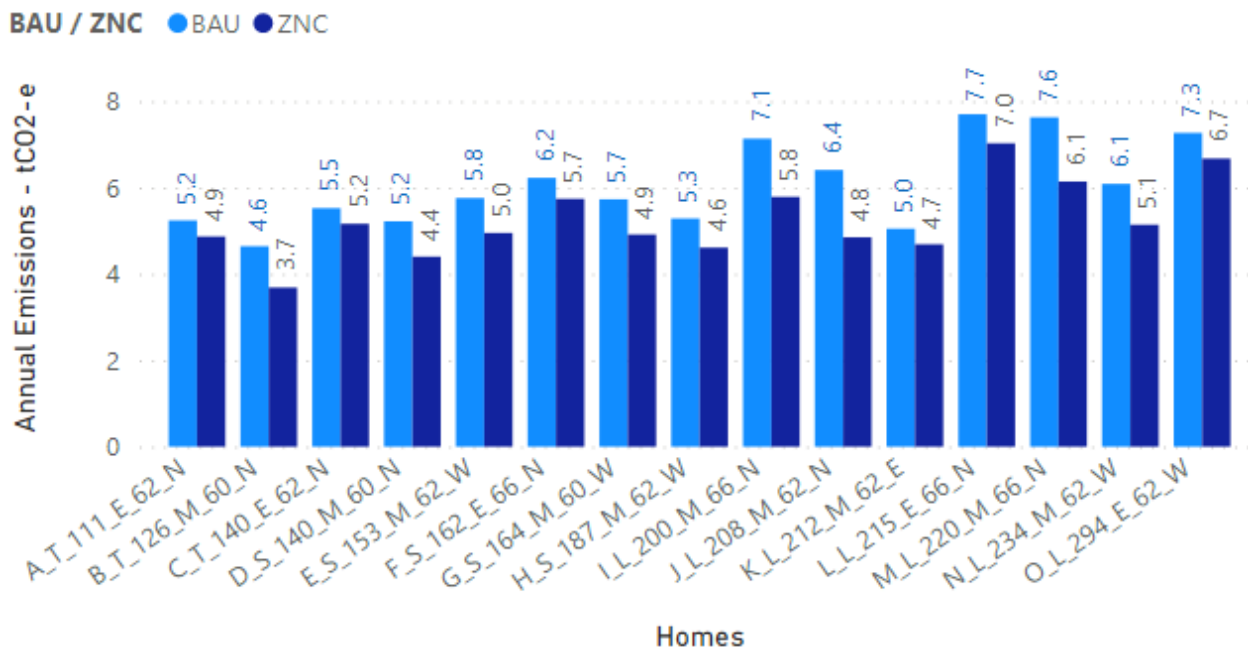
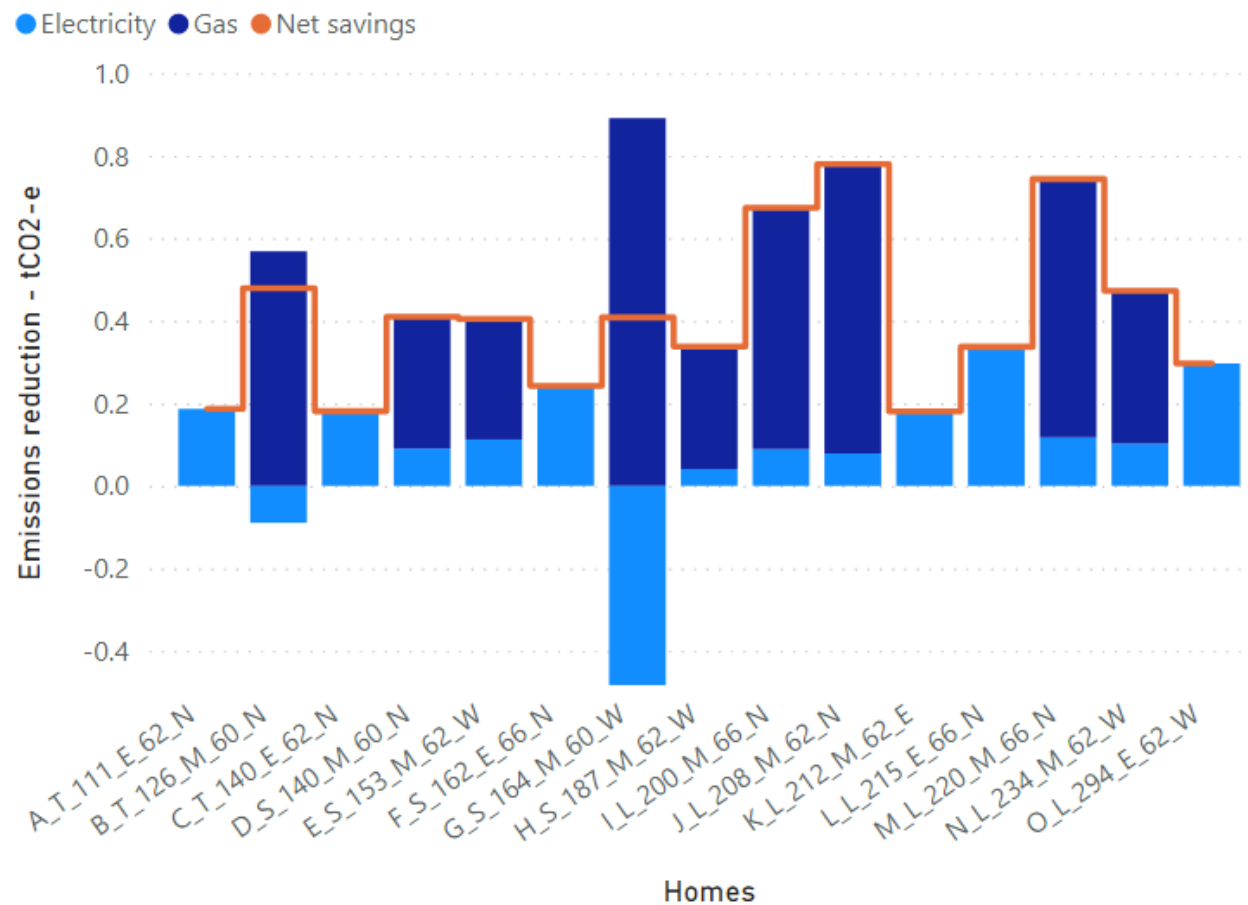


Figure 46: Annual emissions reduction per home – energy efficiency

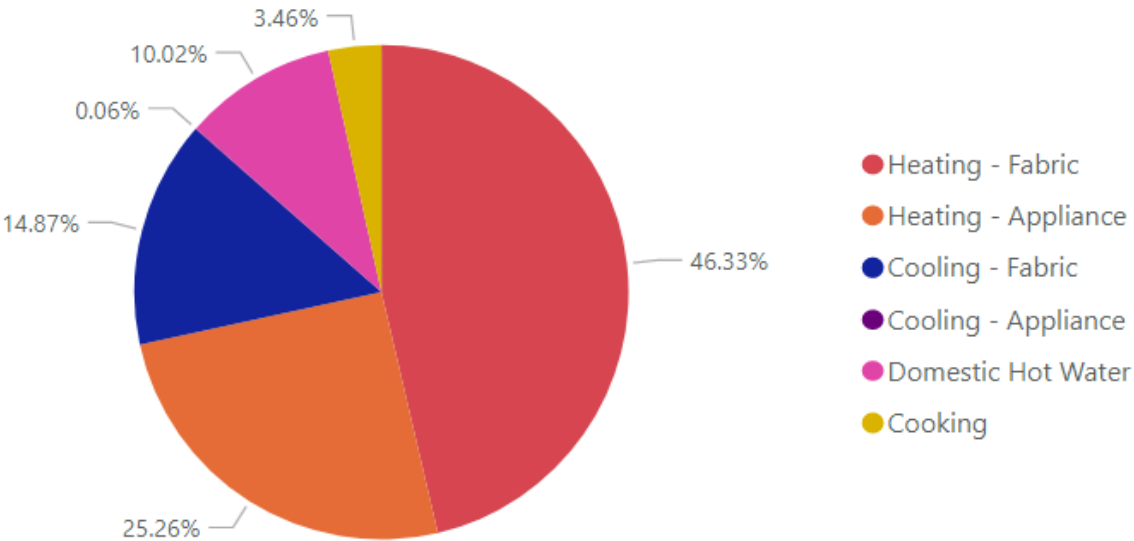


For energy efficiency measures, the results show that natural gas emissions reductions are greater than electricity emissions reductions in every home that has both (Figure 46).

Home B and G show an overall emissions reduction while having an increase in electricity related emissions. This is due to the BAU homes having gas heating and the ZNC homes having electric heating. The increased electricity emissions are compensated by gas emission reductions.

Related to efficiency measures, the greatest reduction was thermal envelope improvements impact on heating ranging from 26% to 82% with an average of ~46% (Figure 47). Heating related improvements were 71% of energy efficiency related emissions reductions. Cooling appliance changes averaged out as being negligible across the homes.

Figure 47: Annual emissions savings from efficiency



## 14. Energy reduction by feature

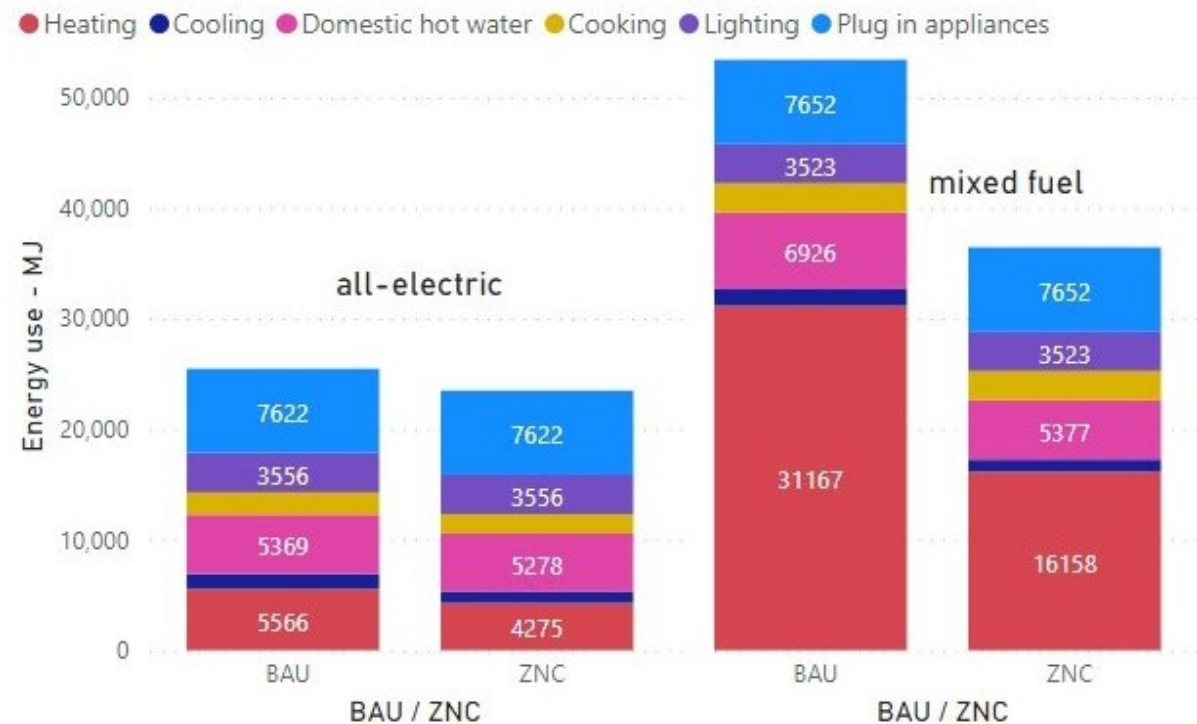
The impact of specific features on energy reduction were also split into thermal envelope, appliances and solar PV.

Mixed fuel homes had an average of 40% lower annual electricity use than all electric homes (Figure 48). Mixed fuel ZNC homes had an average of 50% higher annual energy use and mixed fuel BAU homes had more than double that of all electric. The higher energy use of mixed fuel homes related to gas ducted heating.

Figure 48: Average annual energy consumption by fuel mix – BAU and ZNC



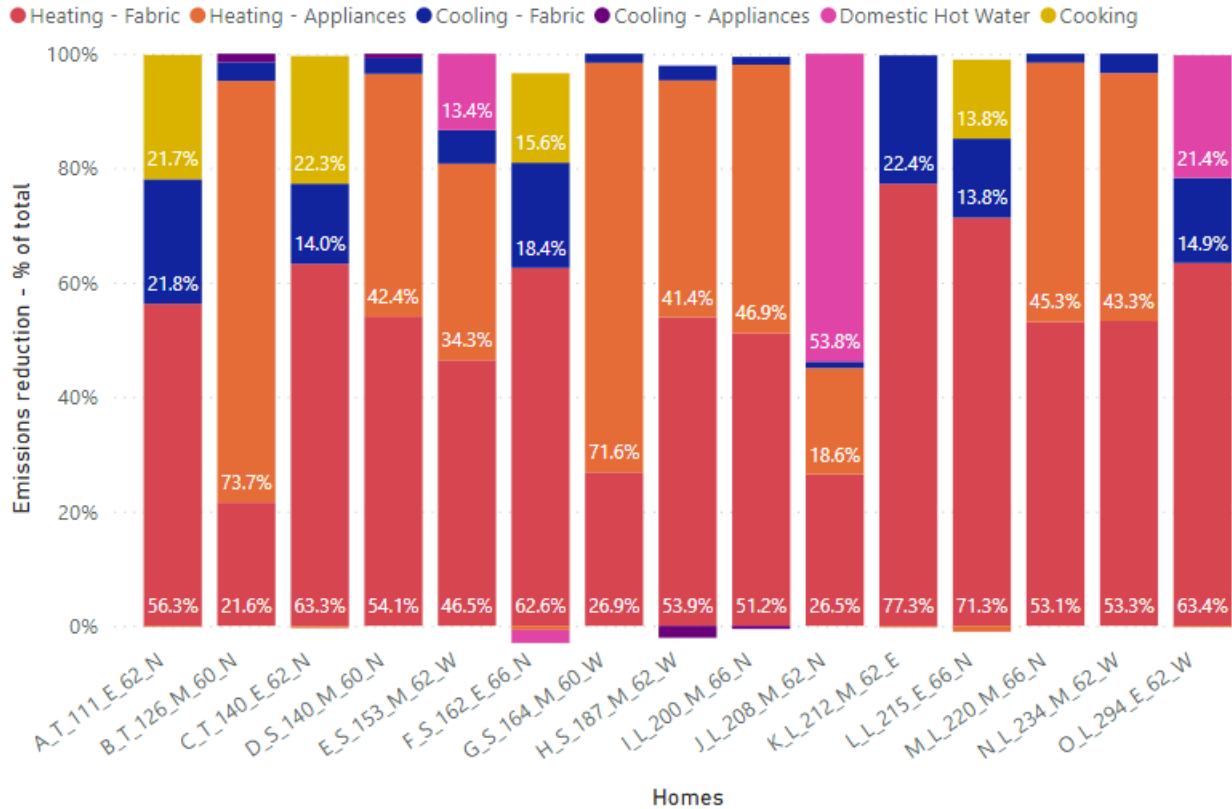
Figure 49: Average annual energy consumption by end use and fuel mix – BAU and ZNC



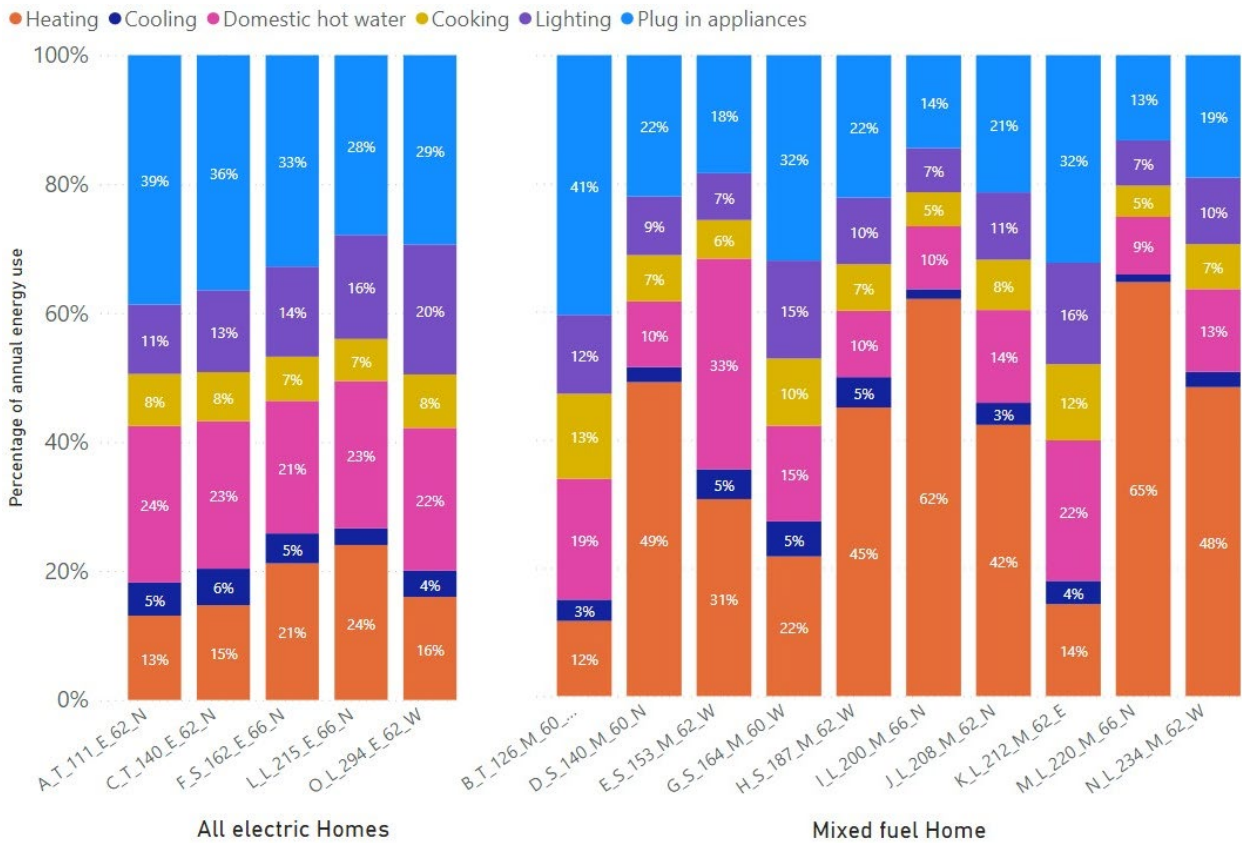
Related to efficiency measures, the greatest reduction was heating appliance improvements at 45%, followed by building envelope improvements impact on heating at 42% (Figure 50). Heating related improvements accounted for 87% of energy efficiency related energy reductions. Cooling appliance changes averaged out as being negligible across the homes.

This correlates well with the improvement to hours outside comfortable temperatures discussed in section 9. A much greater reduction in too-cold hours is shown compared to the reduction in too-hot hours.

Figure 50: Annual energy reduction by improvement type

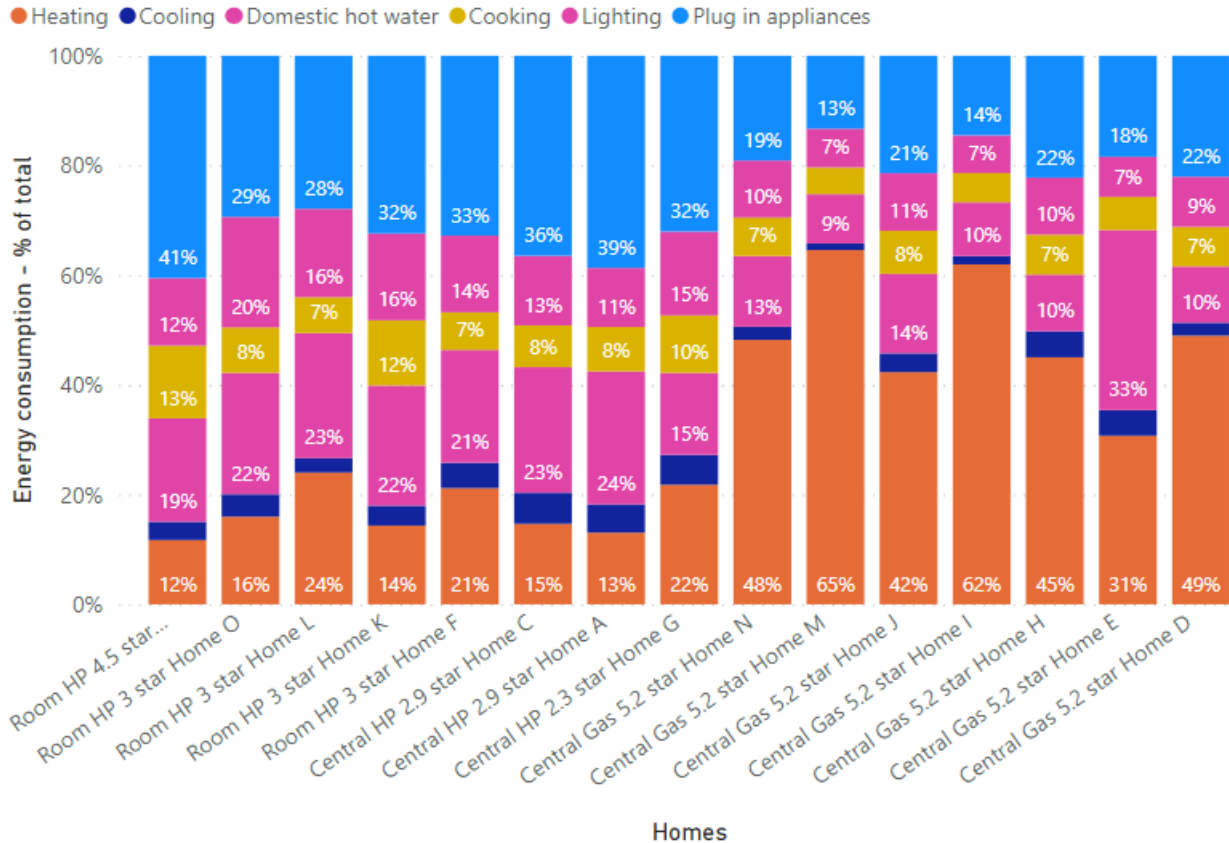


**Figure 51: Annual energy consumption of ZNC by end use**



In mixed fuel homes, gas heating was the main energy user when specified, other than Home E which had gas instantaneous hot water as the highest energy user. Plug-in appliances and hot water were commonly the next largest energy users.

**Figure 52: Annual energy consumption of ZNC by end use and heating type**



For homes with reverse cycle heating, plug-in appliances become the largest energy use, between 28% to 41% of the total. While plug-in appliances currently fall outside the scope of ZNC Homes program specification requirements, careful consideration should be given to them and their increasing importance in delivering zero net carbon homes.

## 15. Net energy to 2050

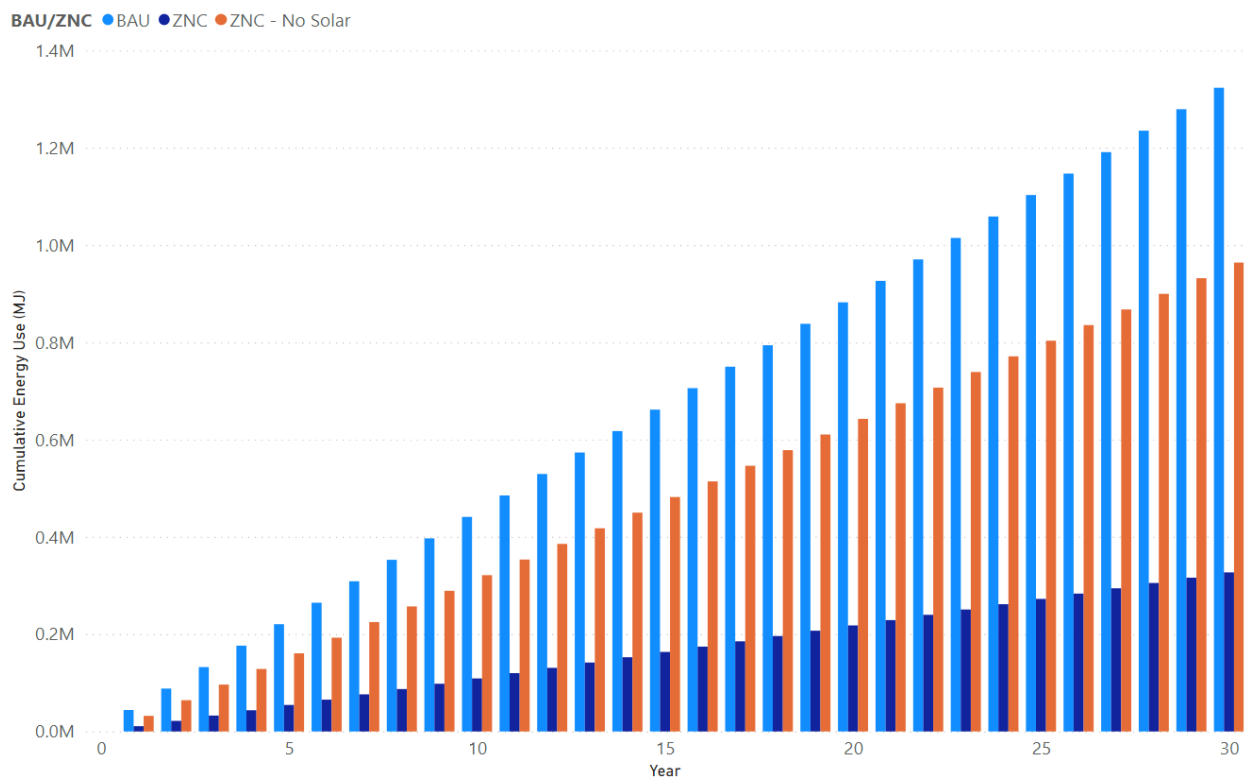
Cumulative energy use for the average 6 star home built in 2020 was compared with the average 7 star ZNC home over a 30 year period.

This shows the large impact that an annual saving has when that saving is realised year on year. After 30 years, cumulative energy use for the average 7 star ZNC home is around 1,000 GJ lower than for the average 6 star BAU home.

Reduced energy demand has a number of benefits beyond reduced greenhouse emissions, including reduced demand on the grid and investment in associated infrastructure (including, importantly - peak demand / peaking power plants), and flow on effects from this including downward pressure on prices.

Burning of fossil fuels, whether that is at large power stations or within the home (e.g. gas cooking) is linked with adverse health outcomes<sup>9,10</sup>. Therefore, reducing overall demand on fossil fuels will reduce the risk of their adverse health outcomes.

**Figure 53: Cumulative Net Energy Use over 30 years, 6 star BAU compared with 7 star ZNC home**



<sup>9</sup> Respiratory Symptoms in Children and Indoor Exposure to Nitrogen Dioxide and Gas Stoves; Garrett, Hooper, Hooper and Abramson; American Journal of Respiratory and Critical Care Medicine 1997; 158 (3).

<sup>10</sup> Damp housing, gas stoves, and the burden of childhood asthma in Australia; Knibbs, Woldeyohannes, Marks and Cowie; Medical Journal of Australia 2018; 208 (7)

**Figure 54: Cumulative net energy use (GJ) over 30 years, 6 star BAU compared with 7 star ZNC home**

	YEAR 5	YEAR 10	YEAR 20	YEAR 30
6 STAR BAU	220.5	441.0	882.1	1,323.2
7 STAR ZNC	54.5	109.0	218.0	327.0

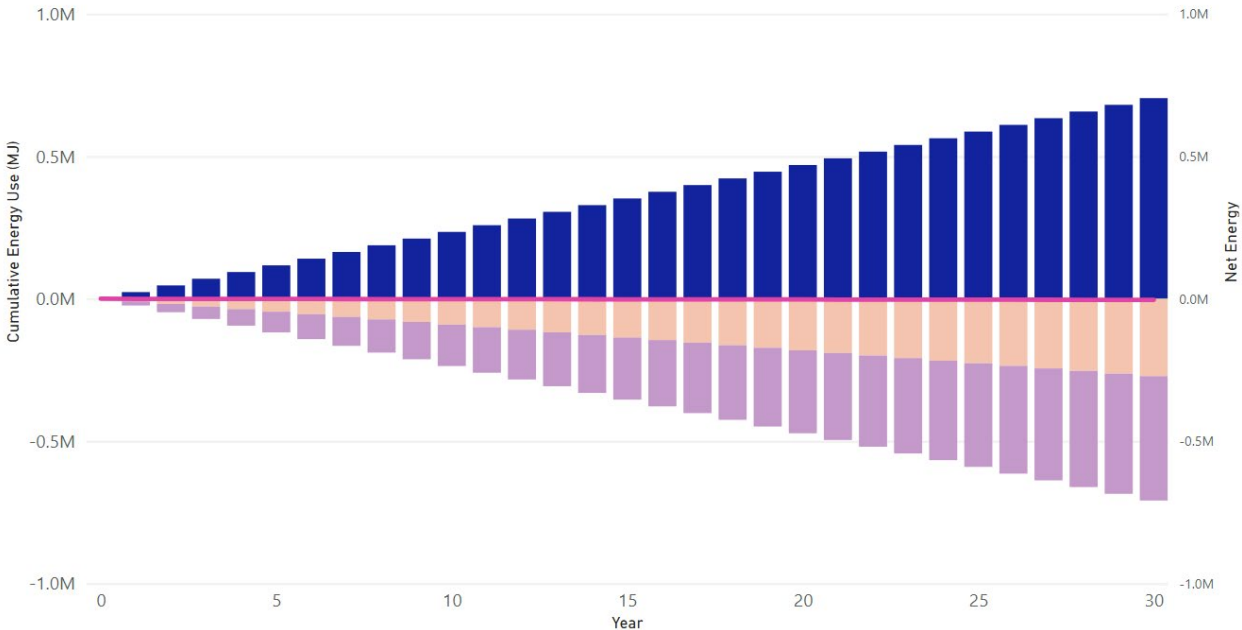
If we consider the detail here for the average 7 star ZNC home (Figure 53), we can see the lower average electricity and gas usage compared with the average 6 star home - due to building fabric and appliance efficiency improvements. We can also see the impact of solar – both on-site usage and export to the grid. Net energy is made up of electricity and gas usage minus solar PV used on-site, minus solar PV exported to the grid. Each of these elements is shown in the stacked column, with the solar PV figures represented in the negative. Cumulative net energy is the line graph.

The contribution of building fabric and appliance efficiency is represented by the difference between the light blue and orange bars on the chart; less electricity and gas usage is observed for the 7 star ZNC home. In addition, the solar PV is then subtracted to arrive at the net energy result.

The net energy, represented by the pink line, is flat (at zero) for all electric homes (Figure 55). These home achieve both zero net carbon and zero net energy. The mixed fuel homes achieve zero net carbon but would need a large solar pv system to achieve zero net energy (Figure 56).

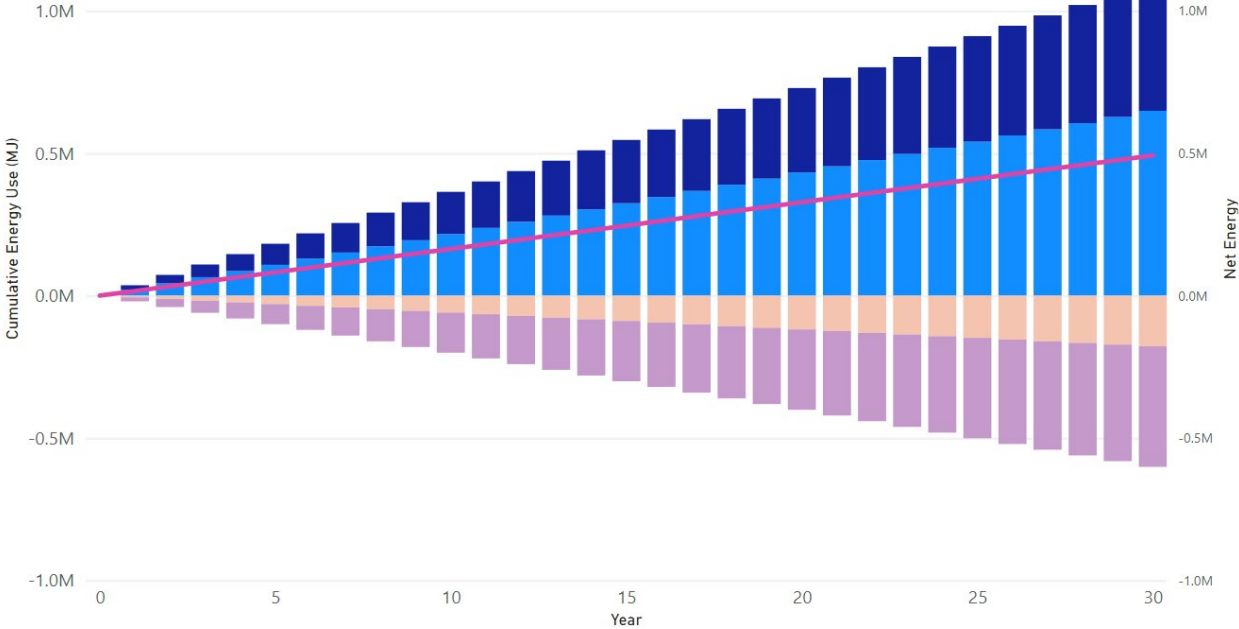
**Figure 55: Cumulative net energy ZNC to 2050 – Average of All Electric Homes**

● Energy Use - Gas ● Energy Use - Electricity ● Solar PV export ● Solar PV usage on site ● Net Energy



**Figure 56: Cumulative net energy ZNC to 2050 – Average of Mixed Fuel Homes**

● Energy Use - Gas ● Energy Use - Electricity ● Solar PV export ● Solar PV usage on site ● Net Energy



## 16. Operational energy costs to 2050

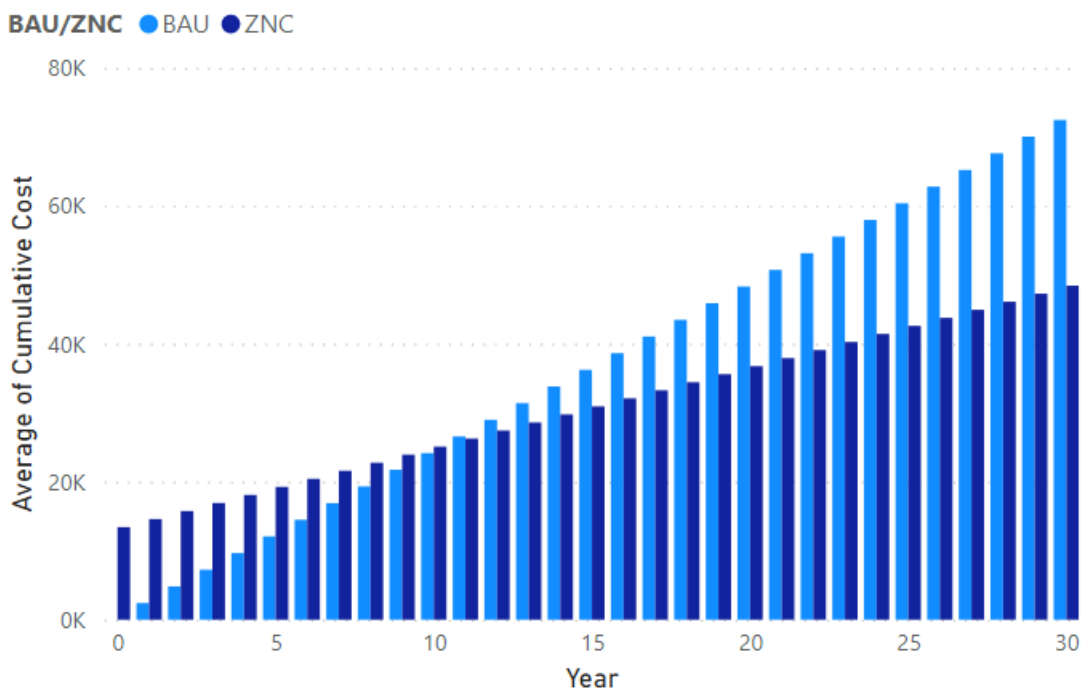
The costs associated with a 6 star home built in 2020 were compared with a 7 star ZNC home over a 30 year period, using the tariffs as detailed in the methodology.

Tariffs were assumed constant over the 30 year period.

The analysis shows an average simple payback period of between 10 and 11 years. This is the time taken for the initial investment in improvements to achieve 7 star ZNC to be recouped via energy cost savings. This can be seen in the graph at the point where the cumulative cost of the BAU home exceeds the ZNC home.

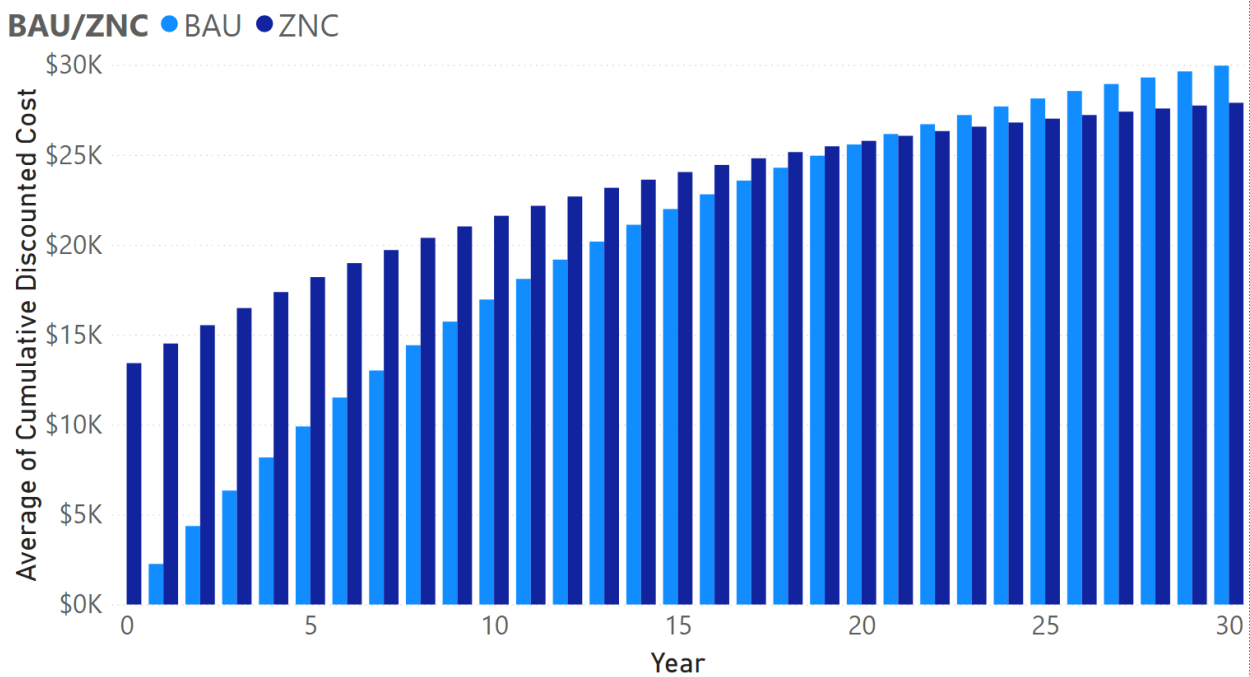
For each subsequent year over the analysis period, the average 7 star ZNC home demonstrates a net saving over the 6 star home. The average net saving after 30 years is \$26,239.

Figure 57: Cumulative Cost over 30 years, 6 star BAU compared with 7 star ZNC home



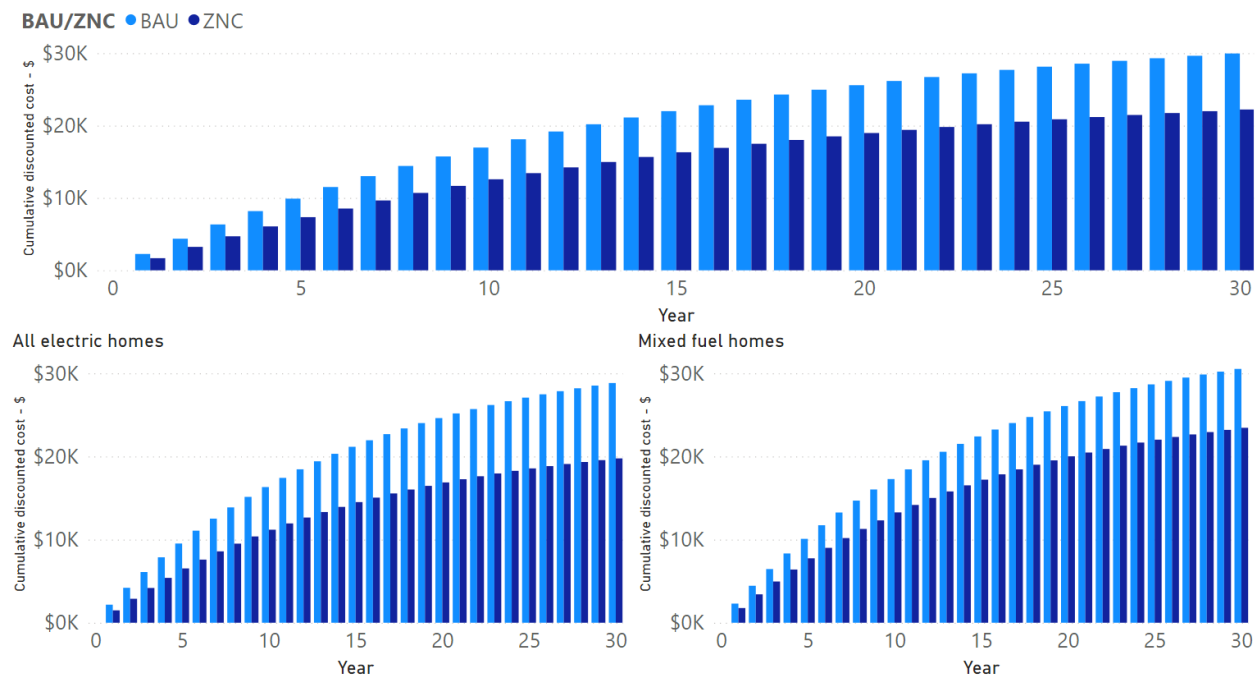
The analysis was repeated with a discount rate of 7% included. It shows an average discounted payback period of between 20 and 21 years. The average net saving after 30 years is \$2064.

**Figure 58: Cumulative Discounted Cost over 30 years, 6 star BAU compared with 7 star ZNC home**



When the improvement costs are included on the mortgage, all 7 star ZNC homes demonstrate a net saving over the 6 star home in the first year. The analysis used a 7% discount rate and 2.48%<sup>11</sup> mortgage over 30 years (see section 6).

**Figure 59: Cumulative Discounted Cost, with ZNC improvements mortgaged over 30 years, 6 star BAU compared with 7 star ZNC home**



<sup>11</sup> moneysmart.gov.au - accessed 1 March 2021

An average discounted saving of \$7,742 was shown, with all electric homes realising higher average savings of \$9,064.

All electric ZNC homes showed an average 15.7% lower cumulative discounted cost over 30 years with improvement costs mortgaged than mixed fuel ZNC homes.

Energy costs are assumed constant over the analysis period due to limited price forecasting availability. Some broad factors expected to influence electricity prices over the coming decade and beyond include the mix of generation capacity including closure of old coal-fired power stations, the proportion of renewable generation into the grid (which has lower marginal generation costs compared with traditional generation), and supply factors including potential increases in demand due to electric vehicle uptake and fuel switching from gas to electricity.

Were electricity tariffs to reduce or natural gas tariffs to rise, the cumulative cost differential between all electric ZNC would increase compared to mixed fuel homes. An example of a 10% increase in the natural gas tariff was modelled. This raised the difference in discounted cost over 30 years with improvement costs mortgaged to 17.5% (up from 15.7%).

## 17. GHG emissions to 2050

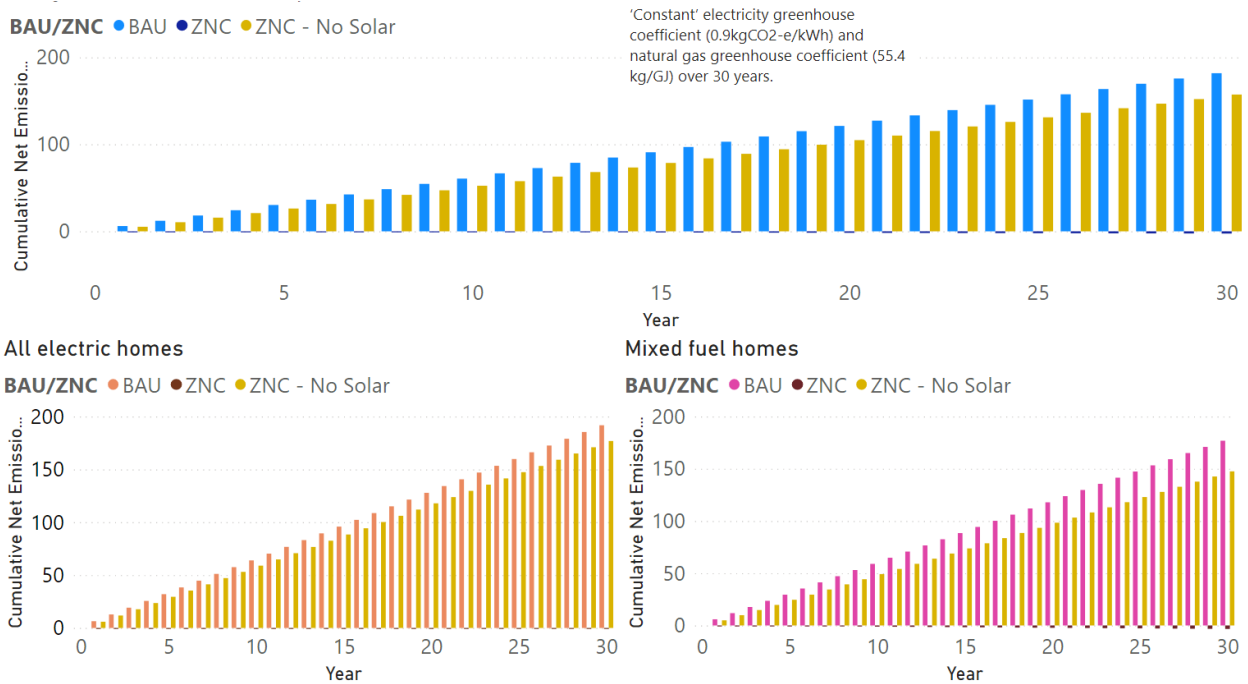
This section considers cumulative greenhouse emissions for the 6 star BAU home compared with the 7 star ZNC home, and the marginal cost of abatement each year over a 30 year period.

Cumulative greenhouse emissions are modelled under three grid emission intensity scenarios:

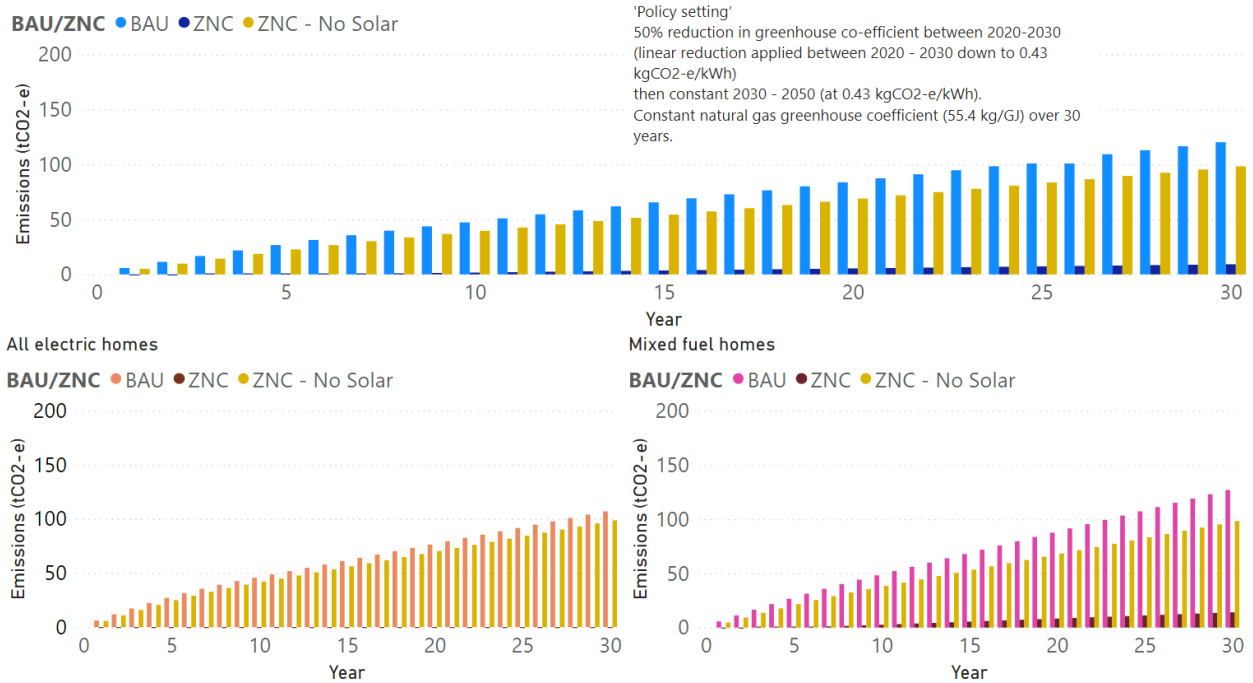
- 'Constant' electricity greenhouse coefficient (0.9kgCO<sub>2</sub>-e/kWh) over 30 years.
- 'Policy setting' - 50% reduction in greenhouse co-efficient between 2020-2030 (linear reduction applied between 2020 - 2030), then constant to 2050.
- 'Policy setting + 2050 zero' - 50% reduction in greenhouse co-efficient between 2020-2030 (linear reduction applied between 2020 - 2030), then 100% reduction between 2030 - 2050). Zero grid electricity greenhouse co-efficient in 2050.

Under all scenarios, the impact of a ZNC program today is stark – emission savings locked into homes today have significant cumulative benefit over future decades.

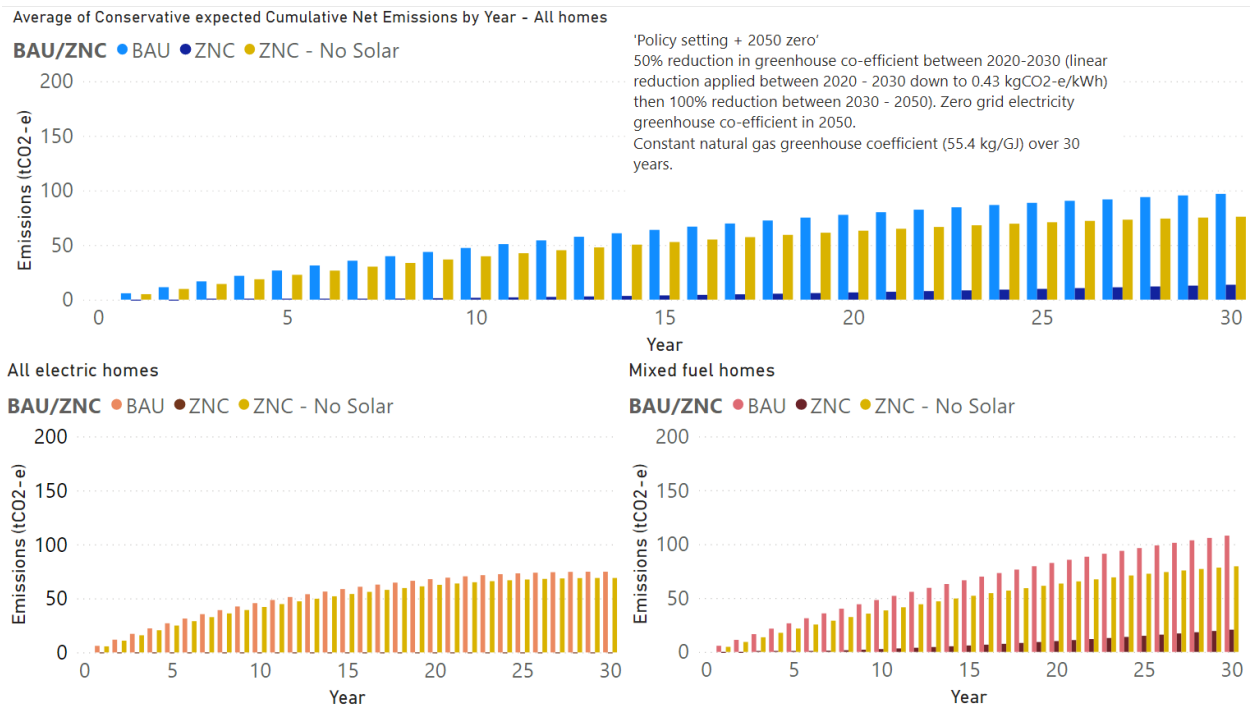
**Figure 60: Cumulative Greenhouse Emissions ('Constant ghg coefficient') for 6 star BAU compared to 7 star ZNC – all homes (blue), all electric only (orange) and mixed fuel only (pink)**



**Figure 61: Cumulative Greenhouse Emissions ('Policy Setting coefficient') for 6 star BAU compared to 7 star ZNC - all homes (blue), all electric only (orange) and mixed fuel only (pink)**



**Figure 62: Cumulative Greenhouse Emissions ('Policy Setting + 2050 zero coefficient') for 6 star BAU compared to 7 star ZNC - all homes (blue), all electric only (orange) and mixed fuel only (pink)**



The impact of a decarbonising electricity grid can be seen in the cumulative greenhouse emissions under 'Policy setting' and 'Policy setting + 2050 zero'.

**Figure 63: Cumulative greenhouse emissions by year and GHG coefficient scenario**

GHG COEFFICIENT SCENARIO	MODEL	YEAR 5	YEAR 10	YEAR 20	YEAR 30
CONSTANT	BAU	30.3	60.6	121.2	181.8
	ZNC - No Solar	26.2	52.4	104.9	157.3
POLICY SETTING	BAU	26.7	47.3	83.8	120.2
	ZNC - No Solar	22.7	39.7	69.0	98.3
POLICY SETTING + 2050 ZERO	BAU	26.7	47.3	77.7	96.9
	ZNC - No Solar	22.7	39.7	63.1	76.0

- The effect of a decarbonising grid has a significant impact on the average home's greenhouse emissions. The 'Policy Setting' scenario will contribute to an approximate 35% reduction in cumulative emissions over the next 30 years compared with the greenhouse coefficient remaining constant. Under a 'Policy setting + 2050 zero' scenario, the reduction in cumulative emissions is 47%.
- While a decarbonising grid has a large effect on cumulative emissions over 30 years, cumulative emissions remain significant across the lifecycle of 6 star homes built today under all three greenhouse co-efficient scenarios.
- All electric ZNC homes deliver 100% emissions savings for the entire 30 years.
- For mixed fuel ZNC homes in a decarbonising grid, the solar PV size to meet ZNC in 2020 is not sufficient to meet ZNC in later years. See section 8 for more discussion on how solar PV size required to meet ZNC is related to the electricity greenhouse co-efficient for mixed fuel homes.

Marginal cost of abatement for the 7 star ZNC homes was also modelled under these three scenarios. In this analysis, marginal cost of abatement refers to the cumulative abatement realised each year divided by the initial improvement costs made in Year 0.

As discussed in other sections of this report, the average payback period is between 10 and 11 years when improvement costs are not mortgaged (under the ZNC tool greenhouse co-efficient) - in this chart this is represented by the point where the marginal cost of abatement equals zero. This is consistent for each of the three modelled greenhouse co-efficient scenarios. Likewise, the point at which the marginal cost equals \$20/tCO<sub>2</sub>-e is Year 9 for all scenarios.

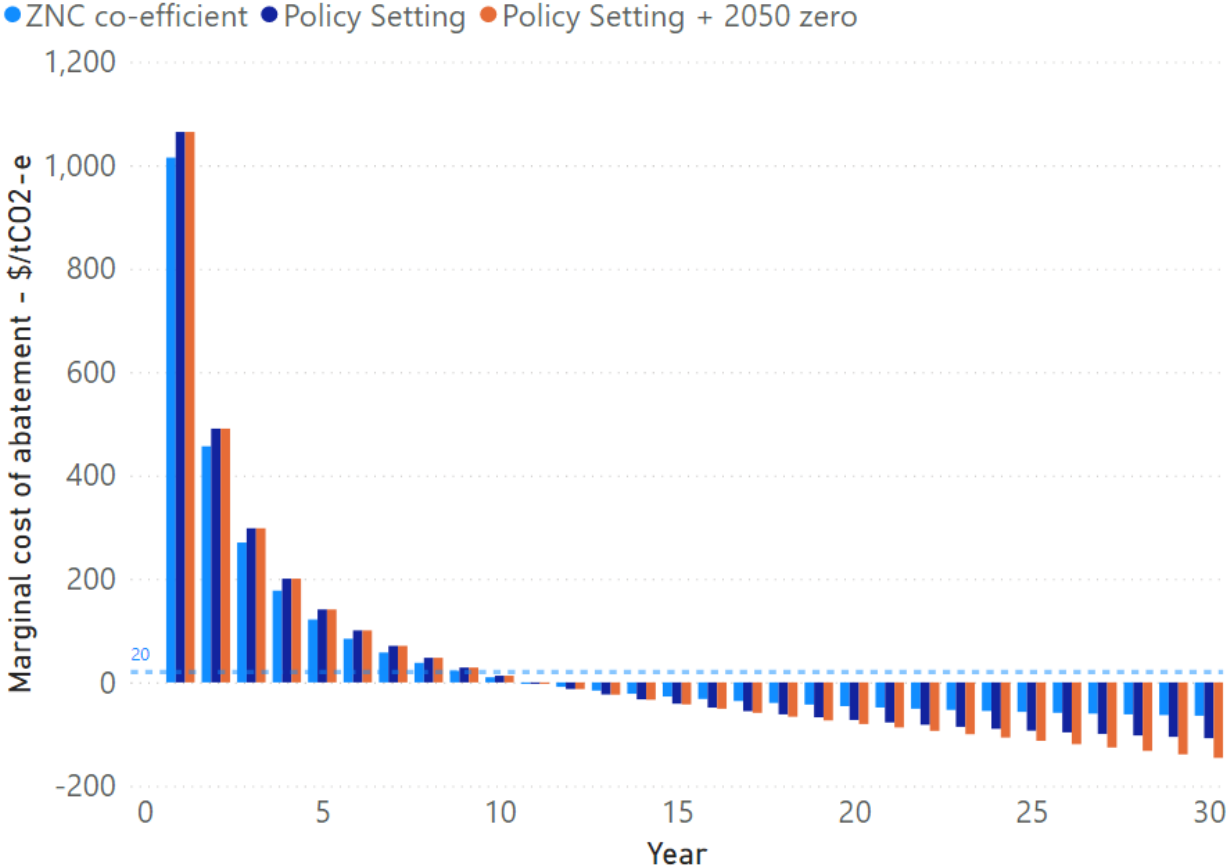
It can be seen in the two scenarios where the grid is decarbonising ('Policy Setting' and 'Policy Setting + 2050 zero'), the magnitude of the marginal cost is larger than the base case, in both the positive and negative directions.

This makes sense; before the break even point, where annual abatement is reducing year on year, the cost per tonne becomes higher than where the abatement is consistent each year. Similarly, after the break even point, where the abatement cost

becomes negative, the negative cost divided by a smaller abatement amount yields a larger negative cost per tonne.

It should be noted, that as shown in section 11

Figure 64: Marginal cost of abatement (improvements not mortgaged) for three ghg co-efficients



# Areas for Further Research

The results from the modelling and analysis provide a broad understanding of the benefits of zero net carbon homes. The homes and the modelling present ongoing opportunities for improving our understanding of these homes, improving the modelling, further dissecting of the data generated and for providing data for precinct, suburb and state scale extrapolation for future program and policy setting.

Opportunities related to further analysis of the dataset generated in the project include:

1. ZNC homes are more comfortable, however, further work is warranted on thermal comfort impacts for homes as a whole and for different room types and uses. Reducing heat and cold stress for climate resilience should also be considered. This could be advanced through expanding the analysis related to thermal comfort impacts of building envelope improvements to include day/night split and to include heat and cold stress mitigation. This could include analysis of number of continuous hours or days above or below threshold temperatures. Situations known to increase risks to health and of morbidity.
2. The relative impact of individual building envelope and appliance choices could be further examined to determine predictive simplified modelling for earlier design decision making. Additional models would strengthen this.
3. Increasing the breakdown of the demand profiles including peak demand to isolate key design decisions for policy setting and building and system design.

Opportunities for further modelling and analysis of the homes already modelled and of future ZNC homes:

4. A finer grain sensitivity analysis on the impact of various greenhouse intensities on Solar PV sizing and on greenhouse and cost savings. This would improve understanding of how ZNC homes relate to and would be affected by the planned reduction in electricity grid greenhouse intensity. This would assist in determining climate change pledges for the building and energy sectors.
5. When a clearer trajectory of the greenhouse intensity of the electricity grid and the distributed gas network are formalised, remodelling to confirm or amend the results of this report would improve understanding and acceptance.
6. Sensitivity analysis of a broader range of heating, cooling, hot water and lighting types and efficiencies.
7. The impact of home batteries on the costs and demand curves warrants analysis. This was noted as a potential scope item at the start of this project, though was not able to be included.
8. With the increase in prevalence and the planned further uptake of electric vehicles, further modelling with inclusion of these as demand only (an energy user) and modelled with bi-directional charging capacity (energy user and energy storage) would provide assistance in decision making for future proofing.
9. The relative importance of plug-in appliances increases with improvements to other design decisions and for all-electric homes. Plug-in appliances were kept constant in this study. Sensitivity analysis of these in relation to predicted operational energy, carbon and Solar PV sizing could inform ongoing policy setting and modelling adjustments.

10. Modelling in climate zones in other states to show the outcomes likely if ZNC homes were built in those states. This would be partly delivered by 4 for the various network greenhouse intensities, however the impact on heating and cooling of diverse climate zones could be considered.

Real world testing:

11. The modelling assumptions in the ZNC tool include that use of heating, hot water and cooking all peak around 7am in winter. This has a significant impact on the winter peak demand as modelled. Further analysis of this assumption including comparison with metered data would assist in future winter peak demand modelling and forecasting.
12. Verifying the built outcomes through operational data would further strengthen the case for ZNC homes and assist in ongoing predictive modelling through reality checking built-in assumptions in the ZNC Homes tool.

## Conclusion

The research project had two key objectives:

1. to analyse the impact of building ZNC homes compared to current building standards
2. to inform decisions related to building design and construction towards ZNC homes e.g. relating to cost and benefit

The results from the modelling show that the ZNC homes program will deliver resource, financial, environmental and health benefits in the medium to long term.

Benefits of improving the building envelope and adding Solar PV systems compared to current building standards are clear. More analysis is recommended for the impacts of appliance choices.

The ZNC homes modelled were better than BAU on every measure included in the research: financial, environmental and social. The case for continued realisation of these benefits through regulation and incentives is clear.

Cumulative impacts of ZNC homes for climate change mitigation is a big opportunity given emissions reductions of 75+ tonnes per home to 2050.

Solar PV showed as providing the largest savings for cost and emissions. However, Solar PV is not the whole solution. The longevity of the building shell, heating, cooling and hot water systems and occupant health should be considered.

As the electricity network greenhouse intensity decreases (the decarbonising grid scenario), all electric homes continue to deliver as zero net carbon. This is less clear for mixed fuel homes as the ratios of electricity to natural gas ghg coefficients impact solar PV offsets. Regulation or incentives to deliver all electric homes would provide higher surety of the long term delivery of zero net carbon homes.

Collated into 16 short facts, the study found that:

1. ZNCH program homes are well orientated for their design
2. Insulation and glazing delivered 7 star NatHERS

3. Big homes need more solar
4. Fabric + solar PV = 90% of improvement cost
5. ZNC homes don't cost the earth
6. ZNC homes give savings from day dot
7. There is plenty of roof
8. Grid emissions intensity matters when using gas
9. ZNC homes are more comfortable
10. ZNC homes help pay your mortgage
11. Heating improvements and solar PV deliver 80% to 99% of savings
12. Solar PV provides 80%+ of emissions reduction
13. Gas heating is big, plug in appliances are growing their share
14. ZNC homes help pay your mortgage
15. ZNC homes save 75 tonnes plus to 2050

The Zero Net Carbon Homes program has been shown to deliver clear benefits compared to BAU across all of the measures included in this study. ZNC homes could make a significant contribution to achieving Victorian climate change and housing affordability targets.

The results indicate that the success of the ZNC homes program should be built on through policy and programs to accelerate delivery of more homes with a view to ZNC homes becoming to new BAU.

# Appendix A

Summary letter by Filter ESD (Erika Bartak) dated 3 September 2020 to Inge Sarunic of Zero Net Carbon Homes Program at Sustainability Victoria.

Re: Zero Net Carbon Homes Program – House Energy Rating Services  
6 Star 'Business as Usual' (BAU) & 7 Star NatHERS files

# Appendix B

Further to section 1, the following NatHERS orientation sensitivity analysis results include the NatHERS modelled star ratings for all the modelled homes for every 45 degree orientation.

Figure 65: NatHERS star rating by orientation BAU

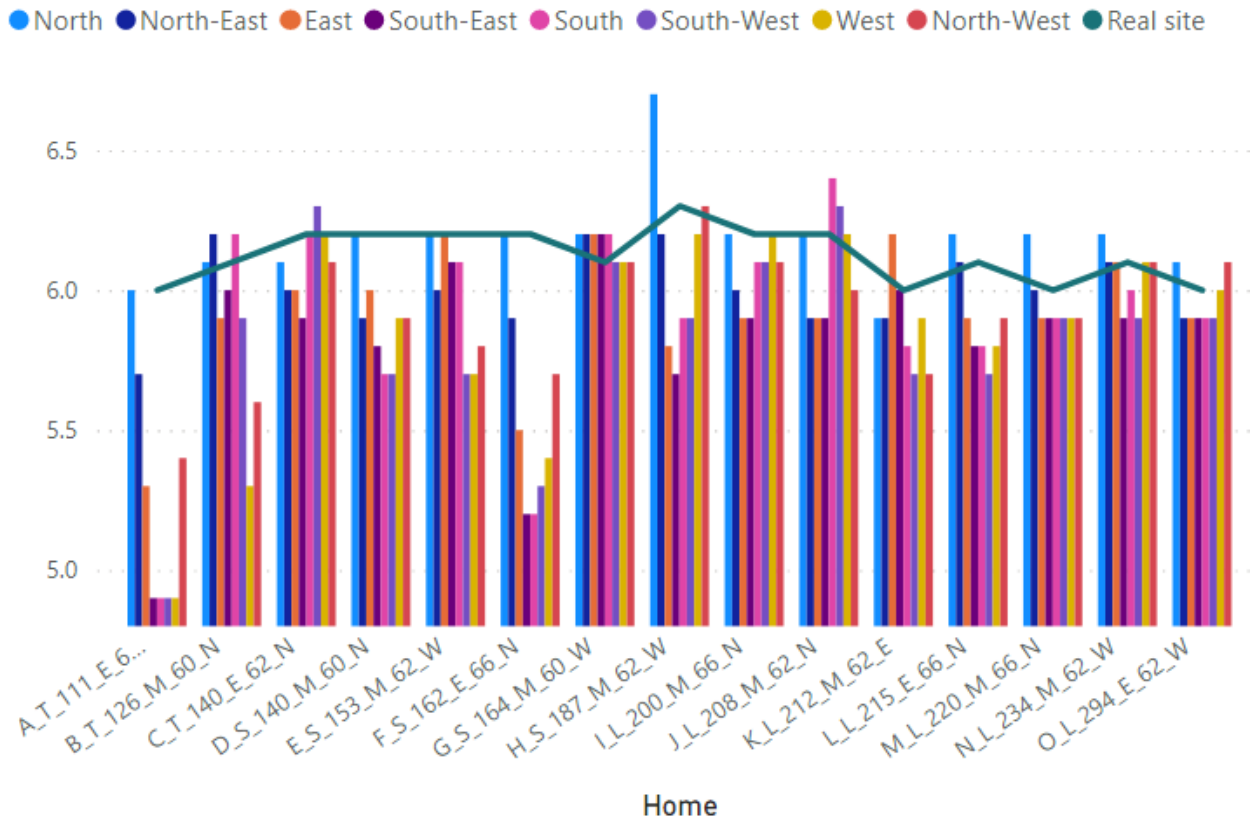
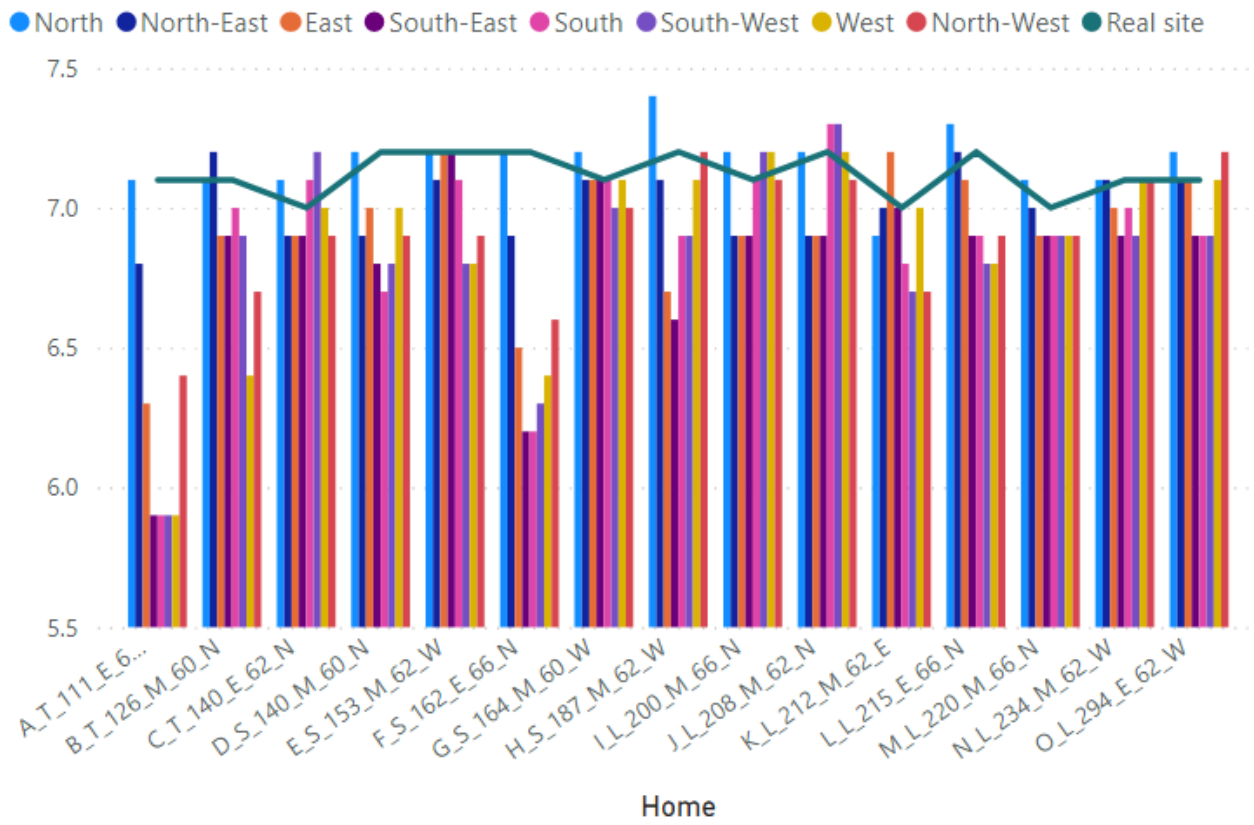


Figure 66: NatHERS star rating by orientation ZNC



# Appendix C

## Detailed Homes Information

### Home A

Reference	A_T_111_E_62_N
Typology	Townhouse
Area (sqm)	111
Fuel Mix	All Electric
Climate Zone	62
Primary Solar PV orientation	North
BAU NatHERS rating	6
ZNC NatHERS rating	7.1

Building Fabric	Improvement to meet 7 star
Insulation - roof	-
Insulation - external wall	-
Insulation - internal garage wall	R1
Insulation - internal bath/laundry wall	R2.5
Roof sarking	-
Glazing - kitchen/living	argon-filled double
Glazing - other rooms	argon-filled double
Other	-

Appliances	BAU	Improved Case
Heating - living	Central Heat Pump - 2.9 star	Central Heat Pump - 2.9 star
Heating - non-living	Central Heat Pump - 2.9 star	Central Heat Pump - 2.9 star
Cooling - living	Central Heat Pump - 2.1 star	Central Heat Pump - 2.1 star
Cooling - non-living	Central Heat Pump - 2.1 star	Central Heat Pump - 2.1 star
Hot Water	Heat Pump	Heat Pump
Cooktop	Electric	Induction
Oven	Electric	Electric

### Home B

Reference	B_T_126_M_60_N
Typology	Townhouse
Area (sqm)	126
Fuel Mix	Mixed Fuel
Climate Zone	60
Primary Solar PV orientation	North
BAU NatHERS rating	6.1
ZNC NatHERS rating	7.1

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	R1.3
Insulation - external wall	R0.5
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	-
Roof sarking	-
Glazing - kitchen/living	argon, low-e
Glazing - other rooms	argon filled, low-e double
Other	Retractable horizontal awning (1.5m) to main Living wall / glazing (north)

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Gas - 3 star	Room Heat Pump - 4.5 star
Heating - non-living	Central Gas - 3 star	Room Heat Pump - 4.5 star
Cooling - living	Central Heat Pump - 2.7 star	Room Heat Pump - 4.5 star
Cooling - non-living	Central Heat Pump - 2.7 star	Room Heat Pump - 4.5 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home C

Reference	C_T_140_E_62_N
Typology	Townhouse
Area (sqm)	140
Fuel Mix	All Electric
Climate Zone	62
Primary Solar PV orientation	North
BAU NatHERS rating	6.2
ZNC NatHERS rating	7

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	-
Insulation - external wall	R0.5
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	R0.5
Roof sarking	foil
Glazing - kitchen/living	low-e
Glazing - other rooms	argon-filled double
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Heat Pump - 2.9 star	Central Heat Pump - 2.9 star
Heating - non-living	Central Heat Pump - 2.9 star	Central Heat Pump - 2.9 star
Cooling - living	Central Heat Pump - 2.1 star	Central Heat Pump - 2.1 star
Cooling - non-living	Central Heat Pump - 2.1 star	Central Heat Pump - 2.1 star
Hot Water	Heat Pump	Heat Pump
Cooktop	Electric	Induction
Oven	Electric	Electric

## Home D

Reference	D_S_140_M_60_N
Typology	Small detached
Area (sqm)	140
Fuel Mix	Mixed Fuel
Climate Zone	60
Primary Solar PV orientation	North
BAU NatHERS rating	6.2
ZNC NatHERS rating	7.2

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	R1.5
Insulation - external wall	R1.0
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	R1.5
Roof sarking	foil
Glazing - kitchen/living	air-filled double
Glazing - other rooms	-
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Room Heat Pump - 3.1 star	Room Heat Pump - 4 star
Cooling - non-living	Room Heat Pump - 3.1 star	Room Heat Pump - 4 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home E

Reference	E_S_153_M_62_W
Typology	Small detached

Area (sqm)	153
Fuel Mix	Mixed Fuel
Climate Zone	62
Primary Solar PV orientation	West
BAU NatHERS rating	6.2
ZNC NatHERS rating	7.2

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.5
Insulation - external wall	R1.0
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	R1.5
Roof sarking	foil
Glazing - kitchen/living	air-filled double
Glazing - other rooms	-
Other	-

Appliances	BAU	Improved Case
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Cooling - non-living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Hot Water	Gas Instantaneous	Gas Instantaneous
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home F

Reference	F_S_162_E_66_N
Typology	Small detached
Area (sqm)	162
Fuel Mix	All Electric
Climate Zone	66
Primary Solar PV orientation	North
BAU NatHERS rating	6.2
ZNC NatHERS rating	7.2

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.5
Insulation - external wall	R0.5
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	-
Roof sarking	-

Glazing - kitchen/living	air-filled double
Glazing - other rooms	-
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Heating - non-living	Room Heat Pump - 5 star	Room Heat Pump - 5 star
Cooling - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Cooling - non-living	Room Heat Pump - 6 star	Room Heat Pump - 6 star
Hot Water	Solar Electric	Heat Pump
Cooktop	Electric	Induction cooktop
Oven	Electric	Electric oven

## Home G

Reference	G_S_164_M_60_W
Typology	Small detached
Area (sqm)	164
Fuel Mix	Mixed Fuel
Climate Zone	60
Primary Solar PV orientation	West
BAU NatHERS rating	6.1
ZNC NatHERS rating	7.1

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	R1.0
Insulation - external wall	R0.5
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	R2.0
Roof sarking	foil
Glazing - kitchen/living	-
Glazing - other rooms	argon-filled double
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Gas - 3 star	Central Heat Pump - 2.3 star
Heating - non-living	Central Gas - 3 star	Central Heat Pump - 2.3 star
Cooling - living	Central Heat Pump - 2.3 star	Central Heat Pump - 2.3 star
Cooling - non-living	Central Heat Pump - 2.3 star	Central Heat Pump - 2.3 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home H

Reference	H_S_187_M_62_W
Typology	Small detached
Area (sqm)	187
Fuel Mix	Mixed Fuel
Climate Zone	62
Primary Solar PV orientation	West
BAU NatHERS rating	6.3
ZNC NatHERS rating	7.2

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.5
Insulation - external wall	R1.0
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	R2.0
Roof sarking	foil
Glazing - kitchen/living	air-filled double
Glazing - other rooms	-
Other	-

Appliances	BAU	Improved Case
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Cooling - non-living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home I

Reference	I_L_200_M_66_N
Typology	Large detached
Area (sqm)	200
Fuel Mix	Mixed Fuel
Climate Zone	22
Primary Solar PV orientation	North
BAU NatHERS rating	6.2
ZNC NatHERS rating	7.1

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.5

Insulation - external wall	R1.0
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	R2.0
Roof sarking	foil
Glazing - kitchen/living	air-filled double
Glazing - other rooms	-
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Cooling - non-living	Room Heat Pump - 1.5 star	Central Heat Pump - 1.5 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home J

Reference	J_L_208_M_62_N
Typology	Large detached
Area (sqm)	208
Fuel Mix	Mixed Fuel
Climate Zone	62
Primary Solar PV orientation	North
BAU NatHERS rating	6.2
ZNC NatHERS rating	7.2

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	R1.5
Insulation - external wall	R0.5
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	R2.0
Roof sarking	-
Glazing - kitchen/living	argon-filled double
Glazing - other rooms	-
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Room Heat Pump	Room Heat Pump - 3.1 star
Cooling - non-living	Room Heat Pump	Room Heat Pump - 3.1 star

Hot Water	Gas Instantaneous	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home K

Reference	K_L_212_M_62_E
Typology	Large detached
Area (sqm)	212
Fuel Mix	Mixed Fuel
Climate Zone	62
Primary Solar PV orientation	East
BAU NatHERS rating	6
ZNC NatHERS rating	7

Building Fabric	Improvement to meet 7 star
Insulation - roof	-
Insulation - external wall	-
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	-
Roof sarking	foil
Glazing - kitchen/living	argon-filled double
Glazing - other rooms	argon-filled double
Other	-

Appliances	BAU	Improved Case
Heating - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Heating - non-living	Room Heat Pump - 5 star	Room Heat Pump - 5 star
Cooling - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Cooling - non-living	Room Heat Pump - 6 star	Room Heat Pump - 6 star
Hot Water	Solar Electric	Solar Gas
Cooktop	Electric	Gas
Oven	Electric	Electric

## Home L

Reference	L_L_215_E_66_N
Typology	Large detached
Area (sqm)	215
Fuel Mix	All Electric
Climate Zone	22
Primary Solar PV orientation	North
BAU NatHERS rating	6.1

ZNC NatHERS rating	7.2
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Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.5
Insulation - external wall	R1.0
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	-
Roof sarking	-
Glazing - kitchen/living	argon-filled double
Glazing - other rooms	-
Other	-

Appliances	BAU	Improved Case
Heating - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Heating - non-living	Room Heat Pump - 5 star	Room Heat Pump - 5 star
Cooling - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Cooling - non-living	Room Heat Pump - 6 star	Room Heat Pump - 6 star
Hot Water	Solar Electric	Solar Electric
Cooktop	Electric	Induction
Oven	Electric	Electric

## Home M

Reference	M_L_220_M_66_N
Typology	Large detached
Area (sqm)	220
Fuel Mix	Mixed Fuel
Climate Zone	22
Primary Solar PV orientation	North
BAU NatHERS rating	6
ZNC NatHERS rating	7

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.3
Insulation - external wall	R0.5
Insulation - internal garage wall	R0.5
Insulation - internal bath/laundry wall	R0.5
Roof sarking	-
Glazing - kitchen/living	argon-filled double
Glazing - other rooms	argon-filled double
Other	-

Appliances	BAU	Improved Case
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Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Central Heat Pump - 2.7 star	Central Heat Pump - 2.7 star
Cooling - non-living	Central Heat Pump - 2.7 star	Central Heat Pump - 2.7 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home N

Reference	N_L_234_M_62_W
Typology	Large detached
Area (sqm)	234
Fuel Mix	Mixed Fuel
Climate Zone	62
Primary Solar PV orientation	West
BAU NatHERS rating	6.1
ZNC NatHERS rating	7.1

Building Fabric	Improvement to meet 7 star
Insulation - roof	R1.3
Insulation - external wall	-
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	-
Roof sarking	-
Glazing - kitchen/living	argon, low-e double
Glazing - other rooms	argon-filled double
Other	-

Appliances	BAU	Improved Case
Heating - living	Central Gas - 3 star	Central Gas - 5.2 star
Heating - non-living	Central Gas - 3 star	Central Gas - 5.2 star
Cooling - living	Central Heat Pump - 2.7 star	Central Heat Pump - 2.7 star
Cooling - non-living	Central Heat Pump - 2.7 star	Central Heat Pump - 2.7 star
Hot Water	Solar Gas	Solar Gas
Cooktop	Gas	Gas
Oven	Electric	Electric

## Home O

Reference	O_L_294_E_62_W
Typology	Large detached
Area (sqm)	294

Fuel Mix	All Electric
Climate Zone	62
Primary Solar PV orientation	West
BAU NatHERS rating	6
ZNC NatHERS rating	7.1

<b>Building Fabric</b>	<b>Improvement to meet 7 star</b>
Insulation - roof	-
Insulation - external wall	-
Insulation - internal garage wall	-
Insulation - internal bath/laundry wall	-
Roof sarking	-
Glazing - kitchen/living	argon, low-e double
Glazing - other rooms	argon-filled double
Other	-

<b>Appliances</b>	<b>BAU</b>	<b>Improved Case</b>
Heating - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Heating - non-living	Room Heat Pump - 5 star	Room Heat Pump - 5 star
Cooling - living	Room Heat Pump - 3 star	Room Heat Pump - 3 star
Cooling - non-living	Room Heat Pump - 6 star	Room Heat Pump - 6 star
Hot Water	Solar Electric	Heat Pump
Cooktop	Electric	Induction
Oven	Electric	Electric