BUILDING CODE UPDATE 2021

Introduction to background reports on H1 Energy Efficiency

Introduction to background reports on H1 Energy Efficiency

The Ministry of Business, Innovation and Employment (MBIE) is committed to being transparent about the activities it undertakes as stewards of the Building Code. For the proposals in this year's annual update, the consultation document contains relevant details on the reasons for change, relevant options considered, analysis of the options, proposed transition periods and draft versions of proposed acceptable solutions and verification methods. While we believe this information is sufficient for the consultation document, we heard feedback that further details would be useful.

We have been asked for further details on the analysis used to formulate the proposals for:

› Proposal 1. Energy efficiency for housing and small buildings

› Proposal 2. Energy efficiency for large buildings

In recognition of this, we have provided the following two reports from BRANZ and Beca that provide background information and assumptions used in the analysis of the proposed changes.

These reports served as a starting point for formulating options for public consultation. They were commissioned in 2020 through a New Zealand Government procurement process with the scope of work split into two halves for small buildings and larger buildings.

Within their specific scope, BRANZ were asked to provide the following information:

- Thermal modelling of a sample of residential dwelling typologies (single-storey detached, two-storey detached, medium density and apartment building) to determine options for new climate zones and thermal envelope performance settings (R-values), including impacts on heating and cooling energy use and indoor temperatures.
- A Cost Benefit Analysis (CBA) of options for thermal envelope performance settings.
- A Carbon Impact Analysis (both embodied carbon and operational energy) of options for thermal envelope performance settings.

Within their specific scope, Beca were asked to provide the following information:

- Investigation of five typical large building types based on recent consents: education, healthcare, office, retail and residential.
- Creation of sample building of each type representing an average across all the buildings of that type.
- Assessment and reallocation of climate zones across New Zealand according to NIWA's 18 climate files.
- Develop cost index of agreed construction details to achieve specified insulation values.
- Financial cost benefit analysis across the various building typologies, climate zones and R values.
- Assessment and reporting of the Cost Benefit Analysis and Net Present Value including recommendations based solely on financial cost benefit.
- Assessment and feedback of revised R-values in terms of emissions and energy reduction.

The focus of this work started with a discussion on energy savings versus the necessary investment in construction to achieve those savings and whether a balance in costs could be achieved over the life of the building. Upon a review of the initial review of draft reports, MBIE identified that more aggressive insulation requirements may be necessary to fulfil longer-term objectives outlined for the Building for Climate Change programme of work. This recognises that there are other drivers for higher levels of insulation in buildings beyond pure energy savings. The importance of other co-benefits (that were unable to be quantified in BRANZ's and Beca's cost benefit analyses) was also highlighted when MBIE presented this topic to the Code Advisory Panel in September and November 2020.

In early 2021, MBIE asked BRANZ to provide further analysis of proposed options for consultation. This information was used to formulate the infographic on energy savings and initial investment in construction (Figure 1.4 and Table 1.8 in the consultation document).

Introduction to background reports on H1 Energy Efficiency

MBIE would like to take this opportunity to thank BRANZ and Beca and the experts who contributed to these reports. MBIE appreciates that these reports provided a solid foundation for us to consider the implications for the design of new buildings in New Zealand. However, for more information on the regulatory context and other factors to consider for these proposals, we encourage you to review the discussion in the consultation document.

Anna Cook
Acting Manager, Building Performance and Engineering

Thermal, financial and carbon review of NZBC energy efficiency clause H1/AS1 thermal envelope requirements for residential and small buildings

Roman Jaques, James Sullivan, David Dowdell,
Matthew Curtis and Jarred Butler

1222 Moonshine Rd
RD1, Porirua 5381
Private Bag 50 908
Porirua 5240
New Zealand
branz.nz

Funded from the
Building Research Levy

The work reported here was partially funded by BRANZ from the Building Research Levy.

Thermal, financial and carbon review of NZBC energy efficiency clause H1/AS1 thermal envelope requirements for residential and small buildings

Acknowledgements

The authors would like to acknowledge the guidance of the Ministry of Business, Innovation and Employment's (MBIE's) Victoria Threadwell and Christian Hoerning throughout the development of this report. Thanks to the expert reviewers Professor Sarah McLaren (on carbon issues), Associate Professor Michael Donn (on thermal issues) and Dr Daniel du Plessis (on economic issues) and also the expertise of BRANZ scientists and technical specialists John Burgess, Dr Ian Cox-Smith and Stephen Foothead.

Reference

Jaques, R., Sullivan, J., Dowdell, D., Curtis, M. & Butler, J. (2020). *Thermal, financial and carbon review of NZBC energy efficiency clause H1/AS1 thermal envelope requirements for residential and small buildings*. Judgeford, New Zealand: BRANZ Ltd.

Abstract

MBIE commissioned BRANZ to undertake a technical study to support the policy review of increasing residential insulation requirements of NZBC clause H1 *Energy efficiency* Acceptable Solution H1/AS1 for housing and small buildings. Four representative dwelling typologies are part of the sample: single-storey stand-alone houses, double-storey stand-alone houses, townhouses and mid-rise apartments. Three key aspects are examined in some detail for each dwelling typology envelope upgrade: year-round passive and active thermal performance, a financial analysis and lifetime carbon emission quantification. The assessment was carried out at the individual building level for the next 50 years (i.e. to 2070). An accurate picture of the thermal, economic and environmental costs and benefits of each upgrade compared with the current minimum NZBC settings are provided.

Contents

Tables

Figures

1. Introduction

MBIE commissioned BRANZ to undertake a background technical study to support the policy review of increasing residential insulation requirements of NZBC clause H1 *Energy efficiency* Acceptable Solution H1/AS1 for housing and small buildings. It supports a public consultation document that aims to balance the benefits and costs to building owners and occupants, government, and broader societal impacts of increasing the thermal requirements of new dwellings.

This technical study is limited to three key aspects: thermal, financial and carbon implications. It provides a detailed and accurate picture of the costs and benefits of each proposed thermal envelope requirement compared with the current minimum settings. Broader health and societal benefits have not been factored into the cost-benefit calculations. This research report does not provide policy advice.

The cost-benefit and carbon analyses of the various R-value scenarios examined in this study are largely based on conventional construction types that the New Zealand construction industry is currently familiar with. Alternative construction types, such as warm wall and roof construction, would likely have different cost and carbon characteristics than those presented in this study, and could potentially provide additional benefits and opportunities, such as reduced thermal bridging.

The following thermally related aspects were out of scope for this study:

- The effects of climate change in terms of influencing space heating and cooling loads.
- The impact of thermal bridging at elemental wall/floor/ceiling junction details and wall corners.
- The implications for interstitial condensation within building elements, for the most extreme constructions proposed.
- Reduction in peak energy loading and the resulting infrastructure savings.

The aim of this study is to provide the information required for MBIE to propose and consult on new insulation requirements for each new climate zone that will apply to housing.

2. Methodology

The methodology applied is summarised as follows:

- A representative sample of the four dwelling types was agreed with MBIE and BRANZ, based on published data where possible. All buildings were modelled as lightweight construction (apart from the apartments).
- Thermal simulation parameters – for setting infiltration rates, heating/cooling setpoints/schedules, orientation – were agreed upon by MBIE and BRANZ.
- Dynamic thermal modelling of these dwellings was used to examine their heating and cooling energy use in 18 New Zealand climates. Based on this, six new climate zones were proposed to replace the three current zones in NZS 4218:2009 *Thermal insulation – Housing and small buildings*.
- Further thermal modelling examined the impact of a range of roof, external wall, floor and glazing R-value options on heating and cooling energy use in the six new climate zones. Conventional approaches were mainly used to reach the approximate target levels based on constructions described in BRANZ *House insulation guide* (BRANZ, 2014).
- The average change of heating/cooling loads as well the increase in construction costs for minimum Code values was determined for each of the individual construction options. Changing the R-values of roof, external wall, floor and glazing based on heating and cooling loads in combination was found to be defensible because the individual results reflected the combined sample results well.
- Based on this, cost-benefit ratios and net carbon impact (operational versus embodied) were calculated for all the construction options for a 50-year lifespan.
- Combinations of these R-values based on cost-benefit, comfort and carbon impact analysis were then selected as potential options for replacing the current Code minimum requirements. This was done for each of the six new climate zones. Cost-benefit and carbon analysis was then run for these final selections.
- Additionally, analysis was run to determine equivalent wall R-values for dwellings with solid timber walls and buildings with high thermal mass walls for each of the final options.

Further sensitivity studies were conducted on key issues:

- The impact on heating and cooling loads from introducing window curtaining, lowering groundwater height, more ‘typical’ space heating regimes, lowering air exchange rate and changes to whole-house orientation. This is to provide more robustness to the heating/cooling figures.
- The impact of substituting yearly total grid electricity emissions with quarterly figures to provide more robustness to the environmental analysis.
- The implications of altering the material and labour costs across the country ranging from-20% through to +20% to better reflect reality and provide more economic robustness.

2.1 Selection of representative dwellings

Four dwelling typologies were required to be modelled – single-storey stand-alone, double-storey stand-alone, medium-density housing and apartments.

There is very little in the way of statistically representative yearly thermal performance information to guide the selection of these types of dwellings for the New Zealand case. Some indicative information does exist in the form of an ongoing longitudinal BRANZ study, which collected approximately 440 recent detached building consent documents (Jaques, 2015, 2019) from three New Zealand cities. From this, two representative stand-alone dwellings were chosen (based mainly on their thermal performance) and used for this study. For the two remaining building typologies – medium-density housing (townhouses) and mid-rise apartments – there is no New Zealand guidance available on what constitutes a representative building. BRANZ and MBIE made the selection based on previous thermal modelling datasets that could be modelled efficiently (Dowdell, Berg, Butler & Pollard, 2020).

2.1.1 Representative model building descriptions

Four representative model buildings were chosen, one for each typology: detached single storey, detached double storey, townhouse and apartment. The four selected representative buildings were not designed to be 'designed for the sun', reflecting the current new build approach. A dwelling that is well designed for the sun will respond to solar access in its window sizing, placement and shading and therefore perform thermally quite differently to the representative dwellings chosen.

Three-dimensional schematics of the representative models are shown in Figure 1 to Figure 4.

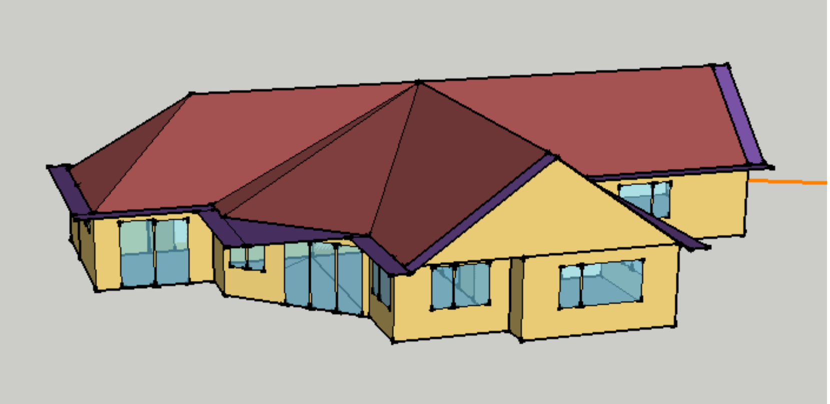


Figure 1: Single-storey stand-alone representative building schematic

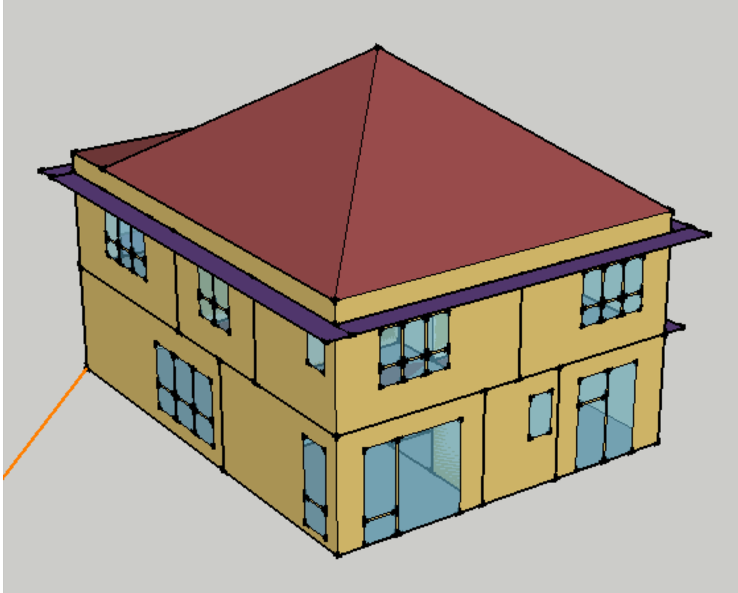


Figure 2: Double-storey stand-alone representative building schematic

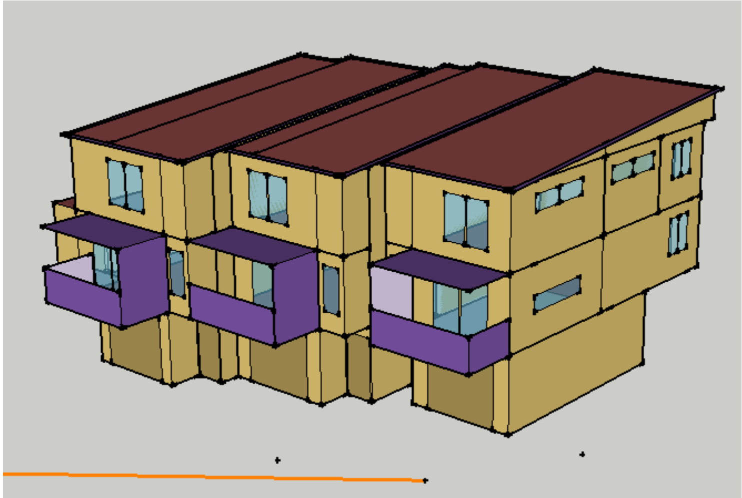


Figure 3: Medium-density representative building schematic (townhouse)

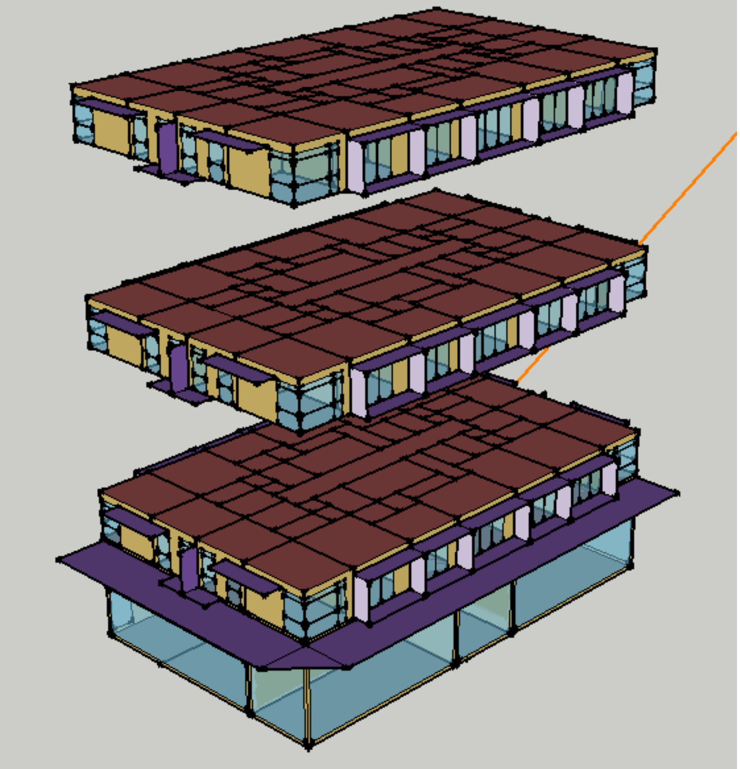


Figure 4: Apartment representative building schematic (with offices on ground floor)

The single-storey house has 4 bedrooms, a double garage, a pitched roof, and 155.9 m^2 of conditioned floor area (i.e. internal zones that are temperature modified to be within a predetermined comfort range). It has a window to wall area ratio of 19%.

The double-storey house has 5 bedrooms, a double garage, a pitched roof and 148 m^2 of conditioned floor area. It has a window to wall area ratio of 17%.

The townhouse has 695 m^2 conditioned floor area and shed style roof and comprises 8 units with three occupants per unit – 24 occupants' in total. It has a window to wall area ratio of 20%.

The 9-level apartment building has a conditioned floor area of 3,123 m^2 (3,721 m^2 gross floor area) made up of 108 units, with offices on the ground floor, a flat roof and a total of 189 occupants. It has a window to wall area ratio of 32%.

The make-up of the roofs, walls, floors and windows are outlined in detail in section 2.2.

2.2 Thermal modelling and simulation methodology

Thermal performance simulation, as with any process that tries to model reality, is a simplification. Where its strength lies is in comparative assessment rather than predicting actual energy use. This needs to be kept in mind when reading this document.

The following thermally related aspects were out of scope for this study:

- The effects of climate change in terms of influencing space heating and cooling loads.
- The impact of thermal bridging at elemental wall/floor/ceiling junction details and wall corners.
- Reduction in peak energy loading and the resulting infrastructure savings.
- Harder-to-quantify implications of having a more comfortable house year-round (better physiological health, lower health costs, lower mental stress).

Thermal modelling was conducted using EnergyPlus (version 9.2)[1] exclusively.

2.2.1 General model assumptions

Surrounding site shading was assumed to be up to the allowed recession planes for the houses or based off the surrounding city buildings in the case of the apartment. Curtains were not modelled due to uncertainty in the appropriate assumptions to make around usage and installation quality.

In the case of the apartment, the model was simplified by only modelling the top, bottom, and middle floors. The total energy use was estimated by multiplying the results of the middle floor to cover the others. This simplification approach has previously been verified for accuracy (Ellis & Torcellini, 2005). Similarly, in the medium-density development, the middle and end dwellings were modelled, with the middle one being multiplied to cover the others.

2.2.2 Internal gains

Internal heat gains are based on NZS 4218:2009. The exception is where the sensible load has been assumed to be the number of occupants multiplied by 75 W, rather than the generic occupancy sensible load assumption of the note in Table G1 of NZS 4218:2009. In the apartments, it was assumed that two people occupied each apartment, while one person occupied each studio apartment. The number of people in a house at any one time is then defined by the NZS 4218:2009 occupancy schedules. They will be divided between zones following the assumption that people will be in bed during the night and in the living spaces during the day (Table 1 and

Table *2*).

Table 1: Occupancy schedule for living zones (living, kitchen, dining, kitchen/living, lounges etc.)

Schedule	12am–8am	8am–11am	11am–6pm	6pm–10pm	10pm–12am
Weekdays	-	60%	60%	100%	-
Weekend	-	100%	50%	70%	-

---

[1] https://energyplus.net

Table 2: Occupancy schedule for bedrooms

Schedule	12am–8am	8am–11am	11am–6pm	6pm–10pm	10pm–12am
Weekdays	100%	-	-	-	100%
Weekend	100%	-	-	-	100%

Intermittently occupied zones such as hallways and bathrooms are assumed to have no significant occupancy load. These number of occupants defined above are then divided up amongst the different zones as follows:

- Night: two occupants in the master bedroom, one in each other bedroom.
- Day: occupancy divided up over living zones according to their relative floor areas.

The sensible heat produced per occupant is assumed to be 75 W as per Table 6.3 in the CIBSE Environmental Design Guide (CIBSE, 2006). Plug loads were modelled following NZS 4218:2009 (Table 3) and applied on a per square metre basis to all zones (except garage and roof space).

Table 3: Plug load schedule following NZS 4218:2009

Schedule	12am–8am	8am–11am	11am–6pm	6pm–10pm	10pm–12am
All days	0.735 W/m^2	5.635 W/m^2	5.635 W/m^2	6.615 W/m^2	4.9 W/m^2

Hot water cylinders are modelled as providing a 100 W load in the zone they exist in.

2.2.3 Infiltration and ventilation

As per NZS 4218:2009, infiltration was assumed to be 0.5 air changes per hour (ach) in most zones. The exception was the roof space, which was assumed to have an infiltration of 5 ach based on consultation with BRANZ experts. Note that this is highly uncertain, and measurements of identical houses on the same site have found significant variation in the recorded roof infiltration.

Following NZS 4218:2009, ventilation was set to activate at 24°C. Maximum ventilation rates were assumed to be 30 ach in the main living spaces where they had good cross-ventilation potential and openable outside doors and 10 ach in other rooms. In the apartment building, due to its design, there is much less capacity for cross-ventilation between different rooms, and ventilation rates may be lower. A maximum of 15 ach was assumed in the living spaces with openable balcony doors and 5 ach in the rooms with only small openable windows. These assumptions were based on estimates of the high-end ventilation rates that were readily reached in more complicated airflow network models when the windows were opened.

It should be noted that ventilation is uncertain and variable, being highly affected by wind speed and how people operate the windows. These assumptions are only the maximum, and much less ventilation is applied most of the time. For example, the average ventilation rate actually applied in the living room of the single-storey stand-alone dwelling in Auckland is around 8 ach. Note that, to avoid potentially fighting the cooling system, the ventilation was set to turn off at 24.9°C (i.e. just below the cooling setpoint) or when the outdoor temperature was as high as the indoor temperature.

2.2.4 Heating and cooling

BRANZ and MBIE agreed that a coefficient of performance (COP) of 2 would be assumed for heat pumps in the living areas (Burrough, Saville-Smith & Pollard, 2015) and a COP of 1 (i.e. electric resistive heating) would be assumed elsewhere in the dwellings. All the reported energy figures were based on these COP figures – i.e. inclusive of the heat pump efficiency.

Setpoints were assumed following NZS 4218:2009 (although with some adjustments) of heating to 18°C in all zones inside the thermal envelope (i.e. excluding garage or roof space). Contrary to NZS 4218:2009, the setpoint was not lowered to 16°C overnight and instead kept at 18°C in order to meet current World Health Organization[2] recommendations. The cooling setpoint was 25°C.

Note that these setpoints were set using operative temperature, which is an average of air and radiant temperature. This is considered to better align with human perceptions of temperature and is what has historically been used in past H1 analysis (Page, 2006). If the mean air temperature was used instead, the estimated energy use would be expected to be lower and so would the potential cost savings.

2.2.5 Ground modelling

The concrete slabs and ground were modelled using the GroundDomain model in EnergyPlus. Soil properties were assumed as shown in Table 4.

Table 4: Soil properties used

Conductivity	1.2 W/m-K	BRANZ recommended value for New Zealand (Trethowen, 2000)
Density	1500 kg/m^3	ANSI/ASHRAE Standard 140-2007 Addendum B Table B18-1 (ASHRAE, 2010); NZS 4214:2006 *Methods of determining the total thermal resistance of parts of buildings* (clay soil)
Specific heat	800 J/kg.K	ANSI/ASHRAE Standard 140-2007 Addendum B Table B18-1 (ASHRAE, 2010)

To model the underslab insulation and account for the fact that the insulation does not go all the way to the edge of the slab (due to the slab thickenings at the foundations), an approximate R-value of the slab insulation was taken. This was taken as the difference between the R-value of an uninsulated slab and a slab with underslab insulation in the *BRANZ House insulation guide*. Thus, it was modelled as providing an additional R-value of ~R0.5 rather than R1.2.

Note that using Kiva (Kruis, 2015) to model the ground heat flows results in lower predicted heating energy use in the order of 25% or more. It is not known which model is most 'correct', and the GroundDomain model was chosen here because its results are more consistent with the slab modelling methods that have traditionally been used in previous H1 analysis (such as Page, 2006).

2.2.6 Construction scenarios

The construction elements (roof, walls, floor and windows) modelled were designed to be examples of conventional approaches (as much as possible) that could be used to reach the approximate target levels based on constructions described in the BRANZ *House insulation guide* (hereafter abbreviated to HIG).

ROOF

The roof construction is based on a typical pitched roof with trusses at 900 mm centres and 90 mm bottom chords providing thermal bridging. To achieve higher R-values, additional insulation is layered on top of the first layer and the chords, reducing thermal bridging. The zone 1 and 2 baseline scenario uses R3.2 batts[3] as this is representative of standard practice,

---

[2] https://www.who.int/publications/i/item/who-housing-and-health-guidelines

[3] Pink® Batts® were used for all the batt-type insulation modelled in this report as, at the time of the study, it is the only New Zealand product to have an associated Environmental Product Declaration (EPD). An EPD is an

even if this does lead to perhaps a slightly higher overall R-value than the R2.9 Code minimum.[4] Also, the next level of commercially available ceiling batts is R2.6, which would fall slightly below Code minimum. A different product could potentially hit the R2.9 minimum exactly (ignoring uncertainties in calculation and installation), but this could distort the carbon and cost comparisons.

One challenge here is meeting the Code minimum R-values (R2.9 and R3.3) using standard constructions, as ceiling batts only come in certain R-values and these do not always exactly line up with the Code. For example, the most common roof constructions would be R3.2/R3.6 batts in a truss roof with chords at ~900 mm centres. According to the HIG, these produce overall roof R-values of approximately R3.1 and R3.4 – slightly higher than Code minimum. Potentially alternative products or different levels of bridging could be used to adjust these R-values, but this could also distort cost and carbon analysis later on. For the sake of simplicity, we have imagined the insulation was installed sub optimally in those scenarios, thus lowering the effective R-value delivered. This is a common source of uncertainty in reality. In practice, it should be noted that a difference of ~R0.1 or ~R0.2 would have minimal effect on the overall whole-house heat losses, perhaps in the order of ~2%, so it should not be a significant concern. As can be seen in Table 5, the three highest R-values exceed the available HIG construction R-values. They require two layers of batt insulation to achieve the stated construction R-values and may require more care in placement in situ. Also, due to the two-layer depth, there may be some stepping back required of the upper-level batt to account for the lowering truss on the perimeter.

Table 5: *Ceiling insulation and roof construction R-values*

R2.9	**R3.3**	**R3.6**	**R4.3**	**R4.9**	**R5.9**	**R6.6**
R3.2 batts, 5% framing – assumed installed slightly inefficiently to bring R-value down to Code minimum (HIG: R3.1)	R3.6 batts, 5% framing – assumed installed slightly inefficiently to bring R-value down to Code minimum (HIG: R3.4)	R4.0 batts, 5% framing	R5.0 batts, 5% framing	R3.2 batts between chords + R1.8 batts over top	R3.6 batts between chords + R2.6 batts over top	R3.6 batts between chords + R3.2 batts over top
HIG page 29	HIG page 29	HIG page 29	HIG page 29			

The apartment building departs from this set-up slightly, as it uses a suspended ceiling system with the insulation layered over the ceiling grid rather than a truss system. This produces a slightly different sequence of insulation levels (Table 6).

Table 6: *Apartment building ceiling insulation and roof construction R-values*

R2.9	**R3.3**	**R3.9**	**R4.3**	**R5.3**	**R6.3**	**R7.3**
R2.6 batts	R3.2 batts – assumed effectively R3.0 due to poor installation in order to provide Code minimum R-value	R3.6 batts	R4.0 batts	R5.0 batts	R6.0 batts	R7.0 batts

---

independently verified document that communicates transparent and comparable information about the life-cycle environmental impact of products and is therefore the most reliable information.

[4] 'Code minimum' in this report always refers to the R-values stipulated in the schedule method in NZS 4218:2009 Table 2. These values were used as the baseline R-values.

WALLS

Walls are designed based on the light timber-framed construction typical for New Zealand houses. The framing ratio is assumed to be 24%[5] – the maximum in the HIG – as this is expected to be more representative of what is achieved once the additional framing from elements such as jack studs, lintels and intersections are accounted for. Note that, to increase R-values to any significant degree, structural changes are required. We first simply increase wall framing thickness to 140 mm, but to go beyond ~R3.0, even larger changes are required. Options include double-framed staggered stud systems, external insulation to reduce thermal bridging or high-performance structural insulated panel (SIP) construction. For the sake of consistency with the lower-level light timber frame + batts constructions, we used the staggered stud system described in the HIG for this analysis (Table 7).

Table 7: External timber wall constructions and construction R-values

R1.9	**R2.0**	**R2.5**	**R2.9**	**R4.0**	**R4.6**
R2.2 batts, 90 mm framing (24%)	R2.6 batts, 90 mm framing (24%)	R2.8 batts, 140 mm framing (24%)	R4.0 batts ultra, 140 mm framing (24%)	R2.2 + R2.2 batts, 2 x 90 mm staggered stud (24%)	R2.8 x 2 batts, 2 x 90 mm staggered stud (24%)
HIG page 66	HIG page 66	HIG page 67	HIG page 67	HIG page 71	HIG page 71

Note that the medium-density dwelling also has some retaining walls on the back wall of the ground floor garage (which is insulated). In the plans, these are strapped and lined with 45 mm polystyrene insulation. In order to be consistent with the above wall scenarios, we have modelled various levels of batt insulation with studs at 600 mm centres, assuming that the base retaining wall has an R-value of ~R1.3 as per HIG page 112 (Table 8).

Table 8: Retaining wall insulation and construction R-values[6]

~R2.1	**~R2.1**	**~R2.5**	**~R2.9**	**~R4.0**	**~R4.5**
R1.0 batts masonry, 45 mm framing (10%)	R1.0 batts masonry, 45 mm framing (10%)	R1.2 batts masonry, 75 mm framing (10%)	R1.8 batts, 90 mm framing (10%)	R3.2 batts, 140 mm framing (10%)	R4.0 batts, 140 mm framing (10%)

The floor constructions are focused on concrete slab-on-grade constructions, as that is typical for new houses in New Zealand (Table 9).

Table 9: Slab construction scenarios and approximate construction R-values[7]

~R1.3	**~R1.9**	**~R2.0**	**~R2.7**
Uninsulated slab	R1.2 underslab insulation (50 mm polystyrene)	R1.0 edge insulation (30 mm polystyrene)	R1.0 edge insulation + R1.2 underslab insulation
HIG page 127	HIG page 127	HIG page 127	HIG page 127

Note, however, that there are still some elements where insulated timber floors are present. The medium-density dwelling has some small cantilevered sections, the 2-storey dwelling has the floor over the garage and the apartment building has commercial offices on the ground floor. Lining up the R-values as much as possible with the above-slab construction using common insulation materials, there are two options: batts or polystyrene. Batts were chosen for practicality and cost reasons.

---

[5] A conservative figure that may underestimate the fraction of timber in conventional timber-framed wall constructions and may overestimate the performance gains of higher R-value insulation materials in such walls.

[6] The lowest R-value option here is ~R2.1 using typical masonry wall batt insulation.

[7] These R-values do not include internal linings such as carpet, although they have been modelled.

Table 10: Batt insulation between floor joist and construction R-values

R1.5	**R2.0**	**R2.8**
R1.0 40mm masonry batts strapped, 11% timber framing	R1.6 batts strapped, 11% timber framing	R2.6 batts strapped, 11% timber framing
HIG page 118	HIG page 118	HIG page 118

Note these flooring construction R-values do not include internal linings such as carpet, though they have been modelled.

WINDOWS

Glazing scenarios all use aluminium frames for consistency. It should be noted that the R-values and solar heat gain coefficient (SHGC) can vary significantly depending on quality/cost. Good-quality low-E argon double glazing with a thermally broken frame can achieve R-values as high as ~R0.51 for example – much higher than the R0.39 specified in NZS 4218:2009. For consistency, we have largely used the typical Window Energy Efficiency Rating System (WEERS) values as shown in the HIG. The exception here is for triple glazing, where recent expert advice suggests the value given in the HIG was significantly higher than what triple glazing products available on the market achieve. The SHGC is also quite variable – the HIG gives a range of 0.15–0.6 for triple glazing for instance – and here we have used a value of ~0.4 which represents an average figure. The SHGC was calculated using the Lawrence Berkeley National Laboratory (LBNL) window thermal performance calculation program WINDOW 7. In terms of the triple glazing option and resulting whole-window R- value chosen, an entry-level priced unit provided by industry was chosen. Skylights were not tested as part of this analysis due to none of the representative buildings including skylights.

Table 11: Windows scenarios used and their key values

R0.26	**R0.31**	**R0.31**	**R0.39**	**R0.62**
SHGC 0.74	**SHGC 0.74**	**SHGC 0.7**	**SHGC 0.7**	**SHGC 0.4**
Double glazing, aluminium frame	Double glazing, thermally broken aluminium frame	Double glazing, aluminium frame, low-E coating	Double glazing, thermally broken aluminium frame, low-E coating	Triple glazing, thermally broken aluminium frame, low-E coating, argon fill
HIG Table 6	HIG Table 6	HIG Table 6	HIG Table 6	Industry figures

The external reviewer for the thermal-related aspects covered in Section 2 was Associate Professor Michael Donn, Director of Centre for Building Performance Research, School of Architecture, Victoria University of Wellington.

2.3 Cost-benefit analysis methodology

Improved housing thermal performance has been found to deliver significant health benefits in retrofit situations[8]. BRANZ was unable to find suitable studies that could adequately quantify the health and wellbeing benefits resulting from improved thermal performance in new housing in New Zealand, above that of the existing Code requirements. Therefore, no health and wellbeing benefits have been included in this subsection.

The cost-benefit analysis was first undertaken for individual element R-value increases then for a combination of R-value increase packages (see section 2.2.6). The investigation was kept as

---

[8] https://motu.nz/assets/Documents/our-work/urban-and-regional/housing/Cost-Benefit-Analysis-of-the-Warm-Up-New-Zealand-Heat-Smart-Programme.pdf

simple as practical, targeting only the marginal cost increase of whatever changes were proposed over the 50-year analysis timeframe, with the benefit only being the energy savings over the same period.

Specifically, the cost-benefit analysis study was aimed at answering this question:

> *RQ1: What construction R-values (for a range of defined wall, floor, roof and window constructions) deliver the greatest energy cost savings less additional construction and maintenance/replacement costs compared to constructions that deliver construction R-values currently in NZBC clause H1/AS1 when applied to four different residential typologies (2 stand-alone houses, 1 MDH, 1 apartment) constructed in 2020?*

The process used to answer this was as follows:

Step 1: Determine the marginal additional cost of materials that deliver those defined R-values.
Step 2: Determine the marginal additional replacement benefits of those materials.
Step 3: Compare those costs to energy cost savings as derived through the thermal modelling. (This is the only benefit that was considered.)
Step 4: Inflate the energy cost savings in each year after 2020 by the real electricity price escalation rate.
Step 5: Discount future costs and benefits by our 6% discount rate.
Step 6: Calculate the net present value (NPV) of the cumulative costs and benefits.
Step 7: Calculate the benefit-cost ratio (BCR).

The methodology used in this report is consistent with other comparable cost-benefit analysis methodologies (CBA) previously applied by BRANZ (for example, Page, 2006). For this MBIE study, a CBA was first undertaken for individual element R-value increases then for a combination of R-value increase packages.

Costs for construction materials are based on *QV costbuilder*,[9] which is a transparent online database accessible by industry. Material manufacturers confirmed that BRANZ cost data was in the range that they would expect. It should be noted that prices may vary significantly in practice (anecdotal evidence suggests variance of up to 50% dependent on scale).

To determine appropriate electricity tariffs when calculating energy-related costs, 150 randomly selected, recently constructed New Zealand dwellings were examined. Their tariffs were then investigated, and a region-weighted average tariff was calculated based on its respective new residential construction activity. It has been assumed that there is a 1.2% escalation rate (i.e. real inflation rate) in electricity prices each year.[10] A 6% discount rate was applied, based on Treasury advice.[11] All prices are GST exclusive.

A sensitivity study was conducted on varying material costings. This was carried out in recognition of the uncertainty and variation in building material costs (purchase price variation between builders) – both regionally and nationally – that occurs in New Zealand. Cost variants of +20%, +10%, -10% and -20% were chosen to provide some more certainty of the way the

---

[9] www.qvcostbuilder.co.nz

[10] www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-modelling/new-zealands-energy-outlook/new-zealands-energy-outlook-electricity-insight/. See Excel file titled: ‘Scenario and sensitivity summary: demand, price indicator, emissions’.

[11] https://treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

BCR and NPV change with increasing R-values. The results are shown in Appendix D for all four dwelling typologies.

This section and all others related to economic issues was reviewed by Dr Daniel Du Plessis Senior Research Economist, BRANZ.

2.4 Greenhouse gas assessment methodology

2.4.1 Background

Section 2.2.6 defines the wall, floor, roof and window constructions within the scope of the study. Each of these includes constructions that meet current clause H1 construction R-values as set out in the HIG (termed ‘current constructions’). In addition, several alternative constructions that achieve higher construction R-values than currently required by clause H1 are also defined (termed ‘alternative constructions’).

The reference study period is 50 years.[12] The assessment included the following within the scope:

1. Upfront (or embodied) greenhouse gas emissions that occur through manufacture of materials, and their transport to and installation at a construction site. This included an allowance for materials wastage during construction.
2. Where necessary, replacement[13] of materials that may be necessary in order that the technical and functional performance of the construction in which the material is used is maintained over 50 years.
3. Carbon dioxide sequestration by radiata pine trees grown in New Zealand sustainable forestry plantations and processed into treated timber framing in New Zealand. Further information about the method used is set out in section 2.4.3.2.
4. Greenhouse gas emissions savings estimated to be achievable over the 50-year reference study period due to operational energy savings from use of higher construction R-values. The approach for calculating these savings is set out in section 2.4.4.

The research was scoped to show how combinations of walls, floors, roofs and windows with higher construction R-values applied to four different residential typologies compared from a greenhouse gas perspective to those same typologies with current construction R-values. The outputs are therefore relative and reflect differences in greenhouse gas emissions due to use of higher construction R-values relative to current construction R-values.

As a result, only materials that differ between alternative constructions and equivalent current constructions were included in the assessment. Table 12 provides an example. Note that, in this example, external claddings and internal wall linings are excluded as they are the same in both the current and alternative construction.

---

[12] MBIE requested a 50-year reference study period for this project to align with the minimum 50-year building life requirement of clause B2 *Durability*, which is to be achieved without reconstruction or major renovation. This should not be confused with the service life of the buildings which may be considerably longer.

[13] Replacement cycles were based on the experience of BRANZ durability scientists and industry – see section 2.4.3.3 for further details.

Table 12: Scope of greenhouse gas assessment using a wall construction example

Current construction (R1.9, 24% framing ratio)	Example alternative construction definition (R2.9, 24% framing ratio)	Scope of greenhouse gas assessment[14]
90 mm timber frame	140 mm timber frame	Additional timber with 140 mm framing vs 90 mm framing.
R2.2 glass wool insulation	R4.0 glass wool insulation	Additional insulation (R2.2 vs R4.0).
		Difference between heating/cooling energy demand (current construction vs alternative construction).

From Table 12, this assessment comprised:

- estimated materials-related greenhouse gas emissions, being the sum of 1 to 3 listed above
- estimated operational energy-related greenhouse gas savings (from 4 above) due to reduced heating/cooling demand from use of alternative constructions (achieving higher construction R-values) instead of current constructions. The method used to determine this is set out in section 2.4.4.

2.4.2 Overview of methodology

The greenhouse gas assessment study was aimed at answering this question:

> *RQ1: What construction R-values (for a range of defined wall, floor, roof and window constructions) deliver the greatest greenhouse gas savings compared to constructions that deliver construction R-values currently in NZBC clause H1/AS1 when applied to four different residential typologies (2 stand-alone houses, 1 MDH, 1 apartment) constructed in 2020?*

The process used for answering this was as follows:

Step 1: Determine the materials-related greenhouse gas emissions (section 2.4.3).
Step 2: Determine the operational energy-related greenhouse gas savings (section 2.4.4).
Step 3: Calculate the mass of materials (in scope of the study) per square metre of each construction element and apply emissions factors from Step 1 to obtain square metre rate greenhouse gas emissions for each current and alternative construction.
Step 4: Using defined square metres of walls, floors, roofs and windows for each of the four residential typologies assessed in the study (from section 2.2.6), calculate the materials-related greenhouse gas emissions when different combinations of current and alternative constructions are applied. Assume the buildings are constructed in 2020.
Step 5: For each specific combination of wall, floor, roof and window constructions applied to each of the four residential typologies, simulate the heating and cooling energy demand (across different New Zealand climate zones). From this, calculate the associated greenhouse gas emissions over 50 years, assuming that the source of energy for heating and cooling is New Zealand grid electricity.
Step 6: Sum the total greenhouse gas emissions (materials and operational energy-related) for each combination of alternative constructions applied to the four residential typologies in all assessed climate zones. Express the estimated greenhouse gas emissions/savings of the alternative constructions relative to the current constructions (subtract the former from the latter).

---

[14] For some constructions, materials may additionally require maintenance or replacement during the 50-year reference study period. Details are provided in section 2.4.3.3.

Step 7: Use this to determine what combinations of alternative/current constructions applied to each of the four residential typologies across different climate zones deliver the highest estimated greenhouse gas emissions savings between 2020 and 2070. This step provides the results to answer RQ1.

The methodologies for Steps 1 and 2, which were unique to the greenhouse gas assessment, are provided in section 2.4.3 and 2.4.4. Other steps were part of the overall study methodology set out in the remaining parts of section 2.

2.4.3 Method for determining materials-related GHG emissions

The following process was followed:

- Greenhouse gas impact factors (plus supporting information) needed for RQ1 were identified for materials within the scope of the study and summarised in an Excel spreadsheet on a kg CO_2 eq./kg or kg CO_2 eq./m^2 basis (depending on the material). This data included greenhouse gas emissions from:
    - manufacture
    - transport and use on a construction site
    - replacement if the material needs to be changed during the 50-year reference study period. When a material was replaced, this included manufacture, transport and installation of the new material as well as end of life of the old material.
- Greenhouse gas impact factors and supporting information were reviewed externally to obtain an opinion on their suitability considering the goal and scope of the study. The suggested impact factors, their source and assumptions were discussed at a meeting on 27 May 2020 and in subsequent telephone conversations. The external reviewer for the greenhouse gas assessment was Professor Sarah McLaren, Director of the New Zealand Life Cycle Management Centre at Massey University.
- The finalised greenhouse gas impact factors were applied to material quantities as set out in Step 3 in section 2.4.2.
- Preliminary results (at the building level and including operational energy-related greenhouse gas savings) were assessed, checked and externally reviewed. Based on the findings and in consideration of the quality of data used, aspects suitable for testing with sensitivity analysis were identified and agreed with the external reviewer.
- Sensitivity analyses were carried out, checked, externally reviewed and discussed.
- Findings (including sensitivity analysis) were summarised in this report. The draft results, findings and conclusions were externally reviewed. Comments received from the external reviewer were discussed and incorporated into the draft text.

2.4.3.1 Materials-related GHG emission factors

In most cases, materials-related greenhouse gas emissions factors were taken from data developed for the New Zealand whole-building, whole-of-life framework (www.branz.co.nz/buildinglca) and embedded in publicly available BRANZ resources, such as BRANZ CO2NSTRUCT (www.branz.co.nz/co2nstruct) and LCAQuick v3.4 (www.branzco.nz/lcaquick). The framework has been developed in line with EN 15978:2011 *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*.

Where relevant[15] environmental product declarations (EPDs) existed which have been published but not yet been included in the BRANZ tools, the EPD data was used in

---

[15] Compliant with EN 15804:2012+A1:2013 *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products*.

preference.[16] Information about data used, a data quality assessment and assumptions are provided in Appendix B.

2.4.3.2 Timber framing – carbon dioxide sequestration

Some alternative constructions feature different quantities of timber framing per m^2 of construction in comparison with the equivalent current construction. An example of this is presented in Table 12, where 140 mm wall framing represents an alternative construction to typical current construction (defined as 90 mm wall framing).

For this study, timber for wall framing is assumed to be supplied from New Zealand sustainably managed plantations based on Wood Processors & Manufacturers Association EPD S-P-00997 (WPMA, 2019). Yearly data on New Zealand plantation forestry is published by the New Zealand Forest Owners Association (FOA) and the Ministry for Primary Industries (MPI). For example, the latest published data from the FOA for 2018/19[17] shows that the net stocked plantation area as at 1 April 2018 was 1,725,476 hectares – an increase of 19,047 hectares since 1 April 2017.

Based on EN 16485:2014 *Round and sawn timber – Environmental product declarations – Product category rules for wood and wood-based products for use in construction*, carbon dioxide sequestration can be included if consideration of the biogenic carbon neutrality of the wood is valid. The standard notes that all major European countries producing timber report increasing forest carbon pools and/or through chain of custody certification that demonstrates the wood meets the requirement to originate from certified forests.

According to Appendix C5.5 of the NZ Wood Design Guide *Timber, carbon and the environment* (WPMA, 2020), about 66% of New Zealand commercial forest is owned and managed by companies that have achieved Forest Stewardship Council (FSC) certification. The remaining approximately 30% that are not certified to FSC, or the Programme for the Endorsement of Forest Certification (PEFC), are mostly smallholder forests. These smallholder forests are less than 2,000 hectares in size and the costs of certification can be prohibitive.

Based on recently reported FOA/MPI data and WPMA (2020), we assume the source of timber framing is from sustainable New Zealand forestry. From Figure 1 in EN 16485:2014, the global warming potential (GWP)[18] that can be applied where carbon neutrality can be assumed is -1. According to WPMA (2019), manufacture of 1 m^3 of H1.2 boron-treated surfaced kiln-dried timber is -726 kg CO_2 eq. This comprises total potential carbon dioxide sequestration of -795 kg CO_2 eq./m^3 and fossil fuel emissions of 68.9 kg CO_2 eq./m^3.

The carbon dioxide sequestration value represents the radiative forcing that is avoided over 100 years (sometimes denoted by GWP_{100}) as atmospheric carbon dioxide is kept out of the atmosphere. This is because it is stored in the wood product. However, since the reference study period here is 50 years and adopting a prudent approach, the value of this carbon dioxide sequestration benefit is adjusted by the ratio '50 years/100 years' so we do not include

---

[16] BRANZ updates the data in BRANZ CO_2NSTRUCT and LCAQuick annually, which means that, depending on timing of publication of EPDs, there can be a lag before the data is incorporated into BRANZ tools. For example, WPMA published an EPD for timber products in October 2019 after BRANZ updated its data. We have therefore used data from the WPMA EPD for this assessment.

[17] www.nzfoa.org.nz/images/Facts_and_Figures_2018-2019_Web.pdf

[18] Global warming potential is a measure of the radiative forcing caused by a greenhouse gas up to a specific time horizon, relative to carbon dioxide. It is calculated in units of carbon dioxide equivalents or CO_2 eq. Typically, the time horizon considered is 100 years.

the benefit of carbon dioxide sequestration beyond the boundary for the study.[19] Therefore, the greenhouse gas impact factor over 50 years for manufacture of H1.2 boron-treated surfaced kiln-dried radiata pine framing became:

$$(-795 * (50 / 100)) + 68.9 = -328.6 \text{ kg } CO_2 \text{ eq.}/m^3$$

If we used the full value of -726 kg CO_2 eq. reported in WPMA (2019), we would be taking the full benefit of carbon dioxide sequestration from years 1 to 100 without considering potential greenhouse gas emissions from years 51 to 100. This adjustment is valid for houses constructed in 2020 in which the carbon dioxide is sequestered for the full 50 years of the reference study period. Given that the timber is used for framing, it is likely that the carbon dioxide will remain sequestered well beyond this timeframe.

2.4.3.3 Materials replacement

Given that the study scope is to consider differences between current constructions and alternative constructions, only one situation merited inclusion of materials replacement during the 50-year reference study period, set out below.

Insulated glass units (IGUs) for double and triple-glazed aluminium/uPVC frame windows

BRANZ's opinion is that IGUs are likely to require (glazing-only) replacement after 25 years in service, for example, due to deterioration of seals. There is no frame replacement during the 50 years.

2.4.4 Method to determine operational energy-related GHG savings

Annual grid carbon intensity figures (expressed as kg CO_2 eq./kWh) were provided by MBIE based on the 2019 electricity demand and generation scenarios (EDGS) report (MBIE, 2019). Since these figures were provided on a generation basis, they were adapted to include transmission and distribution losses so that they reflected a supply basis. Transmission and distribution losses were calculated as 7.3%, according to data provided by MBIE.

EDGS 2019 contains five alternative future scenarios that result in minor differences when compared in terms of annual grid carbon intensity. For the purposes of this assessment, the Reference scenario was selected. According to EDGS 2019, this represents a continuation of current trends and reflects a "view of how the electricity system could evolve under current polices and technology trends if no major changes occur" (MBIE, 2019, p. 8). Furthermore, a sensitivity analysis was carried out that considered seasonal differences in grid carbon intensity. The method used is described further in Appendix C.

2.5 Additional work

An additional step was requested by MBIE half-way through the study. This was to better understand how much the R-values of homes in the cooler climates would have to increase to enable them to be heated as easily as homes in a more thermally neutral climate zone. Wellington was nominated as the thermally neutral zone. The normalising process is outlined in Appendix H. This work on normalising the five climate zones to Wellington's climate is coded as 'Equalise' in the full economic/carbon/comfort tables. MBIE requested BRANZ to explore the two new elemental combinations for Christchurch and Queenstown outlined in Table 13.

---

[19] We do not include any greenhouse gas emissions (or savings) beyond the 50 years set for the study such as maintenance and replacement of materials or energy savings due to achievement of higher construction R-values. Similarly, the benefit of carbon dioxide sequestration is modified to reflect the benefit over 50 years rather than 100 years.

Table 13: Additional step extreme R-values for Christchurch and Queenstown

Element	Zone 5 – Christchurch	Zone 6 – Queenstown
Wall	R2.9	R4.6 (staggered studs)
Roof[20]	R8.4	R9.4
Floor	R2.0 (edge)	MAXRaft fully insulated[21]
Glazing	R0.76 (triple glazed, uPVC)	R0.76 (triple glazed, uPVC)

The roof R-values are achieved using double layers of batts, following on from the previous work. The triple glazing R-values were achieved using uPVC frames with an entry-level priced glazing unit selected, provided by industry. Choosing a representative SHGC is problematic – the HIG gives a range of 0.15–0.6 for triple glazing for instance. For this study, we have used a value of 0.39, based on a triple-glazed window documented in a high-performance house building consent using Planitherm XN glass and calculated using LBNL's WINDOW 7. An examination of the substantial impact of the SHGC factor on projected energy use may be found in Appendix B.

The carbon and cost differences associated with the higher-performing window and flooring solutions compared to Code minimums were determined using industry figures (where available) and BRANZ expert opinion. Calculating the impact of triple glazing is difficult as there is a lack of data on the breakdown of both glazing and framing costs. Given the high uncertainty in the cost of triple glazing, we decided to err on the high side of the estimate and assumed that additional replacement cost would simply be equal to the marginal cost of triple glazing. Beyond the fraction that could be associated with the thermal break (~$39/m^2), no attempt was made to estimate how much of the cost difference between double and triple glazing comes from differences in framing between them.

---

[20] A caveat is that these roof R-values are extreme by any measure and achieving them in practice will present a range of practical and technical challenges – for example, insulating to the edge in hip roofs without knee walls, providing enough depth in skillion roofs and dealing with such thick batts in confined attic spaces with obstructive trusses and cross braces. There may even be interstitial moisture issues in some situations. These issues require a more comprehensive study. Currently, the emphasis on this additional step is more to explore theoretical implications of equalising the space conditioning requirements (in kWh/year) over a diverse range of climate zones.

[21] R-values were not derived using the simplistic NZS 4214:2006 calculation method. They were derived using the COMSOL Multiphysics 2D program due to their complex nature and the need for better accuracy. The COMSOL calculated R-values were that an area/perimeter ratio of 2.6 results in a whole-floor R-value of R3.4 and an area/perimeter ratio of 3.3 results in a whole-floor R-value of R3.9. This is true for either 90 mm or 140 mm wall framing. Note that the MAXRaft system is used here as a typical industry example of a fully insulated slab.

3. Results

3.1 Updating New Zealand climate zones[22]

New Zealand is currently (2020) divided into three climate zones based on average temperature data for Acceptable Solution H1/AS1. Zone boundaries are aligned with those of territorial authorities.

- **Zone 1:** Northland, Auckland, Franklin District and the Coromandel Peninsula.
- **Zone 2:** The rest of the North Island except the Central Plateau.
- **Zone 3:** The Central Plateau of the North Island and all of the South Island.

The possibility of having a more granular response to the three existing climate zones to better reflect a reasonably diverse national climate was explored in this review. This was conducted using dynamic thermal modelling to determine the annual heating and cooling loads (kWh/m^2/year) for 18 New Zealand regional climate files developed by NIWA in 2008.

Simulations were run both with existing schedule method insulation level R-values (as per NZS 4218:2009 Table 2 climate zone 3) plus a higher set of R-values for each of the four representative dwellings. Specifically, the dwellings were modelled as lightweight construction with identical R-values, divided into:

- '**Base**' – roof (R3.3), wall (R2.0), floor (R1.3), windows (R0.26).
- '**High_ins**' – roof (R5.0), wall (R4.0), floor (R2.7), windows (0.39).

Climates with similar heating ('H') and cooling ('C') loads were then grouped to create six updated climate zones (annotated as red ovals) as a replacement for the climate zone map in NZS 4218:2009. For each proposed new climate zone, a climate file most representative of both heating and cooling loads and population size has been selected. The exception was the concrete apartment building, which displayed a unique energy pattern. These results and groupings are shown in Figure 5 to Figure 8.

The findings from the 18 climate zone simulations were as follows:

- Space heating energy use order is consistent across representative buildings, regardless of insulation level.
- Based on space conditioning ('T') order, there is potential to partition New Zealand into six climate zones as shown with the red ovals, with qualifiers as there are some 'edge' cases – for example:
    - Rotorua could be best grouped with Wellington
    - Tauranga is hard to place – could go with Auckland or New Plymouth
    - Hamilton could be placed either with Napier/New Plymouth or Wellington.
- Inconsistencies largely come from cooling, as cooling climate zones are not the same as heating climate zones. Provided a building is largely heating dominated, this climate breakdown approximation works reasonably well.
- However, this grouping completely breaks down with the apartment building. Its thermal characteristics are completely different from the smaller-scale buildings, as it is cooling dominated. We suggest that this issue should be considered for future developments to H1.

---

[22] The external reviewer for section 3.1 was Associate Professor Michael Donn, Director of Centre for Building Performance Research, School of Architecture, Victoria University of Wellington.

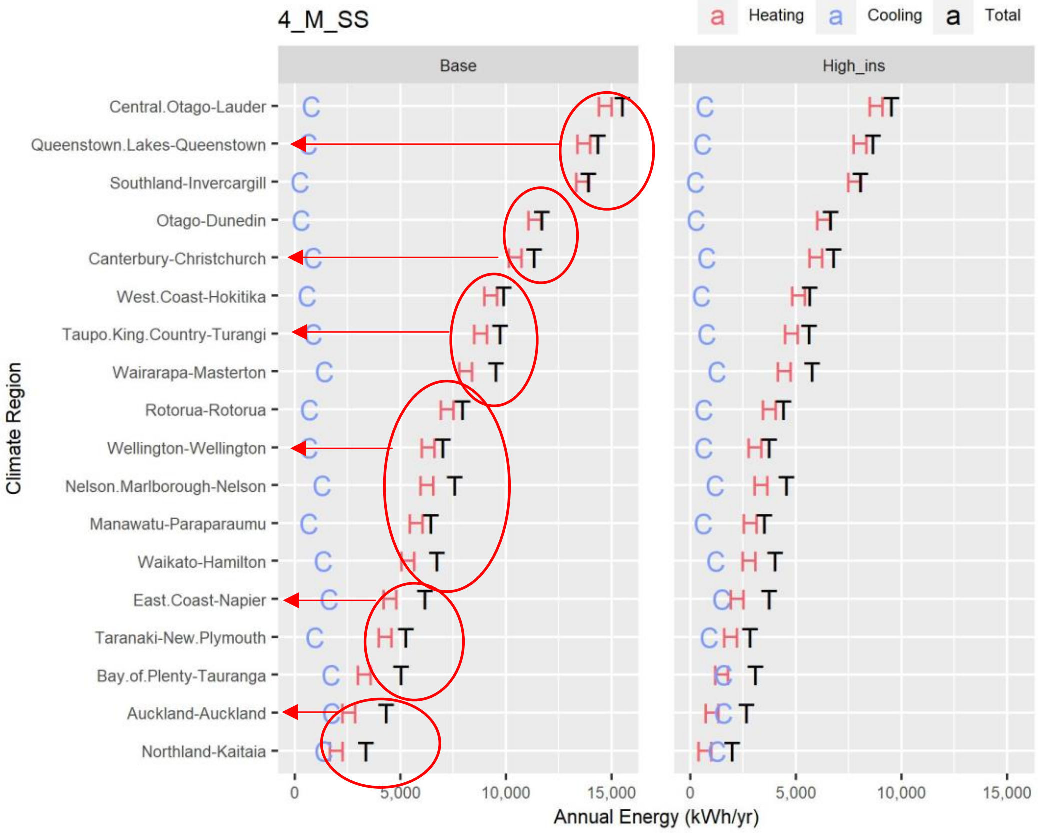


Figure 5: Energy use in different climate zones for the single-storey house

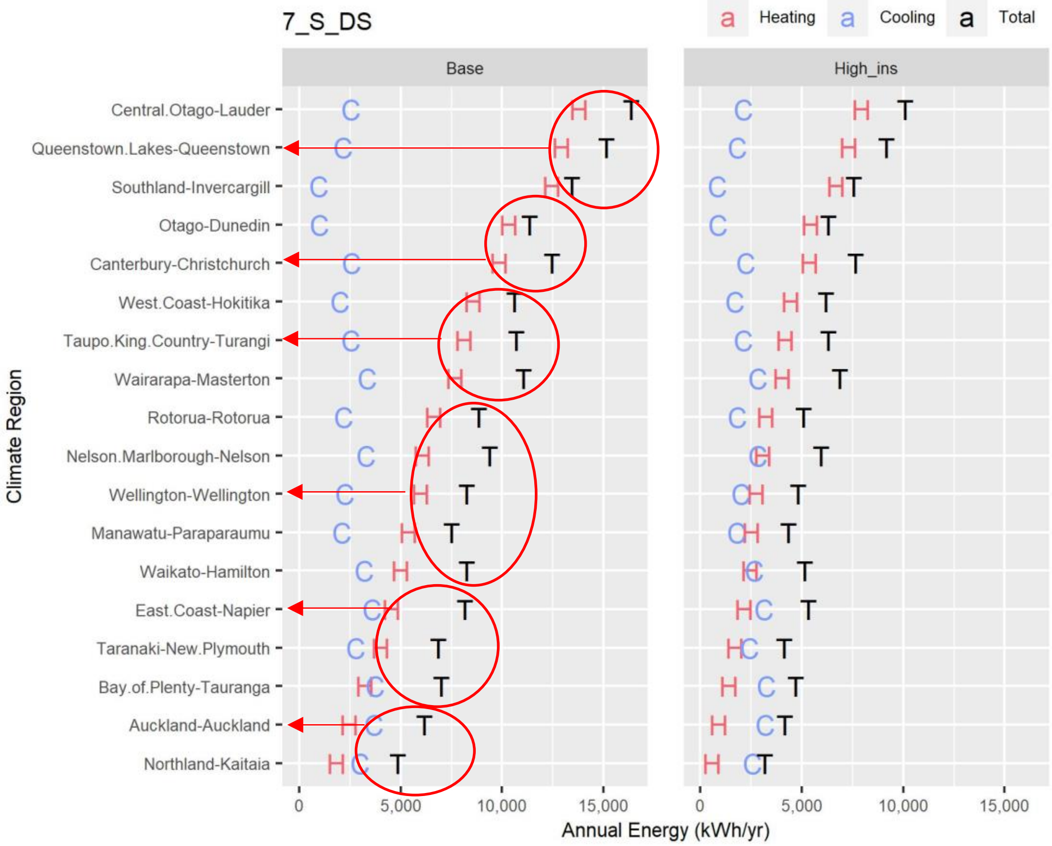


Figure 6: Energy use in different climate zones for the 2-storey detached house

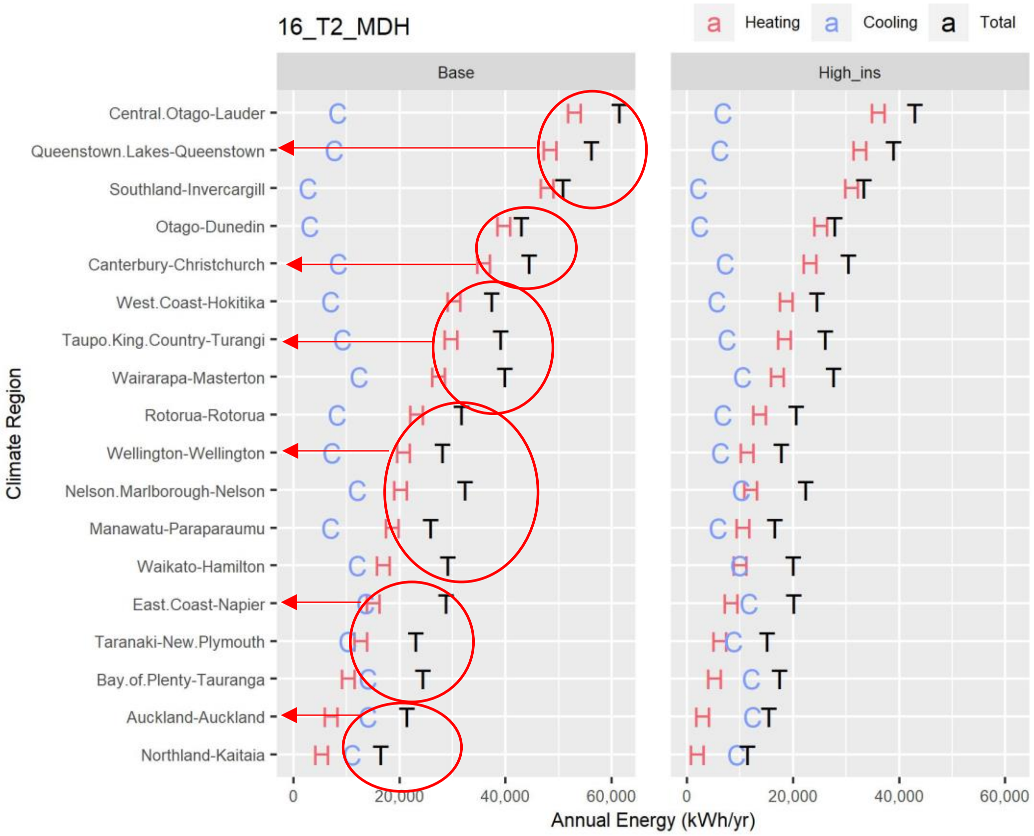


Figure 7: Energy use in different climate zones for the medium-density dwelling

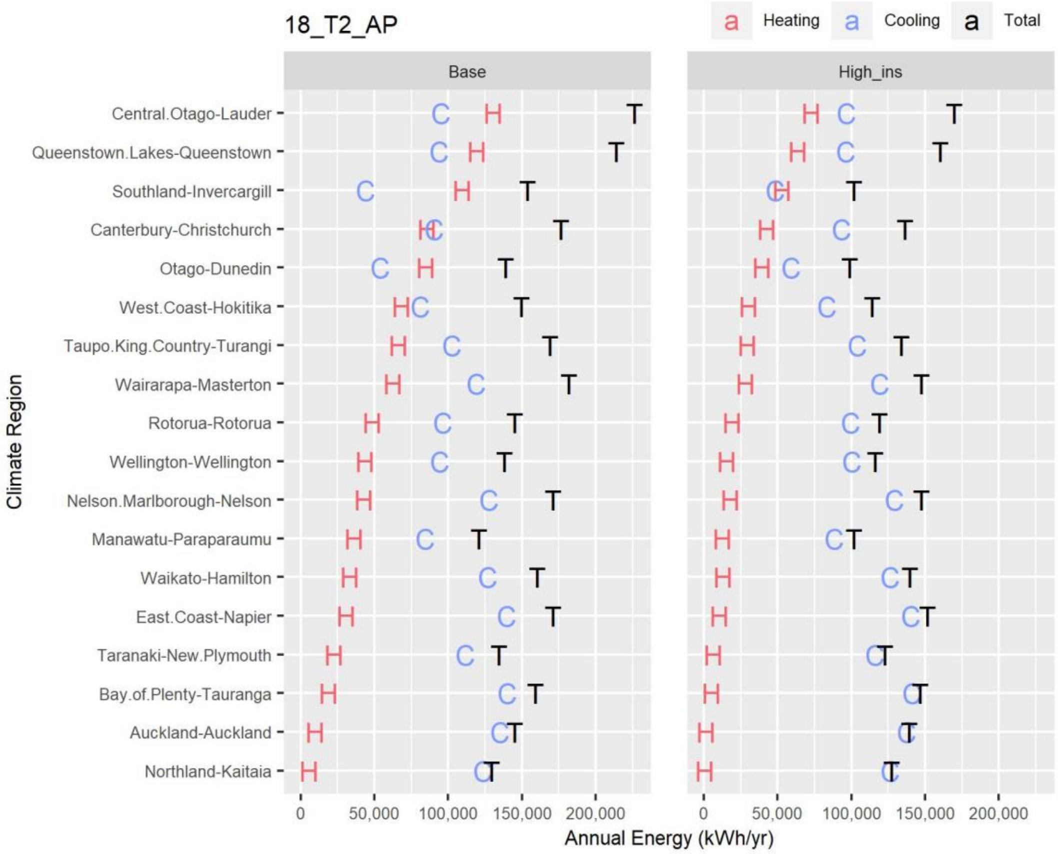


Figure 8: Energy use in different climate zones for the apartment building

Some key points to note

NZS 4218:2009 has traditionally been focused on reducing heat losses, as this was the main thermal concern facing New Zealand houses. The standard does not really account for overheating in any meaningful way and provides no guidance or minimum standards. Also, the standard has traditionally been designed from the perspective of detached houses. Before introducing more stringent heat loss requirements, it would be wise to ensure that overheating is explicitly added to the standard, given modern houses are much warmer than older houses. There are also the effects of climate change to contend with. Such an approach would be focused more on controlling heat gains with greater emphasis on orientation, sizing and positioning of glazing, external shading and adequate ventilation rather than R-values. Developing such a new standard is outside of the scope of the current study.

Large apartment buildings operate very differently from detached houses/MDH, and it does not make sense for them to be in the same standard on the thermal envelope. The optimal insulation levels are likely to be very different, and they need to address cooling. Again, the development of such an alternative standard is outside the scope of the current project.

We suggest that, given the traditional focus of NZS 4218:2009 and the design of the current project, the study proceeds using the six heating climate zones identified as they appear to work well for smaller low-density and medium-density housing. It is acknowledged that the climate zone groupings provided are somewhat arbitrary and can be manipulated around the edges.

The issues around apartment design and overheating should be flagged. Sensitivity analysis should be carried out to highlight the issues, potential implications and need for further work in future studies. Ultimately, there are significant uncertainties around overheating problems and ventilation and cooling behaviour in modern New Zealand houses. Given the current study's focus on reducing heat losses, it does not seem sensible to attempt to redesign it to try to focus more on cooling.

It is worth explaining the uncertainty in the cooling energy use estimates. In a computer simulation of user window operation for cooling, it is difficult to replicate the parameters affecting the degree of overheating in the real world.[23] For example, setting the windows to open 1°C below the cooling setpoint and closing them when the cooling is turned on is unlikely to have a large impact. However, as the quick comparison in Figure 9 shows, opening windows at 3°C below the cooling setpoint (in order to provide more opportunity for ventilation) reduces cooling needs by ~50–80%. Of course, this assumes people are at home all day as retirees or with a young family to manually operate the windows as required.

---

[23] No account is taken of real-world parameters. These parameters include daytime concerns about security, heating the building up during the day, safety restrictors on windows that stop them from being fully opened and the lack of cross-ventilation opportunities in conventional apartments.

	WINDOWS OPEN AT	
Climate	**24°C**	**22°C**
Auckland-Auckland	3,197	1,623
Bay.of.Plenty-Tauranga	3,243	1,661
Canterbury-Christchurch	2,089	1,161
Central.Otago-Lauder	2,063	1,246
East.Coast-Napier	3,091	1,708
Manawatu-Paraparaumu	1,649	416
Nelson.Marlborough-Nelson	2,787	1,052
Northland-Kaitaia	2,544	1,016
Otago-Dunedin	701	169
Queenstown.	1,737	811
Rotorua-Rotorua	1,799	780
Southland-Invercargill	662	186
Taranaki-New.Plymouth	2,301	683
Taupo.King.Country-Turangi	2,084	993
Waikato-Hamilton	2,724	1,398
Wairarapa-Masterton	2,793	1,749
Wellington-Wellington	1,769	455
West.Coast-Hokitika	1,550	386

Figure 9: Effect of opening windows at different setpoints on energy use (kWh/yr) for 2-storey house

Brief checks suggest that while the effect of the reduced solar transmission from the low-E glazing coating can significantly affect the cooling load (in the order of ~20%), it would not change the general conclusion here. Adjusting the high_ins model of 4_M_SS to have the same solar heat gain coefficient as clear double glazing shifts the difference in cooling from ~-152kWh to +202kWh in Auckland – still considerably smaller than the change in heating. For 7_S_DS, it shifts from ~-468kWh to +163kWh.

As a result of this mini-study, MBIE has agreed to continue with the following six new climate zones: #1: Auckland; #2: Napier; #3: Wellington, #4: Turangi, #5: Christchurch and #6: Queenstown. These new climate zones will be used for the remainder of this review.

3.2 Sensitivity to whole-house orientation

The sensitivity of the space conditioning energy requirements resulting from incrementally changing the whole house orientation was examined. Dwellings were rotated from their design orientation in 45° steps. The full graphical results and analysis can be found in Appendix A, and this is a summary of the findings:

- Heating energy use is minimally affected by orientation, with the shifts generally being less than 10%. This may be explained by the fact that, when some windows move more north, others will move more south, thus counteracting the overall effect[24]. Thus, much of the heating occurs in places and times where there is less sun. This is particularly true in the case of the schedules here that are heating all zones and are heating during the night as well.
- Cooling energy use is affected to a substantially larger degree, with differences of 50% or more. This makes sense, as cooling needs are much more closely related to solar gains. This may not be a major concern for houses such as detached homes, which are very heating dominated, but can become a significant issue for buildings that are cooling dominated such as the apartment.

---

[24] This would be different in the case of solar-designed homes, which are specifically designed for only one orientation.

3.3 Relative materials-related GHG results for constructions

This section sets out the materials-related greenhouse gas results for each construction on a per m^2 basis, relative to the construction delivering the lowest construction R-value. Each section shows the estimated greenhouse gas emissions by material and by life cycle stage. (Please refer to section 2.2.6 for a more detailed description of each of the constructions and Appendix B for the data used as the basis for deriving materials-related greenhouse gas emissions factors.)

In interpreting the results, the following naming convention is used for the different life cycle stages, reflecting LCA practice:

- **Modules A1–A3 (product stage)**, representing manufacture of materials up to the factory gate.
- **Modules A4–A5 (construction process stage)**, representing transport and construction.
- **Module B4 (use stage)**, representing replacement of materials during the 50-year reference study period.

The end-of-life stage is not considered (modules C1 – C4) as this is outside the 50-year reference study period. End of life of materials becoming waste within the reference study period (during construction or because of replacement) is considered.

Climate change impacts are calculated using global warming potentials (GWPs) over a 100-year timeframe. The 100 years relates to the time horizon over which the radiative forcing impact of GHGs in the atmosphere is considered. In all time horizons, carbon dioxide emissions have a GWP of 1 as it is the reference gas, but the GWPs for methane, nitrous oxide and other greenhouse gases will be different, depending on the time horizon over which the radiative forcing is calculated. For example, a gas wither a shorter atmospheric life such as methane has a higher GWP if assessed over a 20-year timeframe compared to its GWP over a 100-year timeframe (as it has a shorter lifetime in the atmosphere). This does not relate to the 50-year building service life used in the study.

3.3.1 Walls

Two types of external wall were included in the scope of the study:

- Standard external wall: timber frame (having a 24% framing ratio) with batt insulation.
- Retaining wall: timber frame retaining wall (10% framing ratio) with batt insulation (used as part of the MDH typology).

Figure 10 and Figure 11 show additional greenhouse gas emissions (GWP_fossil fuels[25]) and additional storage due to carbon dioxide sequestration (GWP_sequestration[26]) in timber wall framing separately. The black dot on each chart shows the net greenhouse gas impact, being the difference between savings and emissions.

Points to note:

- The graphs consider embodied carbon only and not any greenhouse gas impacts from reduced heating/cooling energy use as a result of the increased insulation.
- Additional emissions associated with the R2.0 construction (as compared to R1.9 construction) are solely due to extra manufacture, transport and installation of insulation.

---

[25] Global warming potential from fossil fuels combustion.

[26] Global warming potential from carbon dioxide sequestration.

- The R2.5 and R2.9 constructions are based on 140 mm rather than 90 mm framing. This results in additional carbon dioxide sequestration of just over 1 kg CO_2 eq./m^2, which remains stored in the wall for the 50-year reference study period.
- The net greenhouse gas impact of the R2.5 construction (considering the additional carbon dioxide sequestration in the extra timber) is less than the R2.0 construction, despite the use of insulation with a higher R-value. The R2.9 construction has the highest net greenhouse gas impact of an additional 0.83 kg CO_2 eq./m^2.
- The R4.0 and R4.6 constructions are two rows of staggered studs, which increases the amount of timber framing in the wall. This results in additional carbon dioxide sequestration of just over 4 kg CO_2 eq./m^2, which is retained in the construction during the 50-year reference study period.
- The additional carbon dioxide sequestration in the R4.0 staggered stud construction is greater than the greenhouse gas emissions needed to process and transport the insulation and timber. The opposite holds true for the R4.6 staggered stud construction. The R4.0 construction delivers the best materials-related savings of all variants (at -1.62 kg CO_2 eq./m^2). The R4.6 construction has a net greenhouse gas impact close to the R2.9 construction.

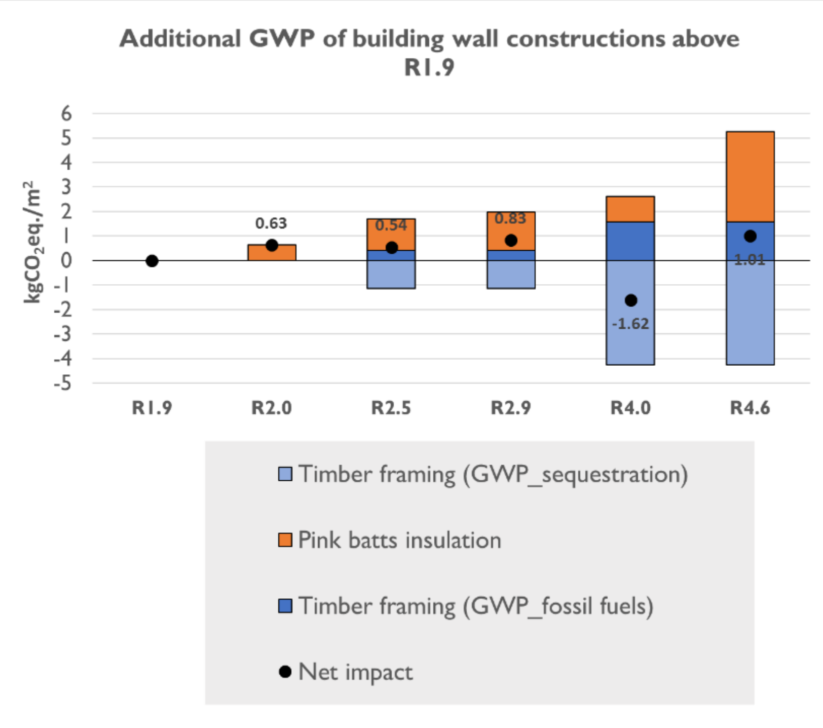


Figure 10: Additional GHG emissions for standard timber frame wall cf R1.9 wall construction, by material

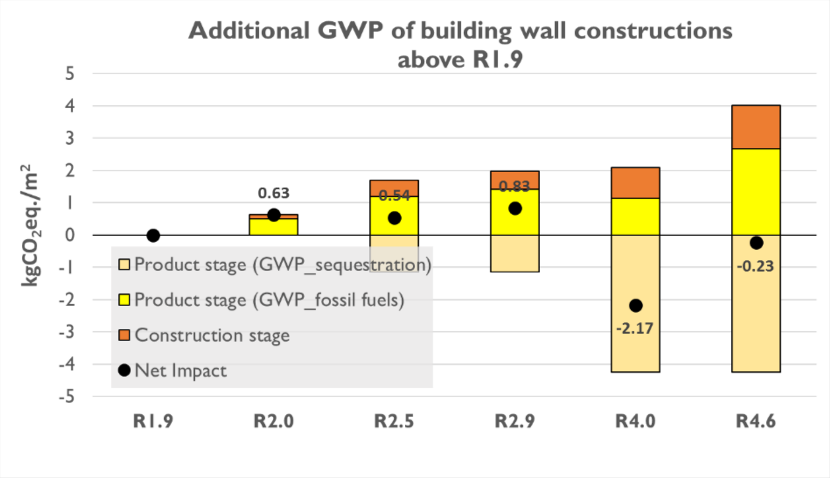


Figure 11: Additional GHG emissions for standard timber frame wall cf R1.9 wall construction, by life cycle stage

Figure 12 and Figure 13 display results for the retaining wall construction. The R2.5 construction increases framing to 75 mm (from 45 mm) and then 90 mm framing (for R2.9) and 140 mm framing (for R4.0 and R4.5). R-values for insulation increase from R1.0 up to R4.0. Observed trends are as follows:

- Additional carbon dioxide sequestration is less than 0.2 kg CO_2 eq./m^2 (for the R2.5 and R2.9 constructions) to almost 0.4 kg CO_2 eq./m^2 for the R4.0 and R4.5 constructions. This remains sequestered during the 50 year reference study period.
- Increasing greenhouse gas impacts with higher R-value are due to extra manufacturing impacts for the insulation.
- The R1.9 to R2.9 constructions deliver the lowest materials-related net greenhouse gas impacts.

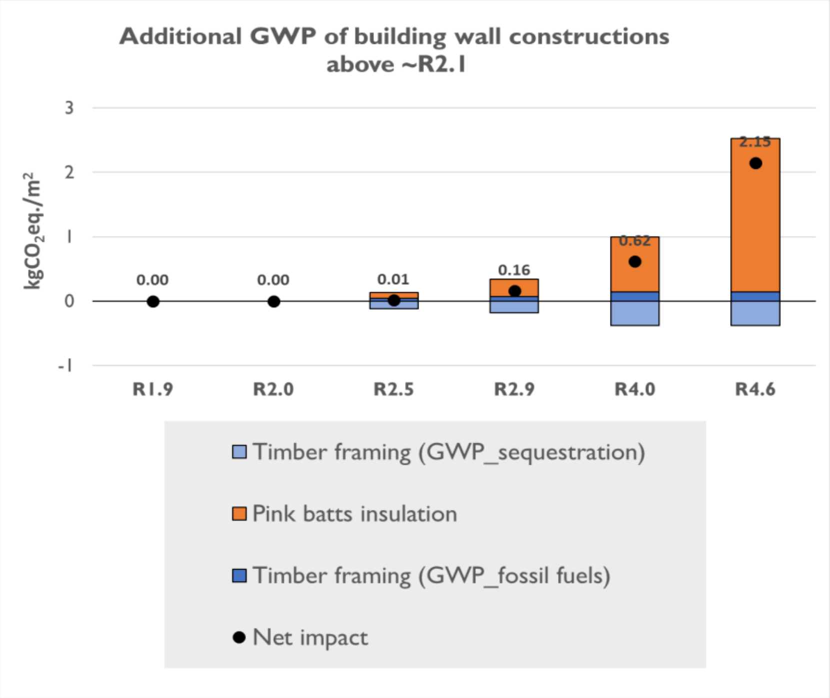


Figure 12: Additional GHG emissions for retaining wall relative to R2.1 wall construction, by material

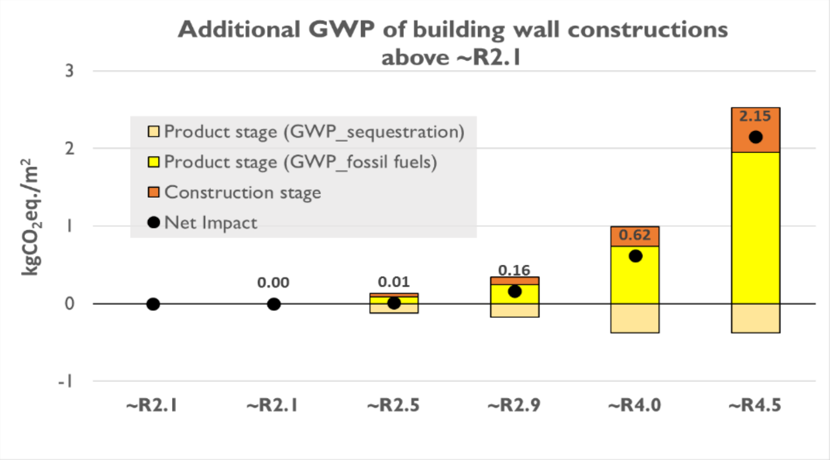


Figure 13: Additional GHG emissions for retaining wall relative to R2.1 wall construction, by life cycle stage

3.3.2 Floors

As with the walls, there are two floor types as follows:[27]

- Concrete floor slab: R1.9 = under slab polystyrene insulation; R2.0 = edge polystyrene insulation; R2.7 whole slab insulation.
- Timber floor: R2.0 = polystyrene between floor joists; R2.7 = double layer polystyrene insulation between floor joists.

A point to note for Figure 14 and Figure 15 is that adding edge insulation (as in constructions with R2.0 and R2.7) introduces the need to add edge protection. The two-part edge protection used here is a plaster-composite with a fibreglass mesh and does not need to be painted or require steel flashing. This is a high-quality edge insulation system and if flashings are used then this will significantly increase material carbon and costs.

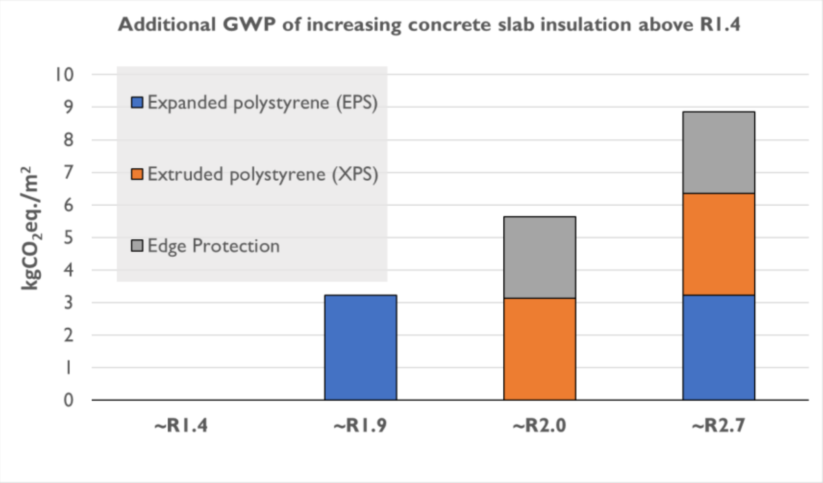


Figure 14: Additional GHG emissions for concrete slab relative to R1.4 slab construction, by material

---

[27] See section 112.2.6 for full construction descriptions

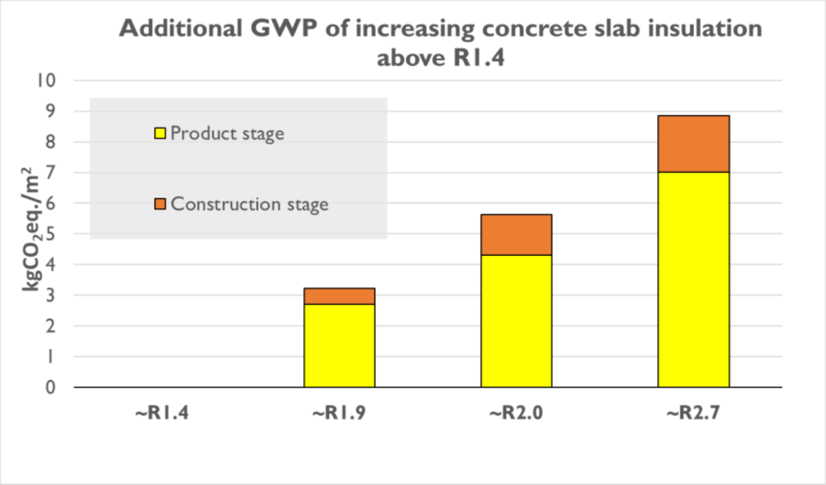


Figure 15: Additional GHG emissions for concrete slab relative to R1.4 slab construction, by life cycle stage.

A timber floor considers increasing insulation from R1.3 to R2.7, so additional greenhouse gas emissions are from manufacture, transport and installation of the insulation material only.

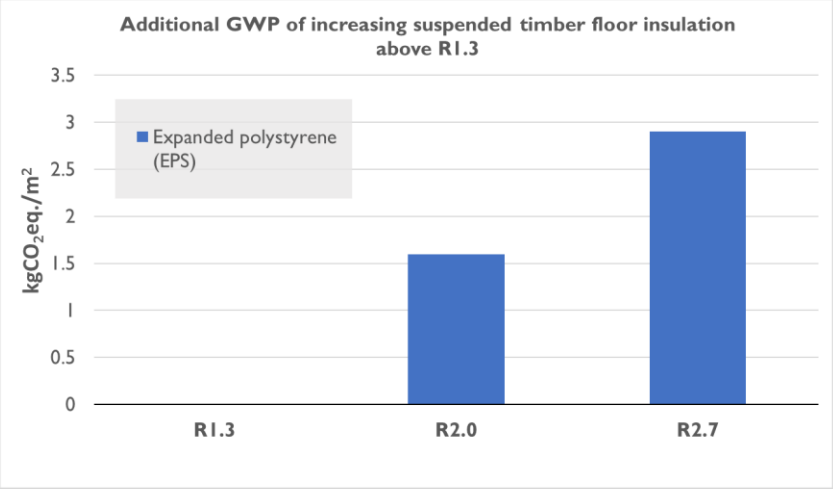


Figure 16: Additional GHG emissions for timber floor relative to R1.4 floor construction, by material

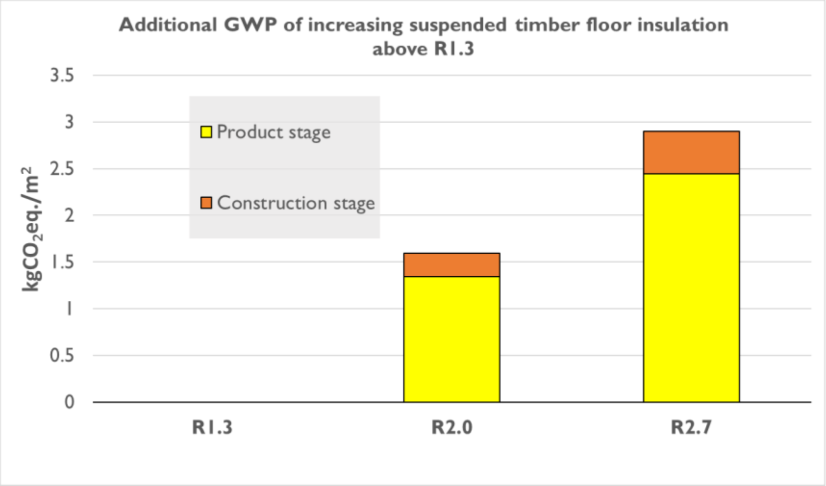


Figure 17: Additional GHG emissions for timber floor relative to R1.4 floor construction, by life cycle stage

3.3.3 Roofs

Here, a pitched roof (for stand-alone houses) with increasing construction R-value from R2.9 to R6.6 and an apartment roof with increasing R-value from R2.9 to R7.3 are considered[28]. In both cases, the increases in construction R-value are achieved by using insulation with a higher R-value and (in the case of the pitched roof) adding a second layer of insulation above the chords.

Figure 18 and Figure 19 show the additional materials-related greenhouse gas emissions by increasing the construction R-value up to R6.6.

As can be seen, there is a lower greenhouse gas emission for the R4.9 construction in comparison with the R4.3 construction. This is because the mass of a single layer of R5.0 batts between the chords (for the R4.3 construction) is greater than the combined mass of a layer of R3.2 batts between the chords and another layer of R1.8 batts above the chords.

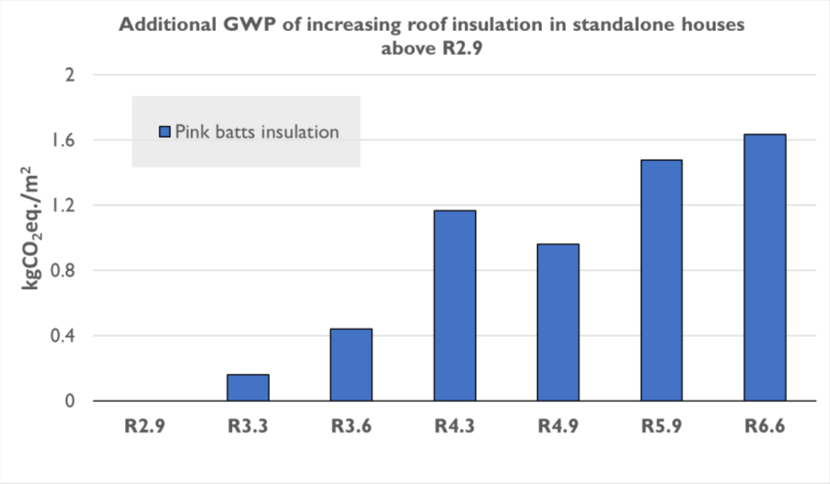


Figure 18: Additional GHG emissions for pitched roof relative to R2.9 roof construction, by material.

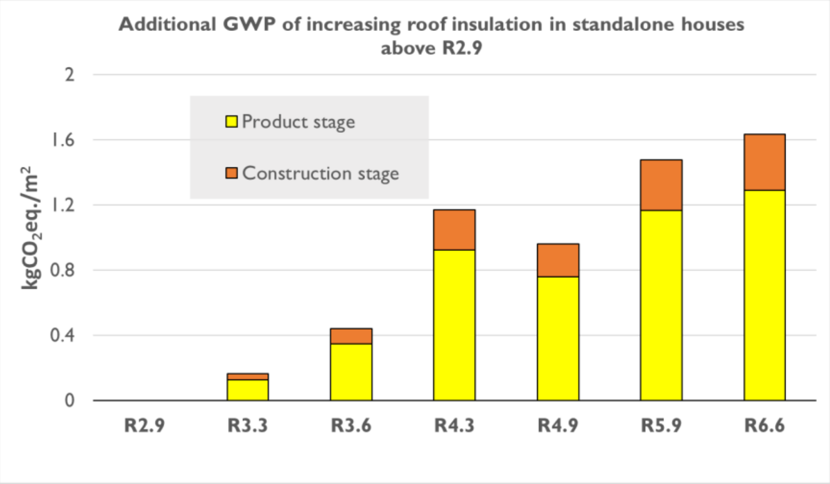


Figure 19: Additional GHG emissions for pitched roof relative to R2.9 roof construction, by life cycle stage

Figure 20 and Figure 21 show the increasing contribution to materials-related greenhouse gas impact by increasing the insulation value.

---

[28] See section 2.2.6 for construction details.

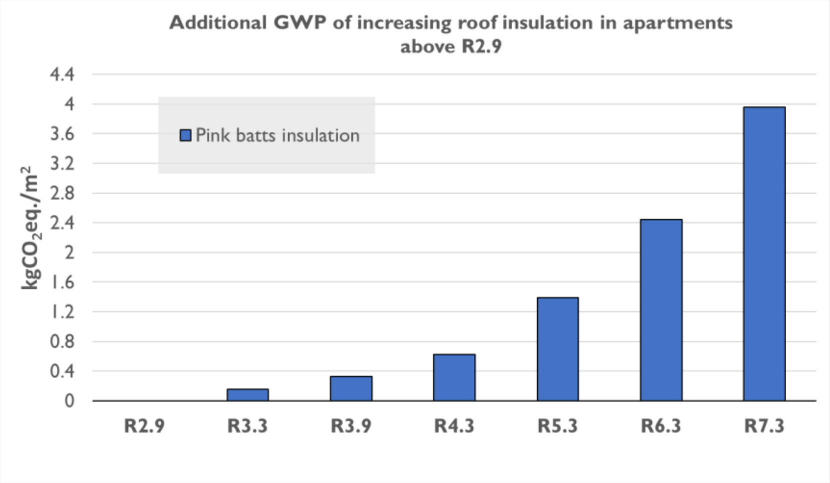


Figure 20: Additional GHG emissions for apartment roof relative to R2.9 roof construction, by material

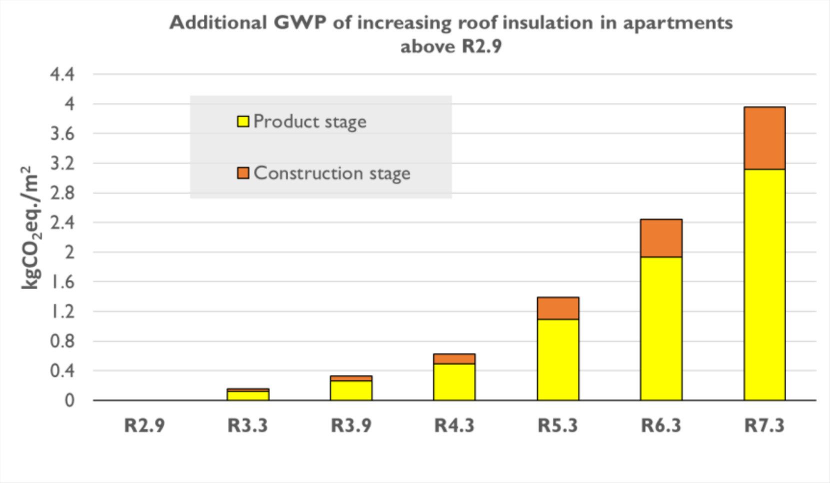


Figure 21: Additional GHG emissions for apartment roof relative to R 2.9 roof construction, by life cycle stage

3.3.4 Windows

Window R-values in the study increase from R0.26 to R0.76, using a combination of thermally broken aluminium frames and low-E coatings right up to triple glazing with a uPVC frame and low-E coating.

Figure 22 and Figure 23 show the additional greenhouse gas emissions (compared to a non-thermally broken aluminium-framed window achieving R0.26) arising from other assessed window types.

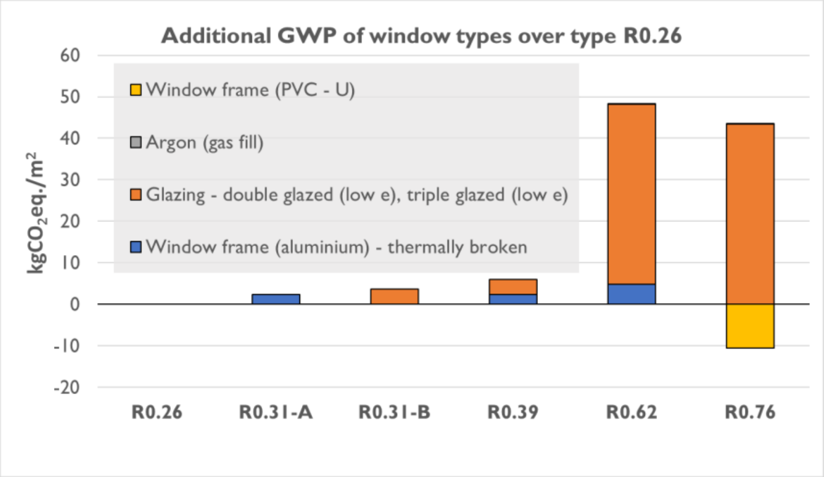


Figure 22: Additional GHG emissions for windows relative to R0.26 window construction, by material.

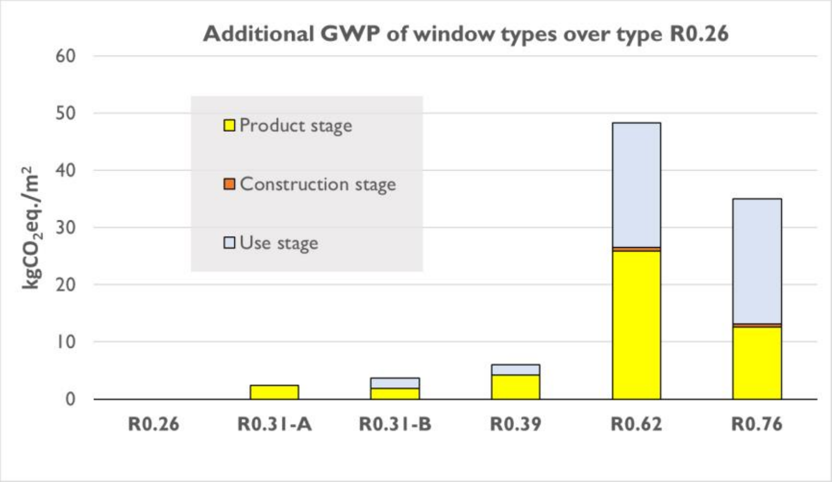


Figure 23: Additional GHG emissions for windows relative to R0.26 window construction, by material life cycle

Observed results:

- Two window types achieve R0.31. R0.31-A achieves this with a thermally broken frame, whilst R0.31-B achieves the same with a low-E coating. Since the service life of the insulated glass unit (IGU) is taken as 25 years it needs replacing once during the reference study period. The low-E coating needs replacing (as part of the IGU) also. The additional upfront additional greenhouse gas impact of the low-E coating appears to be lower than the additional upfront greenhouse gas impact of the thermally broken frame. However, the need to replace the IGU once during the 50-year reference study period means the combined additional greenhouse gas impact for the option with a low-E coating appears marginally higher than the option with a thermally broken frame.
- Since the R0.39 option is a combination of a thermally broken aluminium frame and low-E coating, its estimated additional greenhouse gas impact is the sum of both the R0.31 options.
- The triple glazing options have considerably higher additional materials-related greenhouse gas impact in comparison with the double-glazed options. In part, this is due to the manufacture of additional materials (mainly glass) plus the need to replace the additional glass once during the reference study period. The argon gas fill makes a negligible additional contribution. Note that Figure 22 shows a negative figure for PVC .

This is because the embodied carbon footprint of the PVC option is slightly less than the carbon footprint of the aluminium frame used for the R0.26 option.

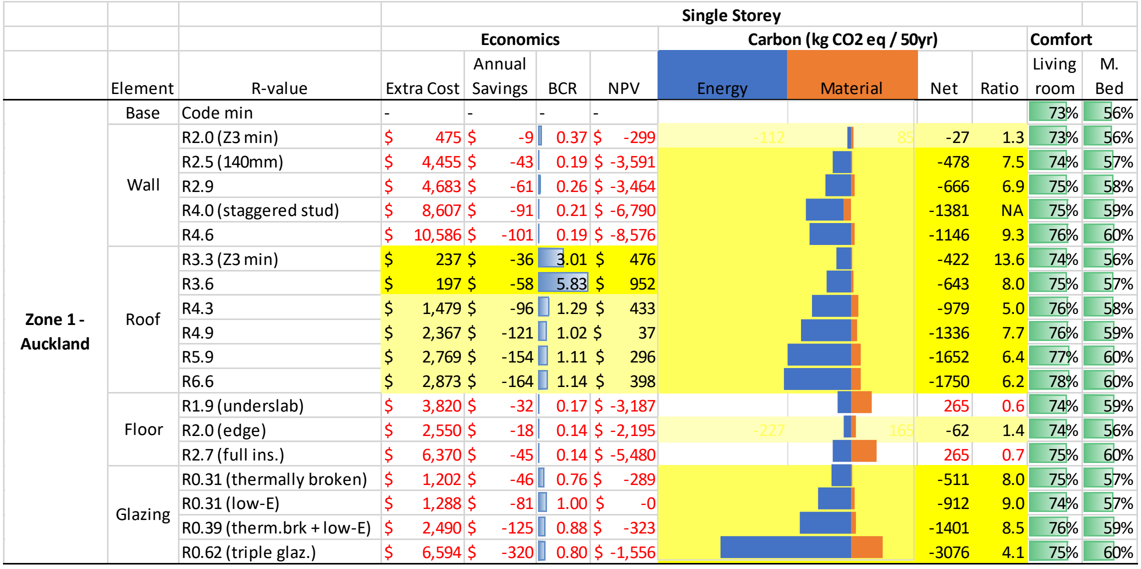
- For the purposes of this assessment, we assume that the argon gas fill is maintained in the IGU up to the point when the IGU is replaced. Deterioration of seals years prior may mean that argon is lost before replacement, which would decrease the construction R-value of the window. The implications of this have not been assessed.

3.4 CBA summary of individual element upgrades

This subsection should be read in conjunction with the Excel file ‘**Final_results_static3**’. It has tables for each of the six climate zones, four dwelling typologies and construction upgrades.

Table 14 provides a (partial) screenshot of the CBA summary table combining the economic, carbon and thermal comfort figures resulting from individual building envelope element upgrades. All figures are given as the marginal cost or benefit compared to Code minimum. Only the results from the single-storey dwelling located in Zone 1 – Auckland are provided here. The remaining whole-building results for the six climates are located in Appendix E. The complete set (which also provides results by floor area) can be viewed in the Excel file ‘**net_carbon_static4**’.

Table 14: CBA summary of individual upgrades for single-storey house (Auckland)



			Single Storey									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					73%	56%
	Wall	R2.0 (Z3 min)	$ 475	$ -9	0.37	$ -299	-112	85	-27	1.3	73%	56%
		R2.5 (140mm)	$ 4,455	$ -43	0.19	$ -3,591			-478	7.5	74%	57%
		R2.9	$ 4,683	$ -61	0.26	$ -3,464			-666	6.9	75%	58%
		R4.0 (staggered stud)	$ 8,607	$ -91	0.21	$ -6,790			-1381	NA	75%	59%
		R4.6	$ 10,586	$ -101	0.19	$ -8,576			-1146	9.3	76%	60%
	Roof	R3.3 (Z3 min)	$ 237	$ -36	3.01	$ 476			-422	13.6	74%	56%
		R3.6	$ 197	$ -58	5.83	$ 952			-643	8.0	75%	57%
		R4.3	$ 1,479	$ -96	1.29	$ 433			-979	5.0	76%	58%
		R4.9	$ 2,367	$ -121	1.02	$ 37			-1336	7.7	76%	59%
		R5.9	$ 2,769	$ -154	1.11	$ 296			-1652	6.4	77%	60%
		R6.6	$ 2,873	$ -164	1.14	$ 398			-1750	6.2	78%	60%
	Floor	R1.9 (underslab)	$ 3,820	$ -32	0.17	$ -3,187			265	0.6	74%	59%
		R2.0 (edge)	$ 2,550	$ -18	0.14	$ -2,195	-227	165	-62	1.4	74%	56%
		R2.7 (full ins.)	$ 6,370	$ -45	0.14	$ -5,480			265	0.7	75%	60%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -46	0.76	$ -289			-511	8.0	75%	57%
		R0.31 (low-E)	$ 1,288	$ -81	1.00	$ -0			-912	9.0	74%	57%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -125	0.88	$ -323			-1401	8.5	76%	59%
		R0.62 (triple glaz.)	$ 6,594	$ -320	0.80	$ -1,556			-3076	4.1	75%	60%

Table 14 is highlighted as follows for faster interpretation and to identify the best choices.

RED = Negative overall result/poor return

LIGHT YELLOW = Technically positive overall result

DARK YELLOW = Strong overall result (benefit/cost ratio > 3, reasonable odds of staying positive even with less-optimistic energy saving projections)

These are the three themes assessed, each within its own set of columns:

- ‘**Economics**’ includes the extra material cost of applying the given upgrade, the estimated annual energy cost savings from reducing the space conditioning requirements and the benefit/cost ratio (BCR) and net present value (NPV) over a 50-year life. NPV is total benefits minus total costs. Therefore, the scale of the intervention matters, and higher-cost interventions that provide larger benefits would be favoured. BCR is the total benefits divided by the total costs. Higher BCRs are favoured to lower BCRs, and typically the highest BCR would be the preferred option.

- ‘**Carbon**’ includes a stacked bar plot of the operational emissions (‘Energy’) and the material-related emissions (‘Material’) showing their relative contributions. Also displayed is the sum of the operational and material emissions over a 50-year life. Here, a negative figure is a net carbon saving taking into account material and operational emissions. Finally shown is the ratio of operational to material emissions.
- ‘**Comfort**’ is the percentage of hours indoor temperatures are between 18–25°C in the main living space in the day and in the master bedroom overnight via passive means only.

Preliminary findings for the four building typologies have been divided into two groups, reflecting the fundamental thermal differences in response the apartments have from the other typologies.

FINDINGS: Detached single-storey, double-storey and MDH typologies

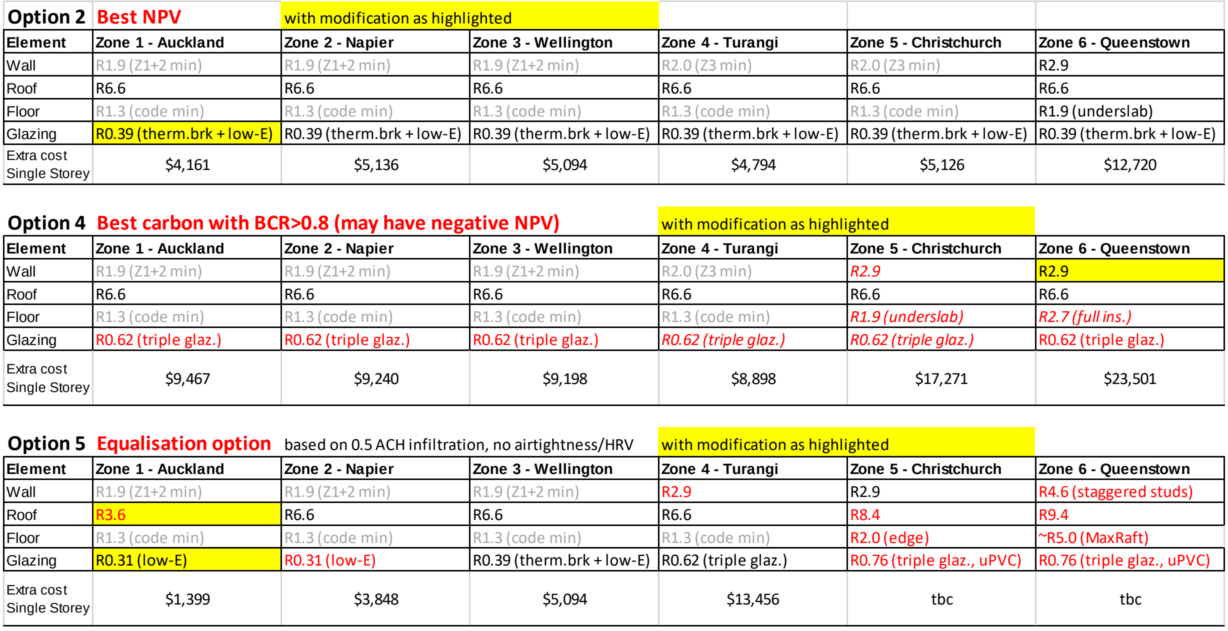
- Patterns of what options returned favourable/unfavourable results are consistent across the three typologies.
- Favourable carbon results are more consistent compared to favourable economic results.
- Comfort as a metric is relatively insensitive to the various changes.
- Returns on roof insulation are the best, as it is cheap to insulate. Glazing is the next best to upgrade, although the returns here depend on what overheating/cooling setpoint and schedule assumptions are made.
- Wall upgrades are very expensive and not economical due to the cost of extra framing. However, extra timber may be a good thing from a carbon standpoint as it allows for additional sequestration.
- Edge insulation appears to have a poor return from both a carbon and financial perspective, mostly due to the need for protection. Underslab insulation may be economical in the coldest parts of the country.

FINDINGS: Apartments

- Most of the above points for the other three dwelling typologies still apply, although the apartments experience considerably higher cooling loads compared to the other dwelling types. The thermal performance of glazing is the only element that significantly affects cooling thermal performance, as glazing with lower SHGC (low-E coatings, triple glazing) reduces solar heat gains. Wall, floor and roof R-values only have a minor impact on cooling loads.
- This means that upgrades to apartments that only address heat loss and not heat gain can make their overall performance worse.
- The comfort metric is more sensitive to the move from double to triple glazing compared to the other building typologies.
- Roof upgrades are still cost-effective, but it only affects a small part of the building
- Due to the design of the apartment building examined, this study is unable to provide any information on the impacts of improved floor insulation in apartment buildings.

3.5 Detailed CBA analysis

These building-level worksheets were examined by MBIE to shortlist combinations to go forward with more detailed analysis. In all, 18 R-value combinations were decided on for further consideration, where technical and practical challenges were considered alongside the three main characteristics (carbon, cost and comfort) already included. The R-value combinations examined are shown in Figure 24.



Option 2 **Best NPV** with modification as highlighted

Element	Zone 1 - Auckland	Zone 2 - Napier	Zone 3 - Wellington	Zone 4 - Turangi	Zone 5 - Christchurch	Zone 6 - Queenstown
Wall	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R2.0 (Z3 min)	R2.0 (Z3 min)	R2.9
Roof	R6.6	R6.6	R6.6	R6.6	R6.6	R6.6
Floor	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R1.9 (underslab)
Glazing	R0.39 (therm.brk + low-E)	R0.39 (therm.brk + low-E)	R0.39 (therm.brk + low-E)	R0.39 (therm.brk + low-E)	R0.39 (therm.brk + low-E)	R0.39 (therm.brk + low-E)
Extra cost Single Storey	$4,161	$5,136	$5,094	$4,794	$5,126	$12,720

Option 4 **Best carbon with BCR>0.8 (may have negative NPV)** with modification as highlighted

Element	Zone 1 - Auckland	Zone 2 - Napier	Zone 3 - Wellington	Zone 4 - Turangi	Zone 5 - Christchurch	Zone 6 - Queenstown
Wall	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R2.0 (Z3 min)	*R2.9*	R2.9
Roof	R6.6	R6.6	R6.6	R6.6	R6.6	R6.6
Floor	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	*R1.9 (underslab)*	*R2.7 (full ins.)*
Glazing	R0.62 (triple glaz.)	R0.62 (triple glaz.)	R0.62 (triple glaz.)	*R0.62 (triple glaz.)*	*R0.62 (triple glaz.)*	R0.62 (triple glaz.)
Extra cost Single Storey	$9,467	$9,240	$9,198	$8,898	$17,271	$23,501

Option 5 **Equalisation option** based on 0.5 ACH infiltration, no airtightness/HRV with modification as highlighted

Element	Zone 1 - Auckland	Zone 2 - Napier	Zone 3 - Wellington	Zone 4 - Turangi	Zone 5 - Christchurch	Zone 6 - Queenstown
Wall	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R1.9 (Z1+2 min)	R2.9	R2.9	R4.6 (staggered studs)
Roof	R3.6	R6.6	R6.6	R6.6	R8.4	R9.4
Floor	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R1.3 (code min)	R2.0 (edge)	~R5.0 (MaxRaft)
Glazing	R0.31 (low-E)	R0.31 (low-E)	R0.39 (therm.brk + low-E)	R0.62 (triple glaz.)	R0.76 (triple glaz., uPVC)	R0.76 (triple glaz., uPVC)
Extra cost Single Storey	$1,399	$3,848	$5,094	$13,456	tbc	tbc

Figure 24: Screenshot of MBIE R-value preferences and combinations

These three themes were explored:

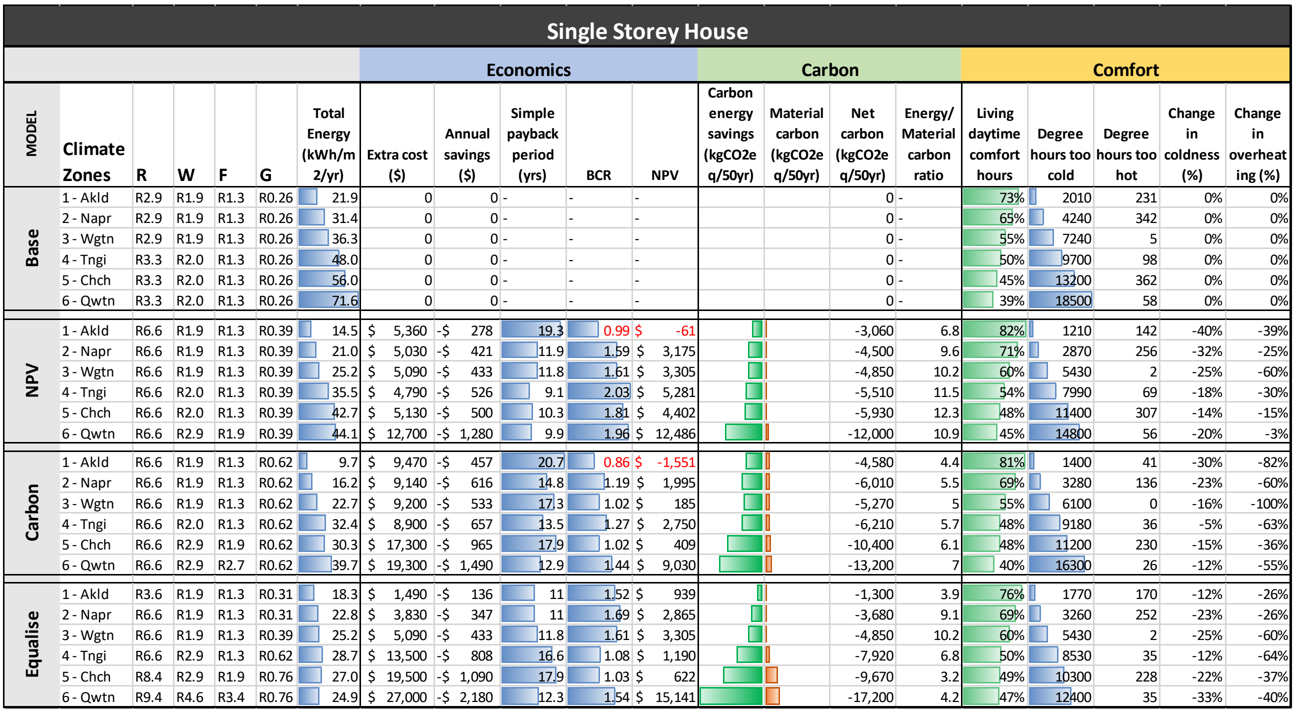
- **Best NPV:** for furthering the economic analysis.
- **Best carbon:** for furthering the environmental implications with the caveat that the benefit to cost ratios needed for each individual element R-value option are higher than 0.8.
- **Equalisation option**: for further understanding how much houses in the cooler climates would need to increase their R-values to enable the homes to have similar space conditioning loading as those houses in a thermally more neutral zone. Wellington's climate was selected as the thermally neutral zone.

These 18 R-value shortlisted combinations were then more fully investigated in terms of their economic, carbon and comfort characteristics for each of the six climate zones. These more comprehensive results were grouped into four meta-tables, one for each building typology, as shown in Figure 25 to Figure 28. Each of the three themes explored (NPV, carbon and equalisation) were compared to the base case NZBC-equivalent building ('Base'). Once again, six climate zones are explored: #1: Auckland, #2: Napier, #3: Wellington, #4: Turangi, #5: Christchurch and #6: Queenstown. Note that the place names associated with the six newly chosen climate zones do not necessarily describe the geographic location of the climate zone but rather the location of the chosen weather file representing the climate zone.

As can be seen in Figure 25 to Figure 28, all of these options provide reasonable performance upgrades. The question becomes, how much are stakeholders willing to pay for what level of performance? In terms of climate change implications, it is difficult to say anything about how close these results are in reaching absolute targets when this science is still being finalised.

There are many parallels for the four typologies, so the commonalities can be summarised:

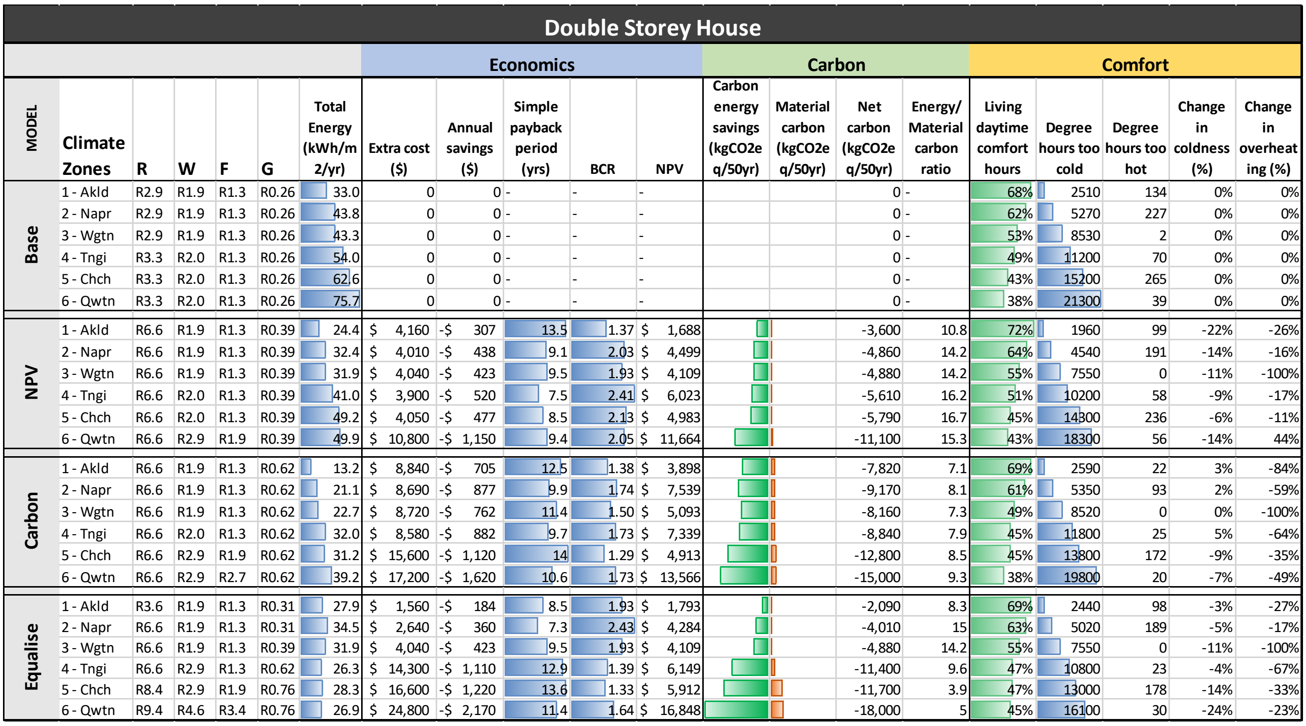
- **Economics:** The BCRs are low for all options and only greater than 2 for a few options.
- **Carbon:** There are benefits for all options considered, resulting in a net reduction in carbon emissions in all cases.
- **Comfort:** The degree hours too cold in all options changes considerably from the base case, as does the degree hours too hot. Note that the comfort metrics were all based on using thermal modelling to examine the internal temperatures achieved passively throughout the year without active heating or cooling.



Single Storey House

							Economics						Carbon				Comfort				
MODEL	Climate Zones	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/ Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	1 - Akld	R2.9	R1.9	R1.3	R0.26	21.9	0	0	-	-	-			0	-	73%	2010	231	0%	0%
	2 - Napr	R2.9	R1.9	R1.3	R0.26	31.4	0	0	-	-	-			0	-	65%	4240	342	0%	0%
	3 - Wgtn	R2.9	R1.9	R1.3	R0.26	36.3	0	0	-	-	-			0	-	55%	7240	5	0%	0%
	4 - Tngi	R3.3	R2.0	R1.3	R0.26	48.0	0	0	-	-	-			0	-	50%	9700	98	0%	0%
	5 - Chch	R3.3	R2.0	R1.3	R0.26	56.0	0	0	-	-	-			0	-	45%	13200	362	0%	0%
	6 - Qwtn	R3.3	R2.0	R1.3	R0.26	71.6	0	0	-	-	-			0	-	39%	18500	58	0%	0%
NPV	1 - Akld	R6.6	R1.9	R1.3	R0.39	14.5	$ 5,360	-$ 278	19.3	0.99	$ -61			-3,060	6.8	82%	1210	142	-40%	-39%
	2 - Napr	R6.6	R1.9	R1.3	R0.39	21.0	$ 5,030	-$ 421	11.9	1.59	$ 3,175			-4,500	9.6	71%	2870	256	-32%	-25%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	25.2	$ 5,090	-$ 433	11.8	1.61	$ 3,305			-4,850	10.2	60%	5430	2	-25%	-60%
	4 - Tngi	R6.6	R2.0	R1.3	R0.39	35.5	$ 4,790	-$ 526	9.1	2.03	$ 5,281			-5,510	11.5	54%	7990	69	-18%	-30%
	5 - Chch	R6.6	R2.0	R1.3	R0.39	42.7	$ 5,130	-$ 500	10.3	1.81	$ 4,402			-5,930	12.3	48%	11400	307	-14%	-15%
	6 - Qwtn	R6.6	R2.9	R1.9	R0.39	44.1	$ 12,700	-$ 1,280	9.9	1.96	$ 12,486			-12,000	10.9	45%	14800	56	-20%	-3%
Carbon	1 - Akld	R6.6	R1.9	R1.3	R0.62	9.7	$ 9,470	-$ 457	20.7	0.86	$ -1,551			-4,580	4.4	81%	1400	41	-30%	-82%
	2 - Napr	R6.6	R1.9	R1.3	R0.62	16.2	$ 9,140	-$ 616	14.8	1.19	$ 1,995			-6,010	5.5	69%	3280	136	-23%	-60%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.62	22.7	$ 9,200	-$ 533	17.3	1.02	$ 185			-5,270	5	55%	6100	0	-16%	-100%
	4 - Tngi	R6.6	R2.0	R1.3	R0.62	32.4	$ 8,900	-$ 657	13.5	1.27	$ 2,750			-6,210	5.7	48%	9180	36	-5%	-63%
	5 - Chch	R6.6	R2.9	R1.9	R0.62	30.3	$ 17,300	-$ 965	17.9	1.02	$ 409			-10,400	6.1	48%	11200	230	-15%	-36%
	6 - Qwtn	R6.6	R2.9	R2.7	R0.62	39.7	$ 19,300	-$ 1,490	12.9	1.44	$ 9,030			-13,200	7	40%	16300	26	-12%	-55%
Equalise	1 - Akld	R3.6	R1.9	R1.3	R0.31	18.3	$ 1,490	-$ 136	11	1.52	$ 939			-1,300	3.9	76%	1770	170	-12%	-26%
	2 - Napr	R6.6	R1.9	R1.3	R0.31	22.8	$ 3,830	-$ 347	11	1.69	$ 2,865			-3,680	9.1	69%	3260	252	-23%	-26%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	25.2	$ 5,090	-$ 433	11.8	1.61	$ 3,305			-4,850	10.2	60%	5430	2	-25%	-60%
	4 - Tngi	R6.6	R2.9	R1.3	R0.62	28.7	$ 13,500	-$ 808	16.6	1.08	$ 1,190			-7,920	6.8	50%	8530	35	-12%	-64%
	5 - Chch	R8.4	R2.9	R1.9	R0.76	27.0	$ 19,500	-$ 1,090	17.9	1.03	$ 622			-9,670	3.2	49%	10300	228	-22%	-37%
	6 - Qwtn	R9.4	R4.6	R3.4	R0.76	24.9	$ 27,000	-$ 2,180	12.3	1.54	$ 15,141			-17,200	4.2	47%	12400	35	-33%	-40%

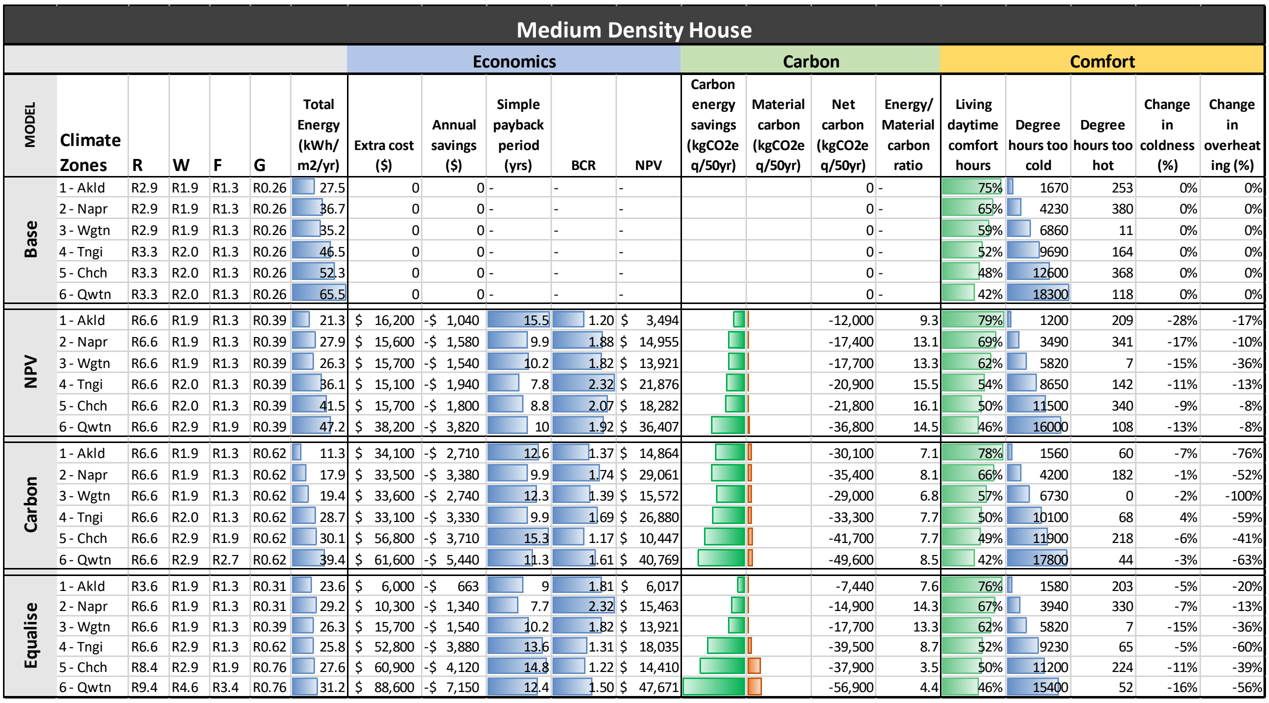
Figure 25: Screenshot of single-storey dwelling example: combined economics, carbon and comfort results



Double Storey House

							Economics						Carbon				Comfort				
MODEL	Climate Zones	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/ Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	1 - Akld	R2.9	R1.9	R1.3	R0.26	33.0	0	0	-	-	-			0	-	68%	2510	134	0%	0%
	2 - Napr	R2.9	R1.9	R1.3	R0.26	43.8	0	0	-	-	-			0	-	62%	5270	227	0%	0%
	3 - Wgtn	R2.9	R1.9	R1.3	R0.26	43.3	0	0	-	-	-			0	-	53%	8530	2	0%	0%
	4 - Tngi	R3.3	R2.0	R1.3	R0.26	54.0	0	0	-	-	-			0	-	49%	11200	70	0%	0%
	5 - Chch	R3.3	R2.0	R1.3	R0.26	62.6	0	0	-	-	-			0	-	43%	15200	265	0%	0%
	6 - Qwtn	R3.3	R2.0	R1.3	R0.26	75.7	0	0	-	-	-			0	-	38%	21300	39	0%	0%
NPV	1 - Akld	R6.6	R1.9	R1.3	R0.39	24.4	$ 4,160	-$ 307	13.5	1.37	$ 1,688			-3,600	10.8	72%	1960	99	-22%	-26%
	2 - Napr	R6.6	R1.9	R1.3	R0.39	32.4	$ 4,010	-$ 438	9.1	2.03	$ 4,499			-4,860	14.2	64%	4540	191	-14%	-16%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	31.9	$ 4,040	-$ 423	9.5	1.93	$ 4,109			-4,880	14.2	55%	7550	0	-11%	-100%
	4 - Tngi	R6.6	R2.0	R1.3	R0.39	41.0	$ 3,900	-$ 520	7.5	2.41	$ 6,023			-5,610	16.2	51%	10200	58	-9%	-17%
	5 - Chch	R6.6	R2.0	R1.3	R0.39	49.2	$ 4,050	-$ 477	8.5	2.13	$ 4,983			-5,790	16.7	45%	14300	236	-6%	-11%
	6 - Qwtn	R6.6	R2.9	R1.9	R0.39	49.9	$ 10,800	-$ 1,150	9.4	2.05	$ 11,664			-11,100	15.3	43%	18300	56	-14%	44%
Carbon	1 - Akld	R6.6	R1.9	R1.3	R0.62	13.2	$ 8,840	-$ 705	12.5	1.38	$ 3,898			-7,820	7.1	69%	2590	22	3%	-84%
	2 - Napr	R6.6	R1.9	R1.3	R0.62	21.1	$ 8,690	-$ 877	9.9	1.74	$ 7,539			-9,170	8.1	61%	5350	93	2%	-59%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.62	22.7	$ 8,720	-$ 762	11.4	1.50	$ 5,093			-8,160	7.3	49%	8520	0	0%	-100%
	4 - Tngi	R6.6	R2.0	R1.3	R0.62	32.0	$ 8,580	-$ 882	9.7	1.73	$ 7,339			-8,840	7.9	45%	11800	25	5%	-64%
	5 - Chch	R6.6	R2.9	R1.9	R0.62	31.2	$ 15,600	-$ 1,120	14	1.29	$ 4,913			-12,800	8.5	45%	13800	172	-9%	-35%
	6 - Qwtn	R6.6	R2.9	R2.7	R0.62	39.2	$ 17,200	-$ 1,620	10.6	1.73	$ 13,566			-15,000	9.3	38%	19800	20	-7%	-49%
Equalise	1 - Akld	R3.6	R1.9	R1.3	R0.31	27.9	$ 1,560	-$ 184	8.5	1.93	$ 1,793			-2,090	8.3	69%	2440	98	-3%	-27%
	2 - Napr	R6.6	R1.9	R1.3	R0.31	34.5	$ 2,640	-$ 360	7.3	2.43	$ 4,284			-4,010	15	63%	5020	189	-5%	-17%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	31.9	$ 4,040	-$ 423	9.5	1.93	$ 4,109			-4,880	14.2	55%	7550	0	-11%	-100%
	4 - Tngi	R6.6	R2.9	R1.3	R0.62	26.3	$ 14,300	-$ 1,110	12.9	1.39	$ 6,149			-11,400	9.6	47%	10800	23	-4%	-67%
	5 - Chch	R8.4	R2.9	R1.9	R0.76	28.3	$ 16,600	-$ 1,220	13.6	1.33	$ 5,912			-11,700	3.9	47%	13000	178	-14%	-33%
	6 - Qwtn	R9.4	R4.6	R3.4	R0.76	26.9	$ 24,800	-$ 2,170	11.4	1.64	$ 16,848			-18,000	5	45%	16100	30	-24%	-23%

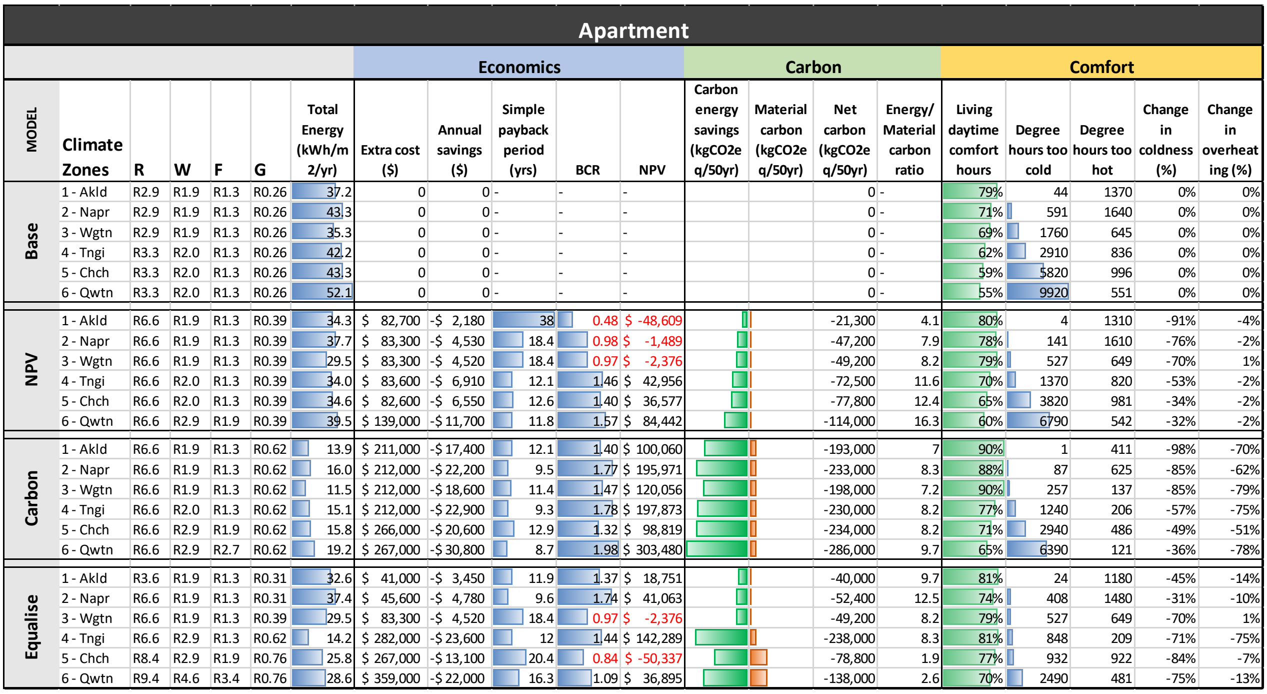
Figure 26: Screenshot of double-storey dwelling example: combined economics, carbon and comfort results



Medium Density House

MODEL	Climate Zones	R	W	F	G	Total Energy (kWh/m2/yr)	Economics: Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon: Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Comfort: Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	1 - Akld	R2.9	R1.9	R1.3	R0.26	27.5	0	0	-	-	-			0	-	75%	1670	253	0%	0%
	2 - Napr	R2.9	R1.9	R1.3	R0.26	36.7	0	0	-	-	-			0	-	65%	4230	380	0%	0%
	3 - Wgtn	R2.9	R1.9	R1.3	R0.26	35.2	0	0	-	-	-			0	-	59%	6860	11	0%	0%
	4 - Tngi	R3.3	R2.0	R1.3	R0.26	46.5	0	0	-	-	-			0	-	52%	9690	164	0%	0%
	5 - Chch	R3.3	R2.0	R1.3	R0.26	52.3	0	0	-	-	-			0	-	48%	12600	368	0%	0%
	6 - Qwtn	R3.3	R2.0	R1.3	R0.26	65.5	0	0	-	-	-			0	-	42%	18300	118	0%	0%
NPV	1 - Akld	R6.6	R1.9	R1.3	R0.39	21.3	$ 16,200	-$ 1,040	15.5	1.20	$ 3,494			-12,000	9.3	79%	1200	209	-28%	-17%
	2 - Napr	R6.6	R1.9	R1.3	R0.39	27.9	$ 15,600	-$ 1,580	9.9	1.88	$ 14,955			-17,400	13.1	69%	3490	341	-17%	-10%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	26.3	$ 15,700	-$ 1,540	10.2	1.82	$ 13,921			-17,700	13.3	62%	5820	7	-15%	-36%
	4 - Tngi	R6.6	R2.0	R1.3	R0.39	36.1	$ 15,100	-$ 1,940	7.8	2.32	$ 21,876			-20,900	15.5	54%	8650	142	-11%	-13%
	5 - Chch	R6.6	R2.0	R1.3	R0.39	41.5	$ 15,700	-$ 1,800	8.8	2.07	$ 18,282			-21,800	16.1	50%	11500	340	-9%	-8%
	6 - Qwtn	R6.6	R2.9	R1.9	R0.39	47.2	$ 38,200	-$ 3,820	10	1.92	$ 36,407			-36,800	14.5	46%	16000	108	-13%	-8%
Carbon	1 - Akld	R6.6	R1.9	R1.3	R0.62	11.3	$ 34,100	-$ 2,710	12.6	1.37	$ 14,864			-30,100	7.1	78%	1560	60	-7%	-76%
	2 - Napr	R6.6	R1.9	R1.3	R0.62	17.9	$ 33,500	-$ 3,380	9.9	1.74	$ 29,061			-35,400	8.1	66%	4200	182	-1%	-52%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.62	19.4	$ 33,600	-$ 2,740	12.3	1.39	$ 15,572			-29,000	6.8	57%	6730	0	-2%	-100%
	4 - Tngi	R6.6	R2.0	R1.3	R0.62	28.7	$ 33,100	-$ 3,330	9.9	1.69	$ 26,880			-33,300	7.7	50%	10100	68	4%	-59%
	5 - Chch	R6.6	R2.9	R1.9	R0.62	30.1	$ 56,800	-$ 3,710	15.3	1.17	$ 10,447			-41,700	7.7	49%	11900	218	-6%	-41%
	6 - Qwtn	R6.6	R2.9	R2.7	R0.62	39.4	$ 61,600	-$ 5,440	11.3	1.61	$ 40,769			-49,600	8.5	42%	17800	44	-3%	-63%
Equalise	1 - Akld	R3.6	R1.9	R1.3	R0.31	23.6	$ 6,000	-$ 663	9	1.81	$ 6,017			-7,440	7.6	76%	1580	203	-5%	-20%
	2 - Napr	R6.6	R1.9	R1.3	R0.31	29.2	$ 10,300	-$ 1,340	7.7	2.32	$ 15,463			-14,900	14.3	67%	3940	330	-7%	-13%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	26.3	$ 15,700	-$ 1,540	10.2	1.82	$ 13,921			-17,700	13.3	62%	5820	7	-15%	-36%
	4 - Tngi	R6.6	R2.9	R1.3	R0.62	25.8	$ 52,800	-$ 3,880	13.6	1.31	$ 18,035			-39,500	8.7	52%	9230	65	-5%	-60%
	5 - Chch	R8.4	R2.9	R1.9	R0.76	27.6	$ 60,900	-$ 4,120	14.8	1.22	$ 14,410			-37,900	3.5	50%	11200	224	-11%	-39%
	6 - Qwtn	R9.4	R4.6	R3.4	R0.76	31.2	$ 88,600	-$ 7,150	12.4	1.50	$ 47,671			-56,900	4.4	46%	15400	52	-16%	-56%

Figure 27: Screenshot of MDH example: combined economics, carbon and comfort results.



Apartment

MODEL	Climate Zones	R	W	F	G	Total Energy (kWh/m2/yr)	Economics: Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon: Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Comfort: Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	1 - Akld	R2.9	R1.9	R1.3	R0.26	37.2	0	0	-	-	-			0	-	79%	44	1370	0%	0%
	2 - Napr	R2.9	R1.9	R1.3	R0.26	43.3	0	0	-	-	-			0	-	71%	591	1640	0%	0%
	3 - Wgtn	R2.9	R1.9	R1.3	R0.26	35.3	0	0	-	-	-			0	-	69%	1760	645	0%	0%
	4 - Tngi	R3.3	R2.0	R1.3	R0.26	42.2	0	0	-	-	-			0	-	62%	2910	836	0%	0%
	5 - Chch	R3.3	R2.0	R1.3	R0.26	43.3	0	0	-	-	-			0	-	59%	5820	996	0%	0%
	6 - Qwtn	R3.3	R2.0	R1.3	R0.26	52.1	0	0	-	-	-			0	-	55%	9920	551	0%	0%
NPV	1 - Akld	R6.6	R1.9	R1.3	R0.39	34.3	$ 82,700	-$ 2,180	38	0.48	$ -48,609			-21,300	4.1	80%	4	1310	-91%	-4%
	2 - Napr	R6.6	R1.9	R1.3	R0.39	37.7	$ 83,300	-$ 4,530	18.4	0.98	$ -1,489			-47,200	7.9	78%	141	1610	-76%	-2%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	29.5	$ 83,300	-$ 4,520	18.4	0.97	$ -2,376			-49,200	8.2	79%	527	649	-70%	1%
	4 - Tngi	R6.6	R2.0	R1.3	R0.39	34.0	$ 83,600	-$ 6,910	12.1	1.46	$ 42,956			-72,500	11.6	70%	1370	820	-53%	-2%
	5 - Chch	R6.6	R2.0	R1.3	R0.39	34.6	$ 82,600	-$ 6,550	12.6	1.40	$ 36,577			-77,800	12.4	65%	3820	981	-34%	-2%
	6 - Qwtn	R6.6	R2.9	R1.9	R0.39	39.5	$ 139,000	-$ 11,700	11.8	1.57	$ 84,442			-114,000	16.3	60%	6790	542	-32%	-2%
Carbon	1 - Akld	R6.6	R1.9	R1.3	R0.62	13.9	$ 211,000	-$ 17,400	12.1	1.40	$ 100,060			-193,000	7	90%	1	411	-98%	-70%
	2 - Napr	R6.6	R1.9	R1.3	R0.62	16.0	$ 212,000	-$ 22,200	9.5	1.77	$ 195,971			-233,000	8.3	88%	87	625	-85%	-62%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.62	11.5	$ 212,000	-$ 18,600	11.4	1.47	$ 120,056			-198,000	7.2	90%	257	137	-85%	-79%
	4 - Tngi	R6.6	R2.0	R1.3	R0.62	15.1	$ 212,000	-$ 22,900	9.3	1.78	$ 197,873			-230,000	8.2	77%	1240	206	-57%	-75%
	5 - Chch	R6.6	R2.9	R1.9	R0.62	15.8	$ 266,000	-$ 20,600	12.9	1.32	$ 98,819			-234,000	8.2	71%	2940	486	-49%	-51%
	6 - Qwtn	R6.6	R2.9	R2.7	R0.62	19.2	$ 267,000	-$ 30,800	8.7	1.98	$ 303,480			-286,000	9.7	65%	6390	121	-36%	-78%
Equalise	1 - Akld	R3.6	R1.9	R1.3	R0.31	32.6	$ 41,000	-$ 3,450	11.9	1.37	$ 18,751			-40,000	9.7	81%	24	1180	-45%	-14%
	2 - Napr	R6.6	R1.9	R1.3	R0.31	37.4	$ 45,600	-$ 4,780	9.6	1.74	$ 41,063			-52,400	12.5	74%	408	1480	-31%	-10%
	3 - Wgtn	R6.6	R1.9	R1.3	R0.39	29.5	$ 83,300	-$ 4,520	18.4	0.97	$ -2,376			-49,200	8.2	79%	527	649	-70%	1%
	4 - Tngi	R6.6	R2.9	R1.3	R0.62	14.2	$ 282,000	-$ 23,600	12	1.44	$ 142,289			-238,000	8.3	81%	848	209	-71%	-75%
	5 - Chch	R8.4	R2.9	R1.9	R0.76	25.8	$ 267,000	-$ 13,100	20.4	0.84	$ -50,337			-78,800	1.9	77%	932	922	-84%	-7%
	6 - Qwtn	R9.4	R4.6	R3.4	R0.76	28.6	$ 359,000	-$ 22,000	16.3	1.09	$ 36,895			-138,000	2.6	70%	2490	481	-75%	-13%

Figure 28: Screenshot of apartment example: combined economics, carbon and comfort results

Note that the apartments have worse returns on many of the options compared to the other three typologies. Also, net carbon stands out as being large – this is the consequence of triple glazing reducing cooling requirements.

The concept of degree hours too cold/too warm is included here. It is a common building science metric that is more useful in understanding the severity of thermal discomfort than, for example, the metric percentage of time uncomfortable.

Degree hours is simply the number of degrees Celsius by which the hourly average indoor temperature is below or above the comfortable temperature setpoint[29]. The extra benefit is that it is a considerably better reflection of severity – i.e. 1 hour at 29°C has four times the impact of 1 hour at 26°C (based on a setpoint temperature of 25°C).

DISCUSSION

There were some interesting mismatches between energy use and passive performance in the results. For example, in the carbon set, despite having lower energy use for heating and cooling than the NPV set, it has worse passive performance, being colder and have fewer comfort hours. Similarly, despite the relative consistency achieved in overall energy use in the equalise set, passive performance continues to vary significantly between climates, with the southern regions being substantially colder and less comfortable.

This may be explained by the difference between heat gains and losses and the multiple effects of high-performance glazing.

Firstly, we must note that most of the upgrades we have applied here are designed to reduce heat losses. This is a highly effective way to improve heating energy efficiency. However, the internal temperatures of the house will ultimately still rely on there being sufficient heat gains to bring them up to a comfortable level. When looking at passive performance, we are reliant upon the internal heat gains from people and appliances as well as the sun. What we see here is that, in colder parts of the country, those heat gains are not enough on their own to counteract how cold the climate is – even if we significantly increase the insulation levels.

Secondly, many of the upgrades made to glazing to improve its thermal performance (low-E coatings, additional layers of glass) also reduce its solar heat gain coefficient (SHGC). This can make it quite effective at reducing overheating but also means that the house may end up colder in winter as it gets less heat from the sun.

When the heater is the main source of heat, this is (generally) not a problem as the reduction in heat losses outweighs the reduction in heat gains. However, when the sun is the main source of heat gains, reducing them can be much more of an issue. This is why the carbon set is passively colder – the triple glazing has much lower solar heat gains.

It should be noted that the benefit/cost ratios of most of the final construction sets were below two. Thus, reducing the benefits by a factor of three or four may result in them becoming negative, and not paying back within the 50-year lifespan examined here. That being said, the ratios for the carbon analysis were significantly higher, and may still provide a positive return in many cases even if the energy savings are significantly reduced.

Also, although the material costings figures were carefully sourced, industry representative information on some products is hard to source and we know there are considerable differences in price – both regionally and nationally. In response to this, a sensitivity study has been carried out looking at costing variants from -20% to 20%. See Appendix D for the full breakdown.

---

[29] Setpoint temperatures applied to this study: Heating to 18°C in all zones inside the thermal envelope. The cooling setpoint was 25°C.

3.6 Sensitivity of various other individual and combined issues

This subsection explores the impact on space conditioning of various other issues – both influencing individually as well as together. The specific issues investigated are shown in Table 15.

The single-storey house is shown here only, with the remaining examples in Appendix F as screenshots.

Table 15: Various dwelling components and operational characteristics

#	Issues and combinations of interventions
1	Adding curtains to all windows (to reduce the heat loss).
2	Changing infiltration to 0.3 ach (which may be common in new houses).
3	Changing infiltration to 0.16 ach (considered airtight, requiring mechanical heat recovery ventilation[30]).
4	Changing the groundwater depth from 2 m to 10 m (decreases heat loss through ground and thus lowers the value of slab insulation).
5	Better orientation (rotated by 90°).
6	More realistic heating schedule representing more typical behaviour (living areas 16°C during day, 18°C in the evening. No heating overnight. Bedrooms 15°C in the evening, otherwise off. Miscellaneous zones not conditioned. Cooling as normal when zones occupied.
7	Combine 2: MBIE realistic schedule, poor orientation, 10 m groundwater, 0.3 ach, curtains, and lowering the ventilation setpoint to 22°C while not closing the windows at 25°C.
8	Combine 1: Cooling only to living room(s) and only occupied zones space heated, 10 m groundwater, 0.3 ach, curtains and lowering the ventilation setpoint to 22°C.

Two types of results are shown: the total energy use changes because of the intervention and changes to the energy savings. Both metrics utilise the unmodified dwelling as the baseline, with both the energy saved and the saving expressed in terms of the percentage.

While the "realistic" heating schedules (e.g. #6) may be more representative of what New Zealanders commonly do, it may also be regarded as unhealthy and not what we actually want our houses to be designed to. At the same time, heating the entire house 24 hours a day even when people are not in the rooms might be regarded as excessive. A middle ground may be found in the other combination set where rooms are heated to 18 degrees when occupied. This variation still uses substantially less energy than 24/7 conditioning, and we may see the potential energy savings reduced by a factor of around four.

Note that these types of limited comparative studies highlight some anomalies and unexpected issues that occur in trying to comprehensively represent the real world, such as:

- R4.0 batt insulation is cheaper than R3.6.
- triple glazing looks better for double-storey stand-alone and MDH as these two representative buildings have a larger issue with overheating than the stand-alone home representative dwellings
- no skylights or sky-windows are included in the study, as none of the four representative buildings have them.

Table 16 shows the results of the various sensitivity issues outlined in Table 15. The blue staked bars provide a quick comparative visualisation of the magnitude of the change. For example, in the Auckland house, introducing curtains to all windows reduces energy savings

---

[30] This is the effective infiltration heat loss rate once we account for the ventilation provided by the system and the lower levels of air leakage.

and benefits produced by the NPV construction upgrades by ~9% compared to the same house without curtains. The methodology for the curtains follows that used in Wareing (2015). The remaining typology results can be found in Appendix F. These were the key findings:

- The largest influencers by far on energy saving for all the dwelling types are the realistic heating schedule and the two combination initiatives. Although this may represent more common behaviour typically found in New Zealand houses, it is still classed as underheating by international guidelines and standards.
- The realistic heating schedule results in ~80% decrease in energy use for the single-storey house, ~60% decrease in the double-storey house, ~70% decrease in the MDH and ~50% decrease in the apartments. It should be noted that these MBIE-suggested temperatures (16°C in the day, 18°C in the evening) would be considered uncomfortably cold by many.
- Poor orientation was one of the least-impacting changes for all dwellings. Although this is true for the representative dwelling examples chosen, for a well-designed solar-responsive dwelling, orientation will be considerably more influential.

Table 16: Various sensitivity studies, both individual and combined savings, on single-storey house

					Single Storey House (percent savings)							
Climate	**Set**	**Roof**	**Wall**	**Floor**	**Glaz.**	**Curtains**	**0.3ACH**	**0.16ACH**	**10m ground water**	**Better oriented (+90)**	**"Realistic" heating schedule**	**Combined 2**	**Combined 1**
Akld	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Napr	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Wtn	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Trngi	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Chch	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Qtwn	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Akld	NPV	R2.9	R1.9	R1.3	R0.26	91%	94%	88%	95%	96%	26%	11%	33%
Napr	NPV	R2.9	R1.9	R1.3	R0.26	91%	95%	91%	98%	95%	25%	14%	46%
Wtn	NPV	R2.9	R1.9	R1.3	R0.26	90%	96%	93%	98%	97%	24%	17%	49%
Trngi	NPV	R3.3	R2.0	R1.3	R0.26	90%	97%	95%	99%	96%	26%	19%	53%
Chch	NPV	R3.3	R2.0	R1.3	R0.26	90%	97%	95%	99%	98%	27%	22%	56%
Qtwn	NPV	R3.3	R2.0	R1.3	R0.26	94%	96%	93%	91%	102%	27%	24%	56%
Akld	Carbon	R2.9	R1.9	R1.3	R0.26	94%	99%	98%	101%	85%	36%	12%	26%
Napr	Carbon	R2.9	R1.9	R1.3	R0.26	92%	99%	98%	102%	84%	30%	14%	37%
Wtn	Carbon	R2.9	R1.9	R1.3	R0.26	89%	100%	99%	100%	87%	24%	14%	41%
Trngi	Carbon	R3.3	R2.0	R1.3	R0.26	88%	100%	100%	102%	86%	25%	16%	46%
Chch	Carbon	R3.3	R2.0	R1.3	R0.26	92%	97%	95%	92%	97%	26%	20%	49%
Qtwn	Carbon	R3.3	R2.0	R1.3	R0.26	92%	98%	97%	97%	98%	26%	23%	55%
Akld	Equalise	R2.9	R1.9	R1.3	R0.26	92%	98%	96%	100%	92%	34%	13%	29%
Napr	Equalise	R2.9	R1.9	R1.3	R0.26	94%	96%	93%	99%	93%	27%	15%	46%
Wtn	Equalise	R2.9	R1.9	R1.3	R0.26	90%	96%	93%	98%	97%	24%	17%	49%
Trngi	Equalise	R3.3	R2.0	R1.3	R0.26	90%	100%	99%	101%	88%	25%	17%	48%
Chch	Equalise	R3.3	R2.0	R1.3	R0.26	92%	97%	94%	93%	97%	26%	20%	50%
Qtwn	Equalise	R3.3	R2.0	R1.3	R0.26	94%	96%	93%	92%	99%	27%	23%	53%

3.7 The impact of massive (heavyweight) structure

This step examined the possibility of generating replacement tables for NZS 4218:2009 Tables 3 and 4. These two tables provide construction R-values (in the form of look-up tables) for dwellings with solid mass timber walls and high thermal mass walls such as masonry block and concrete panels.

The method was to use dynamic thermal modelling to determine what R-values were needed in the high mass dwellings to achieve annual heating and cooling loads similar to when they were modelled in their lightweight format. As before, the six new zone climates were investigated but only the non-apartment dwellings were considered, as the apartments are already a highly massive structure. A conservative approach was taken to this mini-study where we try to make sure none of the houses need more heating than they would with identical lightweight timber construction.

The preferred combinations of construction R-values are shown in Table 17 to Table 19, which group solutions by NPV, Carbon and Equalise options. Note that NZS 4218:2009 Tables 3 and 4 have been amalgamated so both solid timber and concrete walls have been incorporated into one table. For more extensive results, refer to the file ‘**mass_results.xls**’.

Notes

- R-values include surface air, cladding, insulation, mass etc. Values have been rounded down to nearest 0.1 m^{2o}C/W.
- R-values were set based on trying to equalise space heating energy use as this seemed like it would be most consistent with the current tables in the Code. Naturally, mass has the potential to also reduce cooling requirements.
- It should be noted that there is considerable variation between different houses, so consequently there is no one ‘correct’ R-value. The MDH dwelling stands out as benefiting considerably more from mass than the detached houses, resulting in lower energy use. Whether this should be accounted for in future is the question for regulators.

Table 17: Construction R-values for building with mass walls (NPV focus)

Construction R-values for mass walls for the different construction sets						
	NPV					
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**
Heavy (190mm concrete)	1	1.1	1.2	1.2	1.3	2
75mm timber on external walls, none on internal	1.3	1.3	1.4	1.4	1.4	2.1
60mm timber on external walls, 45mm on internal	1.2	1.2	1.3	1.3	1.4	2.1
60mm timber on external walls, 60mm on internal	1.2	1.2	1.3	1.3	1.4	2
90mm timber on external walls, 45mm on internal	1.2	1.2	1.4	1.5	1.5	2.1

Table 18: Construction R-values for building with mass walls (carbon focus)

Construction R-values for mass walls for the different construction sets						
	Carbon					
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**
Heavy (190mm concrete)	1.2	1.2	1.4	1.4	2.1	2.2
75mm timber on external walls, none on internal	1.3	1.3	1.4	1.5	2.2	2.3
60mm timber on external walls, 45mm on internal	1.3	1.3	1.4	1.5	2.2	2.3
60mm timber on external walls, 60mm on internal	1.3	1.3	1.4	1.4	2.2	2.3
90mm timber on external walls, 45mm on internal	1.4	1.4	1.5	1.5	2.2	2.3

Table 19: Construction R-values for building with mass walls (equalise focus)

Construction R-values for mass walls for the different construction sets						
	Equalise					
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**
Heavy (190mm concrete)	1	1	1.2	1.9	2.2	3.5
75mm timber on external walls, none on internal	1.3	1.3	1.3	2.1	2.3	3.7
60mm timber on external walls, 45mm on internal	1.2	1.2	1.3	2	2.2	3.6
60mm timber on external walls, 60mm on internal	1.2	1.2	1.3	2	2.2	3.6
90mm timber on external walls, 45mm on internal	1.1	1.2	1.4	2.1	2.3	3.6

The three tables show:

- an increase of ~20% in construction R-values in the carbon option over the NPV option
- the equalise option has similar construction R-values as for the NPV for the warmer climates (zones 1–3) but for the colder zones, a large increase (of around 60%) in R-values for the various constructions is needed for equivalency
- there are obvious trade-offs – for example, the carbon option provides better carbon savings but costs more.

4. Summary

This technical study was conducted to support the policy review on increasing the residential building insulation requirements of NZBC Acceptable Solution H1/AS1. Four representative residential building typologies were examined in detail – single-stand-alone houses, 2-storey detached, medium-density and apartments. An assessment was carried out at the individual building level for the next 50 years, examining the financial, carbon and comfort implications.

The cost-benefit and carbon analyses[31] of the various R-value scenarios examined in this study are largely based on conventional construction types that the New Zealand construction industry is currently familiar with. Alternative construction types, such as warm wall and roof construction, would likely have different cost and carbon characteristics than those presented in this study, and could potentially provide additional benefits and opportunities, such as reduced thermal bridging.

Currently, New Zealand is divided into three climate zones for Acceptable Solution H1/AS1, based on average temperature data. Zone 1 covers the upper North Island; Zone 2 covers the remaining North Island minus the Central Plateau while Zone 3 covers the remaining areas. The possibility of having a more granular response to better reflect New Zealand’s reasonably diverse climate was explored. This exploration was conducted using dynamic thermal modelling to determine the annual heating and cooling loads using the 18 New Zealand regional climate files developed by NIWA. Simulations were run both with the existing schedule method insulation level R-values, plus a higher set of R-values for each of the four representative dwellings.

It was found that the space heating energy use order is consistent across representative buildings, regardless of insulation level. Climates with similar heating and cooling loads were then grouped to create six updated climate zones. For each proposed new climate zone, a climate file most representative of both heating and cooling loads and population size was selected. This grouping of climates into six zones works well for smaller low-density and medium-density housing. However, due to apartment buildings’ being cooling dominated it is suggested that they would benefit from being considered separately in H1. As a result of this exploration, MBIE decided to apply the following six new climate zones (#1: Auckland; #2: Napier; #3: Wellington, #4: Turangi, #5: Christchurch and #6: Queenstown) for the analysis of different thermal envelope R-value options.

Following are four tables providing new solutions to the existing H1/AS1, effectively substituting for the ones currently provided in NZS 4218:2009. All have benefits and trade-offs that need to be considered by key stakeholders.

Table 20 and Table 21 cover two options for lightweight construction:

- Table 20 presents the R-values that were found to be most economical (NPV focus).
- Table 21 presents the R-values that were found to provide best net carbon reductions with the caveat of individual element R-values still providing a benefit-cost-ratio of at least 0.8 (carbon focus).

For residential buildings with high mass walls, Table 22 and Table 23 provide wall R-values as replacements for those in Tables 20 and 21 respectively. These high mass wall R-values are

---

[31] In addition to exploring cost-benefit and carbon aspects, an ‘equalisation’ option was examined. This was to better understand how much houses in cooler climates would need to increase their R-values to enable similar space conditioning loading as those houses in thermally more neutral zones (see Section 3.5). Given its very exploratory nature (and the extreme R-values resulting) it is not summarised here.

lower than those for lightweight construction, recognising the thermal benefits of the mass of these walls.

Like any focused study modelling reality, the tables come with qualifiers:

- This study focussed on thermal resistance options of the building envelope only. This is only one of many aspects that impact on the energy, comfort and carbon performance of residential buildings. For example, improved overheating design using orientation-specific external shading systems and targeted ventilation was not considered for this study.

  The roof insulation levels examined in
- and Table 21 fall outside of those contained within the BRANZ *House insulation guide* (5th edition). Converting these construction R-values into viable in situ solutions for some building elements will be challenging, requiring further investigation into build practicalities, hygrothermal performance implications and so on. These issues fall outside the scope of this study.
- A recent study (Ryan et al., 2020) found that the average wall framing percentages in 47 case study dwellings were above 34%. This is considerably higher than the 14–18% framing content generally assumed by regulators and the industry (and even the conservative 24% applied in this BRANZ review). Reducing wall framing percentages would make it more viable for higher in situ construction R-values to be achieved.
- Apartments are fundamentally thermally different from the other three dwelling typologies and therefore should be treated accordingly. To highlight the potential implications of the issues around apartment design and overheating, further exploration is needed. The optimal insulation levels are likely to be very different to the other dwelling typologies investigated, and cooling needs to be addressed specifically. The development of such an alternative standard for apartments is outside the scope of this study.
- Note that there are fewer sets of R-values than the proposed six climate zones in both Table 20 (which has three sets only) and Table 21 (which has four sets only). This is because despite the significant differences in New Zealand climates - in terms of dwelling heating and cooling requirements - for some climate zones the optimal R-value options were identical from an economic and carbon perspective.
- Simple and cost-effective solutions using alternative methods of improving the thermal performance of new residential builds should be examined alongside this study – for example: significantly reducing the allowable glazing area percentage of total external wall area before the calculation method is required; passive solar design; improving airtightness combined with whole house mechanical ventilation with heat recovery; and reducing thermal bridging over the whole building envelope.
- Ideally, the NZBC should move past R-value look-up tables for whole-building thermal assessment due to their many limitations and look towards dynamic, multi-zone thermal simulation to account for room-specific cooling also. This will provide considerably more robust and useful insights into year-round comfort and performance. The wide variance in thermal performance found in the BRANZ benchmarking studies illustrates the unreliability of the schedule method (Jaques, 2015, 2019).

Note that that the current (2020) acceptable schedule solution for minimum construction R values (in m^{2o}C/W) for lightweight (non-solid) dwellings, for Roof/Wall/Floor/Glazing equals:

2.9/1.9/1.3/0.26 (for NZS4218 Climate Zones 1 and 2), and
2.9/1.9/1.3/0.26 (for NZS4218 Climate Zone 3), respectively.

Table 20: Construction R-values for buildings with lightweight construction (NPV focus)

Climate	Roof	Wall	Floor	Glazing
Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39
Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39
Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39
Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39
Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39
Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39

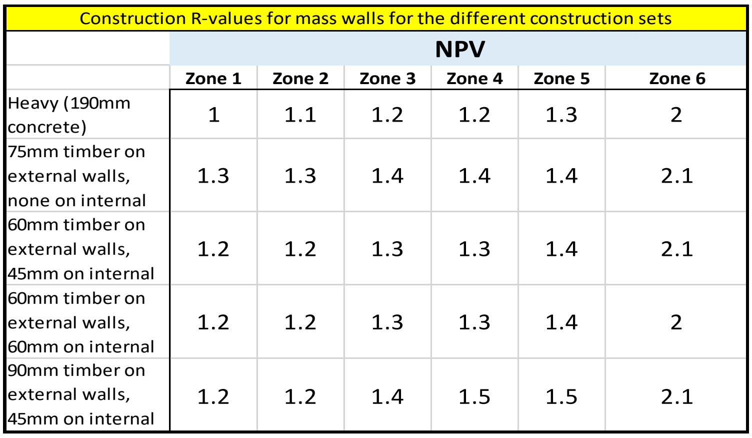
Table 21: Construction R-values for buildings with lightweight construction (carbon focus)

Climate	Roof	Wall	Floor	Glazing
Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62
Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62
Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62
Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62
Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62
Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62

Note that the current (2020) acceptable schedule solution for minimum construction R values (in m^2°C/W) for high thermal mass wall dwellings, for Roof/Wall/Floor/Glazing equals:

3.5/0.8/1.5/0.26 (for NZS4218 Climate Zone 1),
3.5/1.0/1.5/0.26 (for NZS4218 Climate Zone 2), and
3.5/1.2/1.5/0.26 (for NZS4218 Climate Zone 3), respectively.

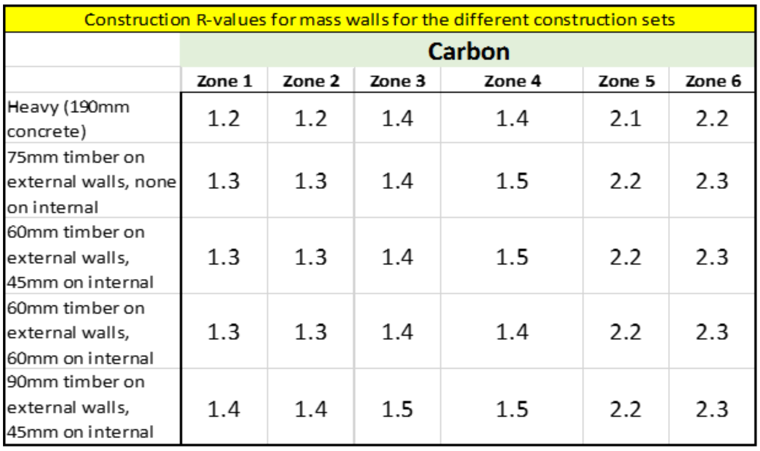
Table 22: Construction R-values for buildings with mass walls (NPV focus)



Construction R-values for mass walls for the different construction sets

	NPV					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Heavy (190mm concrete)	1	1.1	1.2	1.2	1.3	2
75mm timber on external walls, none on internal	1.3	1.3	1.4	1.4	1.4	2.1
60mm timber on external walls, 45mm on internal	1.2	1.2	1.3	1.3	1.4	2.1
60mm timber on external walls, 60mm on internal	1.2	1.2	1.3	1.3	1.4	2
90mm timber on external walls, 45mm on internal	1.2	1.2	1.4	1.5	1.5	2.1

Table 23: Construction R-values for buildings with mass walls (carbon focus)



Construction R-values for mass walls for the different construction sets

	Carbon					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Heavy (190mm concrete)	1.2	1.2	1.4	1.4	2.1	2.2
75mm timber on external walls, none on internal	1.3	1.3	1.4	1.5	2.2	2.3
60mm timber on external walls, 45mm on internal	1.3	1.3	1.4	1.5	2.2	2.3
60mm timber on external walls, 60mm on internal	1.3	1.3	1.4	1.4	2.2	2.3
90mm timber on external walls, 45mm on internal	1.4	1.4	1.5	1.5	2.2	2.3

References

Alcorn, J. A. (2010). *Global sustainability and the New Zealand house* (PhD thesis). Victoria University of Wellington, Wellington, New Zealand.

ASHRAE. (2010). *ANSI/ASHRAE Addendum B to ANSI/ASHRAE Standard 140-2007: Standard method of test for the evaluation of building energy analysis computer programs*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

BRANZ. (2014). *House insulation guide* (5th ed.). Judgeford, New Zealand: BRANZ Ltd.

Bullen, L (2020). *Life cycle based environmental impacts of future New Zealand electricity supply* (Master's thesis). Massey University, Palmerston North, New Zealand.

Burrough, L., Saville-Smith, K. & Pollard, A. (2015). *Heat pumps in New Zealand.* BRANZ Study Report SR329. Judgeford, New Zealand: BRANZ Ltd.

CIBSE. (2006). *CIBSE Guide A: Environmental design*. London, UK: Chartered Institution of Building Services Engineers.

Dowdell, D., Berg, B., Butler, J. & Pollard, A. (2020). *New Zealand whole-building whole-of-life framework: LCAQuick v3.4 – a tool to help designers understand how to evaluate building environmental performance*. BRANZ Study Report SR418. Judgeford, New Zealand: BRANZ Ltd.

Ellis, P. & Torcellini, P. (2005). *Simulating tall buildings using EnergyPlus*. Paper presented at the Ninth International Building Performance Simulation Association (IBPSA) Conference and Exhibition (Building Simulation 2005), Montreal, Quebec, 15–18 August.

Energy Market Authority. (2015). *Singapore energy statistics 2015*. Singapore: Energy Market Authority.

European Extruded Polystyrene Insulation Board Association. (2014). *Extruded polystyrene (XPS) foam insulation with HBCD flame retardant*. Environmental Product Declaration EPD-EXI-20140154-IBE1-EN).

Forman Building Systems/Dow Deutschland GmbH & Co. OHG. (2013). *XENERGY XPS extruded polystyrene foam insulation*. Environmental Product Declaration EPD-DOW-2013111-E.

European Federation of Concrete Admixtures Associations Ltd (EFCA) (2015). *Concrete admixtures – hardening accelerators.* Environmental Product Declaration EPD-EFC-20150089-IAG1-EN.

FWPA. (2015). *Softwood timber*. Environmental Product Declaration S-P-00560.

Gesamtverband der Aluminiumindustrie e.V. (GDA). (2013a). *Blank aluminium sheet*. Environmental Product Declaration EPD-GDA-20130258-IBG1-EN.

Gesamtverband der Aluminiumindustrie e.V. (GDA). (2013b). Col*d-formed aluminium sheet for exterior applications*. Environmental Product Declaration EPD-GDA-20130260-IBG1-EN.

Golden Bay Cement (2019). *EverSure^{TM} GP cement, EverFast^{TM} HE cement*. Environmental Product Declaration S-P-01170.

Hammond, G. & Jones, C. (2011). *Inventory of carbon & energy (ICE)* (v2.0). Bath, UK: University of Bath.

Holcim NZ Ltd (2019). *General purpose Portland cement (Ultracem) bulk supplied and bagged*. Environmental Product Declaration S-P-00850.

IPCC. (2007). *Climate change 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

JACKON Insulation GmbH. (2015). *JACKODUR Plus – extruded polystyrene (XPS) with HFO 1234ze and alternative flame retardant.* Environmental Product Declaration EPD-JAI-20150249-IBC1-EN.

Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. Study Report SR342. Judgeford, New Zealand: BRANZ Ltd.

Jaques, R. (2019). *Measuring our sustainability progress: New Zealand's new detached residential housing stock (first update).* BRANZ Study Report SR426. Judgeford, New Zealand: BRANZ Ltd.

Kruis, N. (2015). *Development and application of a numerical framework for improving building foundation heat transfer calculations* (PhD thesis). University of Colorado, Boulder, Colorado.

MBIE. (2015). *Energy in New Zealand 2015* (2014 calendar year edition). Wellington, New Zealand: Ministry of Business, Innovation and Employment.

MBIE. (2019). *Electricity demand and generation scenarios*. Wellington, New Zealand: Ministry of Business, Innovation and Employment.

Page, I. (2006). *NZBC clause H1 review: House insulation cost benefit analysis.* QC5048. Judgeford, New Zealand: BRANZ Ltd.

PE International. (2011). *Life cycle assessment of float glass*. Brussels, Belgium: Glass for Europe.

Ryan, V., Penny, G., Cuming, J., Baker, G. & Mayes, I. (2019). *Measuring the extent of thermal bridging in external timber-framed walls in New Zealand*. BRANZ External Research Report ER53. Judgeford, New Zealand: BRANZ Ltd.

Sacayon Madrigal, E. (2015). *Assessment of the life cycle-based environmental impacts of New Zealand electricity* (Master's thesis). Massey University, Palmerston North, New Zealand.

Tasman Insulation New Zealand. (2017). *Pink® Batts® glass wool insulation: segments, blankets and boards*. Environmental Product Declaration S-P-01169.

Trethowen, H. A. (2000). *Insulation of slab-on-ground floors.* BRANZ Evaluation Method EM2. Judgeford, New Zealand: BRANZ Ltd.

Wareing, S. (2015). *Thermal performance implications of a housing warrant of fitness in New Zealand* (Master's thesis). Victoria University of Wellington, Wellington, New Zealand.

WPMA. (2019). *Solid, finger-jointed and laminated timber products including timber preservation options.* Environmental Product Declaration S-P-00997.

WPMA. (2020). *Timber, carbon and the environment.* NZ Wood Design Guide. Wellington, New Zealand: Wood Processors & Manufacturers Association.

Appendix A: Orientation sensitivity check

Dwellings were rotated from their original design orientation in 45° steps to check the effect on energy use. Only the three centres of Auckland, Wellington and Christchurch were examined as these were considered to provide a reasonable indication of the national response.

The dwellings are coded such that the last few letters signify the typology. Thus, SS = single-storey detached, DS = double-storey detached, MDH = medium-density housing and AP = apartment. These are the results (see Figure 29 to Figure 32):

- Heating energy use is minimally affected by orientation, with the shifts generally being less than 10%. This may be explained by the fact that, when some windows move more north, others will move more south, thus counteracting the overall effect, and much of the heating occurs in places and times where there is less sun. This is particularly true in the case of the schedules here that are heating all zones and are heating during the night as well.
- Cooling energy use is affected to a substantially larger degree, with differences of 50% or more. This makes sense, as cooling needs are much more closely related to solar gains. This may not be a major concern for houses such as the detached homes, which are very heating dominated, but can become a significant issue for buildings that are cooling dominated such as the apartment (see discussion in the climate analysis on how much cooling should inform the design of this project).
- It was decided not to include orientation in the later sensitivity analysis due to the uncertainty of the cooling estimates, and their relevance to study focused on heat losses still apply.

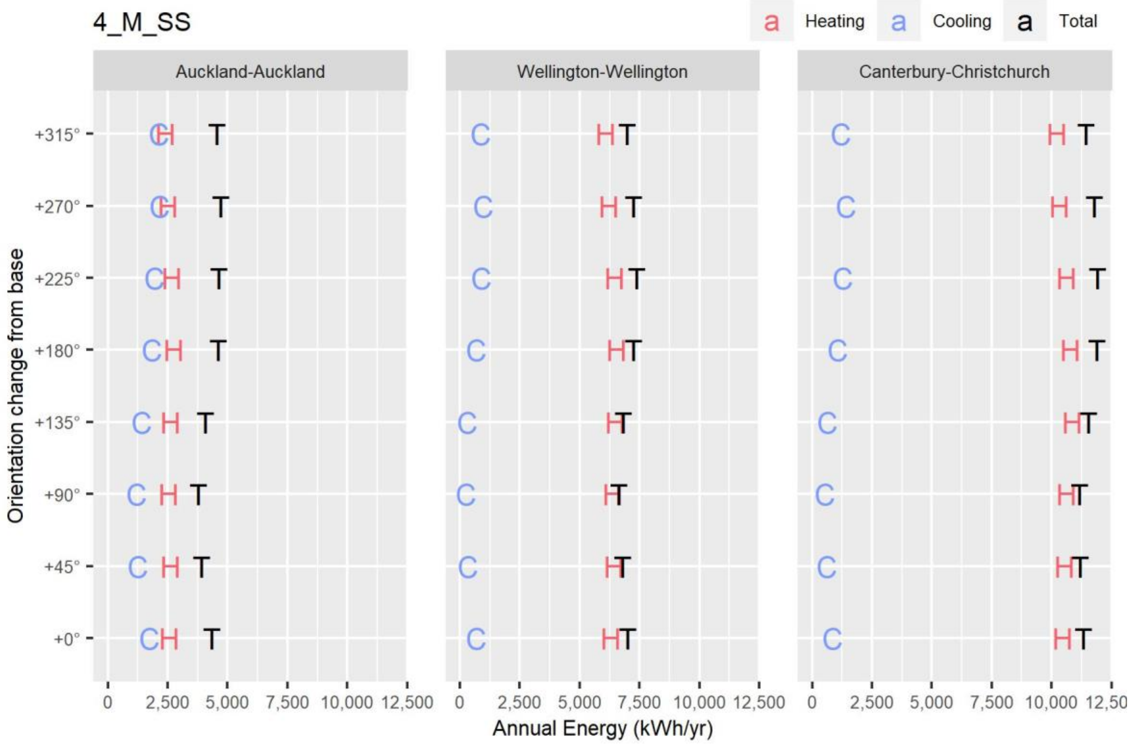


Figure 29: Effect of rotating the single-storey house on energy use in three main climate zones

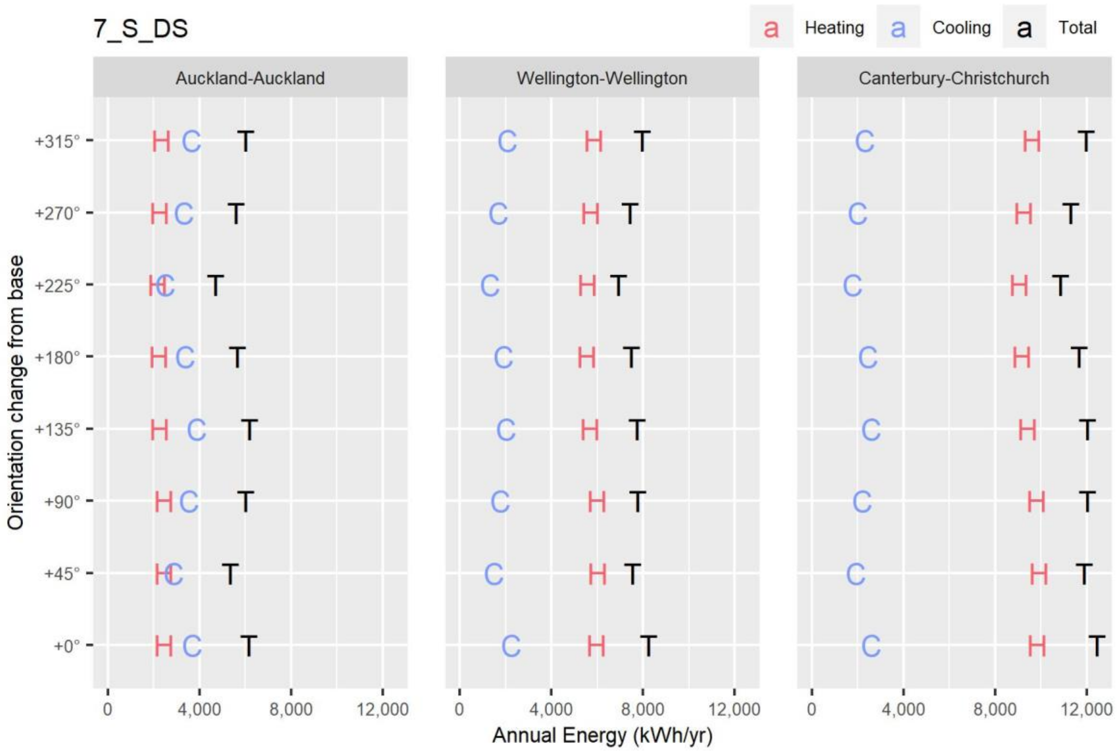


Figure 30: Effect of rotating the 2-storey house on energy use in three main climate zones

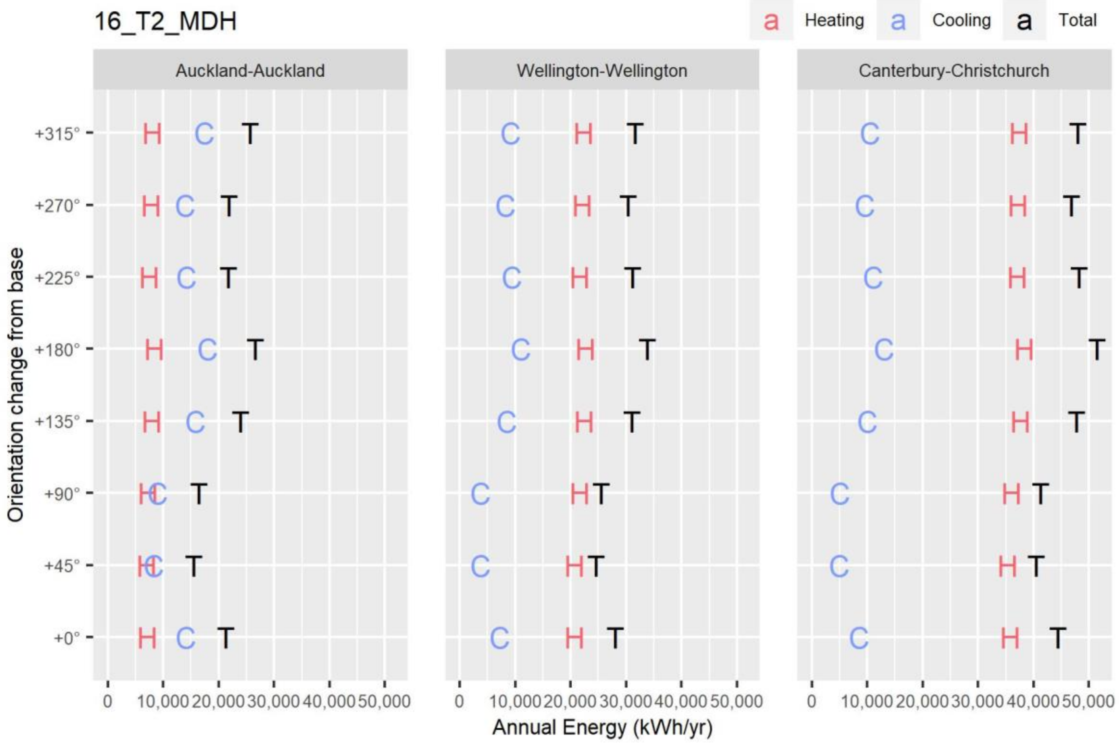


Figure 31: Effect of rotating the medium-density house on energy use in three main climate zones

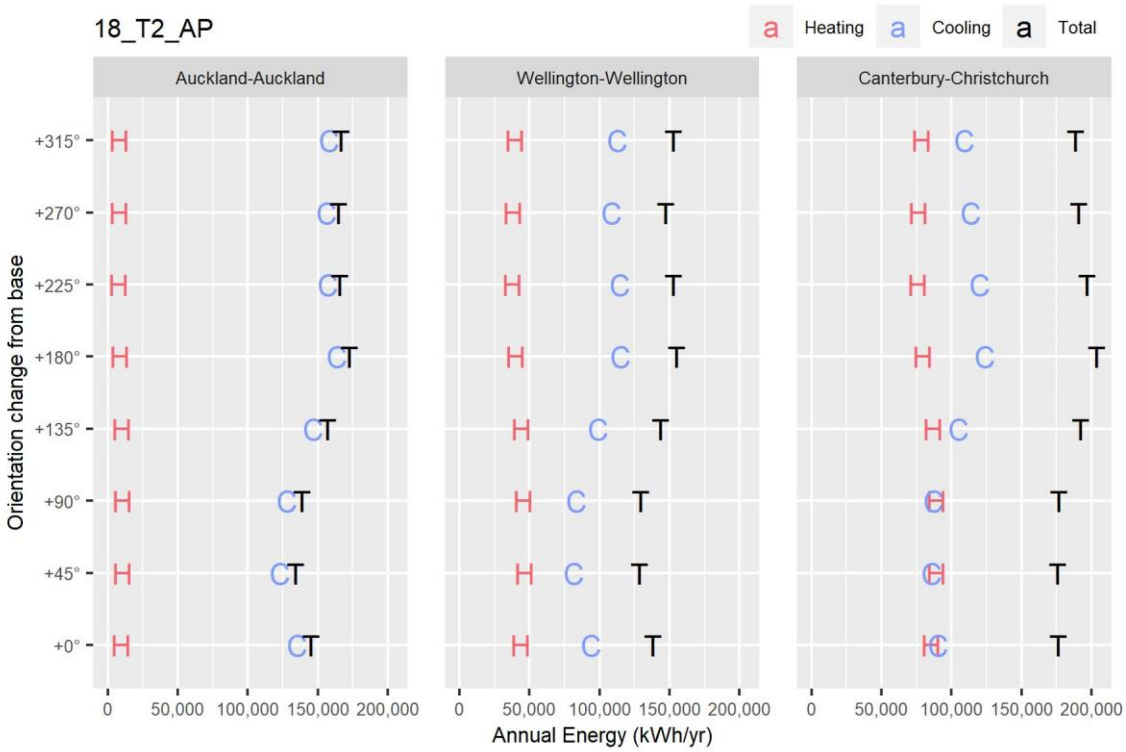


Figure 32: Effect of rotating the apartment building on energy use in three main climate zones

Appendix B: Greenhouse gas assessment - materials data and assumptions

B.1 Introduction

This appendix provides information about the data used as the basis for deriving materials-related greenhouse gas emissions factors and relative materials-related results for each construction on a m^2 basis. It is set out using the modular structure for describing the building life cycle in EN 15978:2011 and illustrated in Figure 33 (taken from Dowdell et al., 2020).

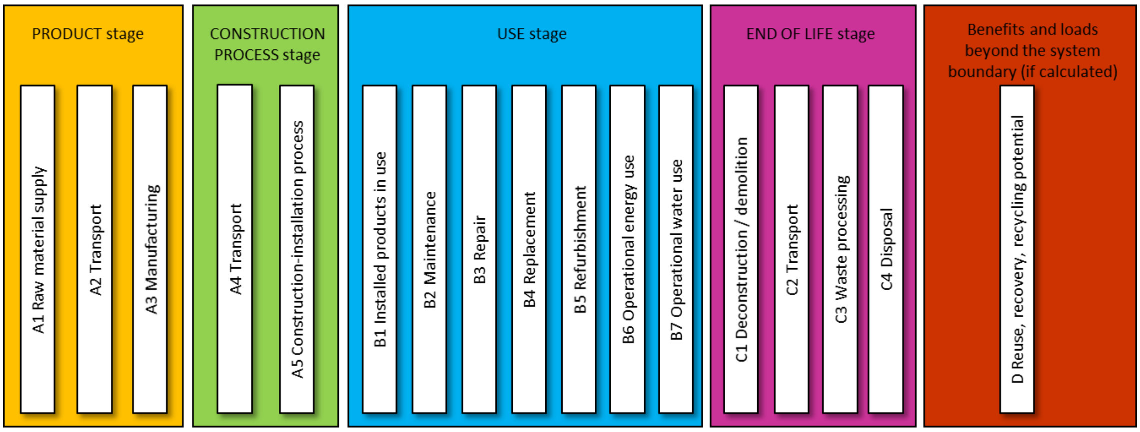


Figure 33: Description of the building life cycle

Section B.2 to B.4 provide supporting information about the data used in this study, whilst section 3.3 shows the relative materials-related greenhouse gas results per m^2 of construction that results from use of these data.

From Figure 33, the following modules are represented in this study:

- Modules A1–A3 (product stage), representing manufacture of materials up to the factory gate.
- Modules A4–A5 (construction process stage), representing transport and construction.

The following module may be included if relevant to the construction (see section 2.4.3):

- Module B4 (use stage), representing replacement of materials during the 50-year reference study period.

In addition, module B6 is represented as the greenhouse gas emissions savings or emissions from use of alternative constructions compared to current constructions. The data used to represent New Zealand grid carbon intensity in kg CO_2.eq./kWh are provided in Appendix C.

Modules B1, B2, B3 and B5 are not considered as they present no point of difference between assessed constructions.

The end-of-life stage is not considered (modules C1–C4) as this is outside the 50-year reference study period. End of life of materials becoming waste within the reference study period (during construction or because of replacement) is considered.

Module D is optional according to EN 15978:2011 and is not calculated.

B.2 Modules A1–A3

This section provides background information, a data quality assessment and assumptions concerning manufacture of materials. It is divided into subsections covering walls, floors, roofs and windows.

B.2.1 Walls

Name	**Insulation (90 mm wall), Pink® Batts® Classic R1.8 Wall (glass wool)** **Insulation (90 mm wall), Pink® Batts® Classic R2.2 Wall (glass wool)** **Insulation (90 mm wall), Pink® Batts® Ultra® R2.6 Wall (glass wool)** **Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Wall (glass wool)** **Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Wall (glass wool)** **Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Wall (glass wool)** **Insulation (masonry wall), Pink® Batts® Masonry R1.0 (glass wool)** **Insulation (masonry wall), Pink® Batts® Masonry R1.2 (glass wool)** **Insulation (roof), Pink® Batts® Classic R1.8 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R2.6 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R3.2 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R3.6 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R4.0 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R5.0 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R6.0 Ceiling (glass wool)** **Insulation (roof), Pink® Batts® Classic R7.0 Ceiling (glass wool)**
Data source	EPD (NZ)
Description	Manufacturing of glass-fibre insulation materials from recycled window glass at Tasman's Penrose site.
Platform/source(s) of data	JACKON Insulation GmbH, GmbH. (2015). *JACKODUR Plus – extruded polystyrene (XPS) with HFO 1234ze and alternative flame retardant.* Environmental Product Declaration EPD-JAI-20150249-IBC1-EN. Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. Study Report SR342. Judgeford, New Zealand: BRANZ Ltd. Jaques, R. (2019). *Measuring our sustainability progress: New Zealand's new detached residential housing stock (first update).* BRANZ Study Report SR426. Judgeford, New Zealand: BRANZ Ltd. Kruis, N. (2015). *Development and application of a numerical framework for improving building foundation heat transfer calculations* (PhD thesis). University of Colorado, Boulder, Colorado. MBIE. (2015). *Energy in New Zealand 2015* (2014 calendar year edition). Wellington, New Zealand: Ministry of Business, Innovation and Employment. MBIEMinistry (2019). *Electricity demand and generation scenarios*. Wellington, New Zealand: Ministry of Business, Innovation and Employment. Page, I. (2006). *NZBC clause H1 review: House insulation cost benefit analysis.* QC5048. Judgeford, New Zealand: BRANZ Ltd. International. (2011). *Life cycle assessment of float glass*. Brussels, Belgium: Glass for Europe. Ryan, V., Penny, G., Cuming, J., Baker, G. & Mayes, I. (2019). *Measuring the extent of thermal bridging in external timber-framed walls in New Zealand*. BRANZ External Research Report ER53. Judgeford, New Zealand: BRANZ Ltd. , 2017
Data characteristics	Product-specific data.
Age	Primary data collected for the manufacturing period May 2017 to April 2018.
Technology coverage	Includes glass batch mixing (80% of raw material is crushed window glass), melting, temperature conditioning, fiberising, forming, curing, trimming and packaging.

Geographical coverage	New Zealand
Assumptions	JACKON Insulation GmbH, GmbH. (2015). *JACKODUR Plus – extruded polystyrene (XPS) with HFO 1234ze and alternative flame retardant.* Environmental Product Declaration EPD-JAI-20150249-IBC1-EN. Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. Study Report SR342. Judgeford, New Zealand: BRANZ Ltd. Jaques, R. (2019). *Measuring our sustainability progress: New Zealand's new detached residential housing stock (first update).* BRANZ Study Report SR426. Judgeford, New Zealand: BRANZ Ltd. Kruis, N. (2015). *Development and application of a numerical framework for improving building foundation heat transfer calculations* (PhD thesis). University of Colorado, Boulder, Colorado. MBIE. (2015). *Energy in New Zealand 2015* (2014 calendar year edition). Wellington, New Zealand: Ministry of Business, Innovation and Employment. MBIEMinistry (2019). *Electricity demand and generation scenarios*. Wellington, New Zealand: Ministry of Business, Innovation and Employment. Page, I. (2006). *NZBC clause H1 review: House insulation cost benefit analysis.* QC5048. Judgeford, New Zealand: BRANZ Ltd. International. (2011). *Life cycle assessment of float glass*. Brussels, Belgium: Glass for Europe. Ryan, V., Penny, G., Cuming, J., Baker, G. & Mayes, I. (2019). *Measuring the extent of thermal bridging in external timber-framed walls in New Zealand*. BRANZ External Research Report ER53. Judgeford, New Zealand: BRANZ Ltd. , 2017
Completeness/ exclusions	JACKON Insulation GmbH, GmbH. (2015). *JACKODUR Plus – extruded polystyrene (XPS) with HFO 1234ze and alternative flame retardant.* Environmental Product Declaration EPD-JAI-20150249-IBC1-EN. Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. Study Report SR342. Judgeford, New Zealand: BRANZ Ltd. Jaques, R. (2019). *Measuring our sustainability progress: New Zealand's new detached residential housing stock (first update).* BRANZ Study Report SR426. Judgeford, New Zealand: BRANZ Ltd. Kruis, N. (2015). *Development and application of a numerical framework for improving building foundation heat transfer calculations* (PhD thesis). University of Colorado, Boulder, Colorado. MBIE. (2015). *Energy in New Zealand 2015* (2014 calendar year edition). Wellington, New Zealand: Ministry of Business, Innovation and Employment. MBIEMinistry (2019). *Electricity demand and generation scenarios*. Wellington, New Zealand: Ministry of Business, Innovation and Employment. Page, I. (2006). *NZBC clause H1 review: House insulation cost benefit analysis.* QC5048. Judgeford, New Zealand: BRANZ Ltd. International. (2011). *Life cycle assessment of float glass*. Brussels, Belgium: Glass for Europe. Ryan, V., Penny, G., Cuming, J., Baker, G. & Mayes, I. (2019). *Measuring the extent of thermal bridging in external timber-framed walls in New Zealand*. BRANZ External Research Report ER53. Judgeford, New Zealand: BRANZ Ltd. , 2017
Plausibility check	Product-specific data, so not plausibility check carried out.
Consistency e.g. with EN 15804	EPD is compliant with EN 15804.

Name	**Timber, surfaced, kiln dried, H1.2 boron treated [from sustainable forest management practices]**
Data source	EPD (NZ)
Description	Surfaced, kiln-dried framing made from New Zealand-grown radiata pine. Moisture content (dry basis) 11% and a density of 486 kg/m^3.
Platform/source(s) of data	WPMA, 2019
Data characteristics	Sector average EPD for New Zealand-made products. Contributors to the EPD included Abodo Wood Ltd, NorthPine Ltd, OTC Timber Co Ltd, Reg Stag Timber, Rosvall Sawmill Ltd, Taranakipine, Techlam, Tenon Clearwood LP, Timberlab Solutions Ltd and Xlam NZ Ltd.
Age	EPD published in 2019. Primary data for participating sites collected for 2016/17 year.
Technology coverage	Includes forestry (based on literature data, updated by Scion), sawing, drying, planning and treatment.
Geographical coverage	New Zealand
Assumptions	Dominant softwood species is radiata pine (*Pinus radiata*) representing 95% of all harvested timber in 2016/17 in New Zealand. For assumptions, see WPMA (2019).
Completeness/ exclusions	Reflects processes of the companies listed under ‘Data characteristics’.
Plausibility check	Calculated GWP (incorporating GWPB and GWPB) figure for H1.2 boron-treated, surfaced, kiln-dried timber is -1.5 kg CO_2 eq./kg. Alcorn (2010) provides a value of -1.32 kg CO_2 eq./kg for kiln-dried, dressed and treated timber. Wood for Good (www.woodforgood.com) has a value of -1.41 kg CO_2 eq./kg for kiln-dried sawn softwood. The Forest and Wood Products Australia (FWPA, 2015)) figure for softwood timber is -1.25 kg CO_2 eq./kg.
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

B.2.2 Floors

Name	**Insulation, polystyrene expanded (EPS)**
Data source	Generic data
Description	Expanded polystyrene is a rigid foam material made from petrochemicals. Carbon dioxide or pentane may be used as a blowing agent.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Based on “Polystyrene, expandable” in EcoInvent 3.1
Age	See www.ecoinvent.org
Technology coverage	EPS is manufactured in New Zealand using imported polystyrene beads. A low boiling point hydrocarbon, usually pentane gas, is added to the beads to assist the expansion process.
Geographical coverage	Rest of the World (RoW) data in EcoInvent, i.e. excluding Europe.
Assumptions	See www.ecoinvent.org.
Completeness/ exclusions	See www.ecoinvent.org.
Plausibility check	ICE database (version 2.0) (Hammond & Jones, 2011) shows good agreement. Alcorn (2010) reports a lower greenhouse gas impact at 2.5 kg CO_2 eq./kg.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Name	**Insulation, polystyrene extruded (XPS)**
Data source	EPD (non-NZ)
Description	Extruded polystyrene is a rigid foam material made from petrochemicals.
Platform/source(s) of data	Forman Building Systems Dow Deutschland GmbH & Co. OHG, 2013

Data characteristics	Data reported in an EPD for plants in two European countries. See 'Geographical coverage'.
Age	EPD published in 2013 based on manufacturing data from 2010.
Technology coverage	Manufacture of XPS boards within a density range from 30 to 50 kg/m^3, supplied in three different compressive strength levels from 100 to 700 kPa within a thickness range of 20 to 200 mm. Covers manufacture by Dow as a weighted average of boards produced at works in Greece and Germany, being 1 m^2 of XPS board with a thickness of 100 mm, i.e. 0.1 m^3 with a density of 35 kg/m^3. Boards may have different surfaces with extrusion skin, planed, grooved or thermally embossed and supplied with butt edge, shiplap and tongue-and-groove profiles. XENERGY is manufactured in a continuous extrusion process. Polystyrene granules are melted together with additives in the extruder under high pressure. Blowing agents are injected into the melted mass and dissolved in it. The melted mass is extruded through a flat die. The drop in pressure causes the polystyrene to foam and cool down to solidify. An endless board of homogeneous closed-cell polystyrene foam is produced. This is cooled further and then cut to dimensions, trimmed, the surface modified if necessary and packed. Carbon dioxide in combination with process aids is used as a blowing agent.
Geographical coverage	XPS imported into NZ. Plants covered by Forman Building Systems (Forman Building Systems Dow Deutschland GmbH & Co. OHG, 2013) are based in Europe (Germany and Greece), therefore assumption is that all or the majority of XPS board (imported by Forman in New Zealand) is derived from these two plants.
Assumptions	See 'Geographical coverage'.
Completeness/ exclusions	Transport from Europe to New Zealand.
Plausibility check	Results are dependent on density of product, which can vary from 30–50 kg/m^3. Results may be adjusted according to the ratio of the following: [Density of product to be considered/Density of product for stated results (35 kg/m^3)] * [Thickness of board to be considered/Thickness of board for stated results (100 mm)]. Results adjusted for density show good alignment with other published EPDs (European Extruded Polystyrene Insulation Board Association, 2014; JACKON Insulation GmbH, 2015). Results lower than provided in EcoInvent 3.1 for "RoW: polystyrene production, extruded, CO_2". Comparison of EcoInvent 3.1 data shows that greenhouse gas results are heavily dependent on the blowing agent used, with significantly higher impacts arising from use of HFC 134a as a blowing agent. Results also marginally higher when HFC 152a used as a blowing agent in comparison with carbon dioxide. Alcorn (2010) shows lower results at 2.5 kg CO_2 eq./kg although density unknown.
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

Name	**Fibreglass reinforced plaster system**
Data source	Mix – EPDs, EcoInvent 3.1, ICE v3.0, other.
Description	Manufacturing of materials comprising a fibreglass reinforced plaster system for application as edge insulation protection for a concrete floor slab. Constituent materials comprise cement, water, polymers, sand and fibreglass.
Platform/source(s) of data	Golden Bay Cement (2019), Holcim Cement (2019), European Federation of Concrete Admixtures Ltd (EFCA) (2015)
Data characteristics	Product specific and generic data derived from: • Cement – Golden Bay Cement and Holcim NZ EPDs. • Water – EcoInvent v3.1 (adjusted with NZ grid electricity) • Polymers – EFCA EPD (2015) • Sand – EcoInvent v3.1 • Fibreglass – used glass fibre reinforced plastic from ICE 3.0 (2019)
Age	Various
Technology coverage	Plaster system comprises the following (based on mass), as provided by the supplier: • Cement 30%

	• Water 30% • Polymers 10% • Sand 25% • Fibreglass 5% Cement manufacture based on Golden Bay Cement operations in New Zealand, and Holcim operations overseas (including import to New Zealand). Polymer manufacture based on manufacture in 10 European countries and Turkey.
Geographical coverage	New Zealand / rest of the world.
Assumptions	Plaster system is applied 5 mm thick and 250 mm high, providing a volume per metre length of 0.00125 m^3. Cement data assumes 50% supplied by Golden Bay Cement and 50% supplied by Holcim. Concrete hardening accelerator used to represent polymers in the plaster system
Completeness/ exclusions	Transport of polymer to New Zealand, and transport to the construction site of the various components. Wastage at the construction site.
Plausibility check	Carbon footprint of a 1 metre length of concrete slab edge (at 250 mm wide and 5 mm depth) estimated to be 1.4 kg CO$_2$eq. (excluding transport to site and site wastage). No data found with which to compare this.
Consistency e.g. with EN 15804	EPDs used are compliant with EN 15804, representing 40% of the product and 54% of the carbon footprint.

B.2.3 Roofs

See 'Insulation' in section B2.1.

B.2.4 Windows

Name	**Aluminium frame, primary (anodised finish), non-thermally broken** **Aluminium frame, primary (anodised finish), thermally broken**
Data source	Generic data
Description	Includes processes and materials to produce an aluminium window frame with 1 m^2 visible area. Aluminium produced in New Zealand from primary resources is based on bauxite mined and refined into alumina in Australia, which is then shipped to Tiwai Point in the South Island. Once cast at Tiwai Point, the ingots are transported for further processing including extruding, cold rolling, anodising and powder coating.
Platform	EcoInvent 3.1 – adapted to include New Zealand grid electricity.
Data characteristics	Includes section bar rolling of steel parts and fittings, section bar extrusion for aluminium parts, extrusion of HDPE plastic. Thermally broken window frame additionally includes glass-fibre reinforced PA6.6. The aluminium model includes mining of bauxite and production of alumina in Australia, shipping to New Zealand, electrolysis and alloying (based on 6060 alloy), casting into ingots, transport to processors (taken as a 1,000 km truck journey), where the ingot is either extruded or cold rolled and may be anodised or powder coated. The alloying process is based on the following composition (%): Aluminium (98.475). Cast iron (0.2) Chromium (0.05) Copper (0.1) Magnesium (0.475) Manganese (0.1) Silicon (0.45) Zinc (0.15) Anodising based on "Anodising, aluminium sheet" from EcoInvent 3.1, updated to reflect use of New Zealand medium voltage grid electricity (JACKON Insulation Insulation GmbH. (2015). *JACKODUR Plus – extruded polystyrene (XPS) with HFO 1234ze and alternative flame retardant.* Environmental Product Declaration EPD-JAI-20150249-IBC1-EN.

	Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. Study Report SR342. Judgeford, New Zealand: BRANZ Ltd. Jaques, R. (2019). *Measuring our sustainability progress: New Zealand's new detached residential housing stock (first update).* BRANZ Study Report SR426. Judgeford, New Zealand: BRANZ Ltd. Kruis, N. (2015). *Development and application of a numerical framework for improving building foundation heat transfer calculations* (PhD thesis). University of Colorado, Boulder, Colorado. MBIE. (2015). *Energy in New Zealand 2015* (2014 calendar year edition). Wellington, New Zealand: Ministry of Business, Innovation and Employment.).
Age	For age of EcoInvent data – see www.ecoinvent.org
Technology coverage	See section B.2.2 for approach to modelling aluminium. Wrought aluminium contributes 76% towards calculated window frame impact, glass-fibre reinforced polyamide (thermally broken window only) 10%, anodising (5%), aluminium extrusion (4%), others (5%). Aluminium electrolysis based on the prebake process and includes production of wrought aluminium, which is cast into ingots, based on the alloy composition in 'Data characteristics'. Electricity for the aluminium electrolysis process is derived from the Manapouri hydro dam under a contract with Meridian Energy. However, since the electricity is delivered via the grid, there is no current mechanism in New Zealand for exclusively purchasing renewable-derived electricity from the grid. Since electricity generation at the Manapouri hydro dam contributes towards national grid average emission factors, electricity demand at Tiwai Point was modelled as being supplied by grid average electricity. In 2014, renewables made up 80% of New Zealand grid electricity (MBIE, 2015). Anodising coating thickness is 20 µm. Includes mechanical surface treatment (50% of workpieces), degreasing, pickling, anodising and sealing. Also includes wastewater treatment.
Geographical coverage	Global data in EcoInvent 3.1 (outside Europe).
Assumptions	Aluminium window frames manufactured using aluminium ingot sourced from Tiwai Point.
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	No comparisons for window frames found. For comparisons for aluminium manufacture (which contributes around three-quarters of the calculated impact), see below. Greenhouse gas impact calculated as 11.4 kg CO_2 eq./kg. This compares with 11.1 kg CO_2 eq./kg published in EPDs (Gesamtverband der Aluminiumindustrie e.V. (GDA), 2013a, 2013b) with a power mix for aluminium production that is largely renewables (as is the case in New Zealand). EcoInvent data show a large variation in greenhouse gas impacts associated with aluminium production, due primarily to the underlying source(s) of energy supplying the electricity to the process. Where electricity is primarily coal derived, greenhouse gas impacts of aluminium production can be significantly higher. Alcorn's original work shows results that are higher, from 14.2 kg CO_2/kg for primary aluminium up to 16.35 kg CO_2/kg for extruded, anodised aluminium (Alcorn, 2010). The ICE database provides values of 12.5 kg CO_2 eq./kg for extruded aluminium and 12.8 kg CO_2 eq./kg for rolled aluminium, providing similar values and showing little difference between extruded and rolled outputs (Hammond & Jones, 2011).
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	PVC-U
Name	Window frame (PVC-U).

Description	Manufacture of an extruded PVC frame profile needed to produce a window frame with a 1 m^2 visible area.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Glass production based on “Flat glass production, uncoated”. Stats NZ data indicates that 68% by value of total imports from 2010–2015 of “glass: multiple walled insulating units of glass” came from Singapore, followed by USA (14%), China (9%) and Europe (9%). Therefore, electricity required for production is based on the Singapore grid, which is 95.5% supplied by natural gas (**Error! Reference source not found.** Authority, 2015).
Age	See www.ecoinvent.org.
Technology coverage	Includes injection moulding and extrusion of PVC, section bar rolling for steel fittings, section bar extrusion for aluminium parts, road transport for production phases. Process data reflects a highly automated process.
Geographical coverage	Global data in EcoInvent 3, with NZ grid electricity.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Name	**Window, IGU, glazing (float glass)** **Window, IGU, glazing (float glass, low emissivity (Low-E) finish**
Data source	Generic data
Description	Glass is made by combining and heating silica sand, lime and soda before passing over a bed of molten tin followed by controlled cooling. It is normally produced in thicknesses ranging from 2 mm up to 25 mm. Float glass may undergo subsequent treatment such as heat strengthening, coating and laminating.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Glass production based on “Flat glass production, uncoated”. Stats NZ data indicates that 68% by value of total imports from 2010–2015 of “glass: multiple walled insulating units of glass” came from Singapore, followed by USA (14%), China (9%) and Europe (9%). Therefore, electricity required for production is based on the Singapore grid, which is 95.5% supplied by natural gas ((**Error! Reference source not found.** Authority, 2015).
Age	Various – see www.ecoinvent.org.
Technology coverage	Includes provision of cullet, melting and forming in a float bath, cooling, cutting and storage. Also includes infrastructure. Low-E glass includes cathodic sputtering of a metal coating on the float glass.
Geographical coverage	Rest of the World data in EcoInvent 3.1, i.e. outside Europe.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	Excludes any packaging used.
Plausibility check	Alcorn (2010) reports an embodied CO_2 figure of 2.45 kg CO_2 eq./kg of toughened glass. The ICE database (Hammond & Jones, 2011) reports 1.35 kg CO_2 eq./kg. Figures used in this study ARE closer to the ICE database figure. A report for Glass for Europe (PE International, 2011) reports 1.23 kg CO_2 eq./kg of float glass (without heat strengthening), which is closest to the figure used in this work.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Name	**Argon gas**
Data source	Generic data
Description	Production of argon gas for use in IGUs.

Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Production by catalytic burning of oxygen
Age	See www.ecoinvent.org.
Technology coverage	Density based on standard temperature and pressure. Actual conditions in an IGU likely to vary.
Geographical coverage	Global data in EcoInvent 3.3.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	Large uncertainties reported for process requirements and infrastructure.
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	See www.ecoinvent.org

B.3 Modules A4–A5

Modules A4 and A5 concern transport of construction materials to the construction site and installation at the construction site. Default data for these modules was guided by scenario datasheets developed for the New Zealand whole-building whole-of-life framework, available at www.branz.co.nz/environment-zero-carbon-research/framework/data. It is important to note that these datasheets do not relate to specific, branded products. Therefore, whilst modules A1–A3 data may be for a specific, branded product, e.g. Pink® Batts® insulation from an environmental product declaration (EPD), modules A4–A5 data is based on scenario data developed by BRANZ and published on the BRANZ website in 2016.

The datasheets used to inform these modules are (available using the link above):

- construction transport (module A4).
- construction site waste (module A5).

Transport to the construction site is modelled as a one-way journey. Transport of waste to landfill is assumed to be 20 km (one-way).

Exclusions are:

- operation of a site office
- transport to site by construction workers
- energy required for use of site equipment and power tools (in most cases)
- disposal of any packaging associated with construction materials
- extra fixings that may be required (for walls – a staggered stud system in comparison with traditional 90 mm framing).

B.4 Module B4

Module B4 concerns replacement of materials during the reference study period because the service life for these materials is unlikely to reach 50 years. In this study, the only material to which this was applied was one replacement of the IGUs in the windows.

Where materials are replaced, the replacement includes the following:

- Manufacture of new materials, based on data in section B.2.1. Note that this replacement will occur in the future but that manufacturing data represents current or historical processes (depending on the source of data). In reality, it is expected that these manufacturing processes will progressively decarbonise as New Zealand and other countries shift towards net zero carbon economies. Given the inherent uncertainties

associated with estimating timings and extent of decarbonisation in different manufacturing operations (in New Zealand and overseas), this has not been considered.
- Transport and installation of new materials, based on data in section B.2.2. As above, this assumes current logistics technology is used. This would be expected to decarbonise over time (for example, through use of hybrid and/or electric trucks). As above, this is not considered due to the inherent uncertainties.
- Disposal of the replaced material, for which the typical (current) end-of-life route(s) described in the building end-of-life (module C1) datasheet are used. Note that this datasheet provides estimates based on commercial buildings, which may differ for residential typologies. This datasheet also contains best-practice (case studies/future) end-of-life routes, which could have been used. However, for the materials concerned (glass), this would make only a small difference to the results. Waste to landfill is assumed to be transported 20 km (one-way).

Exclusions are:

- transport by construction workers
- energy required for use of power tools (in most cases)
- disposal of any packaging associated with construction materials
- fixings that may be required.

Appendix C: Greenhouse gas assessment – grid electricity

Below are the annual New Zealand grid carbon intensity figures used in the study, based on MBIE-supplied generation figures, adapted to be on a supply basis by adding transmission and distribution losses (taken as 7.3%). **These figures are not for public disclosure at the request of MBIE's Michael Smith.**

Year	Season	Annual Electricity EFs - Generation	Seasonal Electricity EFs - Supply
		kg CO_2eq/kWh	kg CO_2eq/kWh
2020	Q1	0.113	0.141
2020	Q2	0.113	0.122
2020	Q3	0.113	0.109
2020	Q4	0.113	0.121
2021	Q1	0.116	0.144
2021	Q2	0.116	0.124
2021	Q3	0.116	0.111
2021	Q4	0.116	0.123
2022	Q1	0.111	0.138
2022	Q2	0.111	0.120
2022	Q3	0.111	0.107
2022	Q4	0.111	0.119
2023	Q1	0.099	0.123
2023	Q2	0.099	0.106
2023	Q3	0.099	0.095
2023	Q4	0.099	0.106
2024	Q1	0.100	0.125
2024	Q2	0.100	0.108
2024	Q3	0.100	0.096
2024	Q4	0.100	0.107
2025	Q1	0.099	0.124
2025	Q2	0.099	0.107
2025	Q3	0.099	0.096
2025	Q4	0.099	0.106
2026	Q1	0.096	0.119
2026	Q2	0.096	0.103
2026	Q3	0.096	0.092
2026	Q4	0.096	0.102
2027	Q1	0.095	0.118
2027	Q2	0.095	0.102
2027	Q3	0.095	0.091
2027	Q4	0.095	0.101
2028	Q1	0.093	0.116
2028	Q2	0.093	0.101
2028	Q3	0.093	0.090
2028	Q4	0.093	0.100
2029	Q1	0.093	0.116
2029	Q2	0.093	0.101
2029	Q3	0.093	0.090
2029	Q4	0.093	0.100
2030	Q1	0.077	0.096
2030	Q2	0.077	0.083
2030	Q3	0.077	0.074
2030	Q4	0.077	0.083
2031	Q1	0.069	0.086
2031	Q2	0.069	0.075
2031	Q3	0.069	0.067
2031	Q4	0.069	0.074
2032	Q1	0.069	0.086
2032	Q2	0.069	0.075
2032	Q3	0.069	0.067
2032	Q4	0.069	0.074
2033	Q1	0.068	0.085
2033	Q2	0.068	0.073
2033	Q3	0.068	0.066
2033	Q4	0.068	0.073
2034	Q1	0.064	0.079
2034	Q2	0.064	0.069
2034	Q3	0.064	0.061
2034	Q4	0.064	0.068

2035	Q1	0.063	0.078
2035	Q2	0.063	0.068
2035	Q3	0.063	0.061
2035	Q4	0.063	0.067
2036	Q1	0.059	0.074
2036	Q2	0.059	0.064
2036	Q3	0.059	0.057
2036	Q4	0.059	0.063
2037	Q1	0.059	0.073
2037	Q2	0.059	0.063
2037	Q3	0.059	0.056
2037	Q4	0.059	0.063
2038	Q1	0.050	0.062
2038	Q2	0.050	0.054
2038	Q3	0.050	0.048
2038	Q4	0.050	0.053
2039	Q1	0.044	0.054
2039	Q2	0.044	0.047
2039	Q3	0.044	0.042
2039	Q4	0.044	0.047
2040	Q1	0.043	0.054
2040	Q2	0.043	0.046
2040	Q3	0.043	0.042
2040	Q4	0.043	0.046
2041	Q1	0.042	0.053
2041	Q2	0.042	0.046
2041	Q3	0.042	0.041
2041	Q4	0.042	0.045
2042	Q1	0.041	0.051
2042	Q2	0.041	0.045
2042	Q3	0.041	0.040
2042	Q4	0.041	0.044
2043	Q1	0.043	0.053
2043	Q2	0.043	0.046
2043	Q3	0.043	0.041
2043	Q4	0.043	0.046
2044	Q1	0.041	0.051
2044	Q2	0.041	0.044
2044	Q3	0.041	0.039
2044	Q4	0.041	0.044
2045	Q1	0.042	0.052
2045	Q2	0.042	0.045
2045	Q3	0.042	0.040
2045	Q4	0.042	0.045
2046	Q1	0.042	0.052
2046	Q2	0.042	0.045
2046	Q3	0.042	0.040
2046	Q4	0.042	0.044
2047	Q1	0.043	0.054
2047	Q2	0.043	0.047
2047	Q3	0.043	0.042
2047	Q4	0.043	0.046
2048	Q1	0.043	0.054
2048	Q2	0.043	0.047
2048	Q3	0.043	0.042
2048	Q4	0.043	0.046
2049	Q1	0.044	0.055
2049	Q2	0.044	0.048
2049	Q3	0.044	0.043
2049	Q4	0.044	0.047
2050	Q1	0.045	0.056
2050	Q2	0.045	0.048
2050	Q3	0.045	0.043
2050	Q4	0.045	0.048

Note that figures for 2050 were used to represent grid electricity carbon intensity thereafter to 2070. Also, these values omit the construction and maintenance GHGs related to the electricity grid infrastructure. Annual grid carbon intensity figures were used for the assessment. A sensitivity analysis was additionally carried out, which used seasonal grid carbon intensity figures, provided in the right-hand column above. The method for obtaining these seasonal grid electricity carbon intensity figures is set out below.

C.1 Sensitivity analysis – seasonal shift in grid carbon intensity

The purpose of this sensitivity analysis was to evaluate how changes to grid carbon intensity during the year (due primarily to availability of hydropower) could impact on results based on annual grid carbon intensity.

Predicting seasonal changes in grid carbon intensity to 2070 is problematic due to the many uncertainties associated with such an undertaking and availability of data. A method was developed that was relatively quick to implement (so could be conducted within the allowed timeframe of the study) and could use available data. Inevitably, there are limitations to the assessment, which could be addressed with a fuller analysis.

Broadly, the process was as follows:

- **Step 1:** Calculate seasonal emission factors (EFs) for 2014 to 2019 based on historical data.
- **Step 2:** For each year 2014–2019, calculate the percentage difference between the four seasonal EFs and the annual average EF for the year. From this, determine a median percentage difference for each season.
- **Step 3:** Apply the calculated seasonal median differences to future annual generation EFs and adapt so that transmission and distribution losses are included.

Seasons were defined as follows (due to format of quarterly data):

- Q1 = January–March = summer
- Q2 = April–June = autumn
- Q3 = July–September = winter
- Q4 = October–December = spring.

C.1.1 Step 1: Calculate historical seasonal emission factors

Seasonal EFs were calculated for 6 years (2014–2019) based on combustion emissions of CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide) from fossil fuel combustion and fugitive geothermal emissions of CO_2 and CH_4 utilising the AR4 (IPCC, 2007) GWPs for these gases (i.e. CO_2=1, CH_4=25, N_2O=298) in line with the GWPs cited in EN 15804:2012.

Quarterly electricity generation emissions data published by MBIE was used for geothermal fugitive emissions and combustion emissions from coal (electricity only) and diesel.

Combustion emissions from gas electricity-only plants were calculated using quarterly data on gas used for electricity generation as reported by MBIE, multiplied by the relevant combustion emission factor reported by MBIE.

Note about emissions from cogeneration plants

Coal or gas fired cogeneration plants produce both heat and electricity as useful co-products and therefore the emissions from cogeneration plants must be allocated between the heat and electricity produced. For the purposes of this assessment, the methodology used by MBIE to allocate cogeneration emissions is replicated to ensure consistency with the method used for calculating future annual electricity EFs.

Emissions from cogeneration facilities classified as ‘auto-producers’ are allocated to the manufacturing sector (i.e. to the heat product), and emissions from cogeneration facilities classified as ‘primary’ electricity are allocated to the electricity sector. All coal cogeneration facilities in New Zealand are classified as auto-producers, therefore no coal cogeneration emissions are allocated to electricity.

Combustion emissions from natural gas cogeneration plants classified as primary plants by MBIE (PCHP) were calculated based on EFs derived for natural gas electricity-only plants in 2017.

These EFs are based on the energy value of natural gas used to produce electricity in gas-fired electricity-only power stations in 2017, multiplied by the relevant combustion EF and divided by the generation from natural gas-fired electricity-only power stations in 2017. This is outlined in the following formula (Bullen, 2020).

$$EF\ \left({}^{kg}/_{kWh}\right) = \frac{natural\ gas\ used\ to\ produce\ electricity\ in\ 2017\ (MJ)\ x\ combustion\ EF\ \left({}^{kg}/_{MJ}\right)}{electricity\ generation\ from\ natural\ gas\ in\ 2017\ (kWh)}$$

Quarterly emissions from PCHP plants from 2014–2019 were calculated from the amount of electricity generated from these plants multiplied by the calculated electricity EFs in Table 24.

Table 24: Combustion emissions for electricity from natural gas cogeneration plants

GHG	Natural gas used in electricity-only generation in 2017 (MJ)	Combustion EF for natural gas (kg/MJ)	Generation from electricity-only plants in 2017 (kWh)	Emission factor (kg/kWh)
CO_2	45.69×10^9	0.0541	56.03×10^8	0.4412
CH_4		9.0×10^{-7}		7.34×10^{-6}
N_2O		9.0×10^{-8}		7.34×10^{-7}

C.1.2 Step 2: Calculate percentage difference between seasonal and annual EFs and determine median difference

Seasonal generation EFs were calculated from the sum of the emissions per quarter as described above divided by the total electricity generation per quarter reported by MBIE.

Seasonal supply EFs were calculated from the sum of the emissions per quarter as described above divided by the total electricity supply per quarter. Transmission and distribution losses are only reported on an annual basis, therefore the supplied electricity per quarter was calculated from the reported quarterly generation less one quarter of the reported annual transmission and distribution loss for that year.

The percentage difference between the quarterly supply EFs and annual generation EFs for the equivalent year were calculated. A median value for the 6 years was calculated for each quarter to represent the average supply seasonal difference relative to annual generation EFs, summarised in Table 25.

Table 25: Annual percentage differences for seasonal supply EFs cf annual generation EFs

Year	Q1-Summer (%)	Q2-Autumn (%)	Q3-Winter (%)	Q4-Spring (%)
2014	4.0	15.7	-2.7	12.5
2015	39.0	-4.1	-4.6	1.2
2016	31.3	22.0	-5.9	-16.2
2017	-21.9	18.9	16.1	14.1
2018	18.9	-6.9	-6.7	27.4
2019	29.8	-0.3	10.8	-11.1
Median (rounded)	**+24.4**	**+7.7**	**-3.7**	**+6.9**

C.1.3 Step 3: Apply calculated seasonal supply median differences to future generation EFs

Annual generation EFs were provided by MBIE based on the 2019 electricity and demand generation scenarios (EDGS). The supply median seasonal differences calculated above were applied to the EDGS reference scenario to calculate seasonal EFs for future electricity generation. The resulting seasonal EFs from application of the median values are presented above.

The annual generation EFs supplied by MBIE for the reference scenario in EDGS 2019 (MBIE, 2019) are summarised in Appendix C and G.

Limitation of the method

Significant variation between years can be seen in the differences between the seasonal and annual EFs in Table 25. The greatest variation occurs during Q1 (January to March) where the range is from -21.9% in 2017 to +39.0% in 2015.

This wide range of results suggests that time varying factors other than seasonal demand differences also contribute to variations from the annual generation EFs. This may include supply-side factors such as low hydro lake levels in some years or limitations on natural gas or coal supply for electricity generation.

The use of a median percentage difference value excludes the more extreme annual differences from the subsequent application to future generation. A comparison of the differences between seasonal and annual generation EFs based on median values indicate that generally Q1 (summer) has a higher EF than the annual average and Q3 (winter) has a lower EF than the annual value.

The issue of time-related changes in grid carbon intensity on a daily, weekly and seasonal basis would merit further assessment, which was not possible for this study.

Data sources

These data sources were used to support the development of operational energy-related greenhouse gas EFs:

- Quarterly and annual data on gas used for electricity only generation was available at www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/gas-statistics/
- Quarterly electricity emissions data and annual combustion EFs were available at www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/new-zealand-energy-sector-greenhouse-gas-emissions/.
- Annual electricity generation (including electricity-only generation from gas) and transmission and distribution losses were available at https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/
- Data on quarterly electricity generation from PCHP plants was obtained from unpublished data provided by MBIE.

Appendix D: Material cost sensitivity mini study

Below are four tables (Table 26 – Table 29), one for each dwelling typology, showing the sensitivity to varying material costings for each of the six climate zones. This was carried out in recognition of the uncertainty and variation in building material costs (purchase price variation between builders) both regionally and nationally.

The cost variants of +20%, +10%, - 10% and - 20% were chosen by BRANZ.

Table 26: Sensitivity study of material costs for the single-storey dwelling, from -20% to +20%

Single Storey House									
		-20%		-10%		10%		20%	
Zone	**Study**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**
1 - Akld	NPV	1.19	886	1.09	456	0.90	-629	0.82	-1,197
2 - Napr	NPV	1.91	4,066	1.75	3,661	1.45	2,640	1.33	2,105
3 - Wgtn	NPV	1.93	4,207	1.77	3,797	1.46	2,763	1.34	2,222
4 - Tngi	NPV	2.44	6,133	2.24	5,746	1.85	4,770	1.69	4,259
5 - Chch	NPV	2.17	5,310	1.99	4,897	1.64	3,858	1.51	3,313
6 - Qwtn	NPV	2.35	14,659	2.15	13,671	1.78	11,182	1.63	9,878
1 - Akld	Carbon	1.03	249	0.94	-569	0.78	-2,631	0.71	-3,711
2 - Napr	Carbon	1.43	3,740	1.31	2,947	1.08	949	0.99	-98
3 - Wgtn	Carbon	1.22	1,940	1.12	1,142	0.93	-868	0.85	-1,921
4 - Tngi	Carbon	1.52	4,455	1.40	3,680	1.15	1,728	1.06	705
5 - Chch	Carbon	1.23	3,509	1.12	2,100	0.93	-1,451	0.85	-3,311
6 - Qwtn	Carbon	1.73	12,470	1.58	10,907	1.31	6,967	1.20	4,903
1 - Akld	Equalise	1.82	1,239	1.67	1,103	1.38	758	1.27	578
2 - Napr	Equalise	2.03	3,556	1.86	3,242	1.54	2,450	1.41	2,035
3 - Wgtn	Equalise	1.93	4,207	1.77	3,797	1.46	2,763	1.34	2,222
4 - Tngi	Equalise	1.30	3,654	1.19	2,534	0.98	-289	0.90	-1,768
5 - Chch	Equalise	1.24	4,086	1.13	2,512	0.94	-1,456	0.86	-3,534
6 - Qwtn	Equalise	1.84	19,854	1.69	17,712	1.40	12,313	1.28	9,484

Table 27: Sensitivity study of material costs for the double-storey dwelling, from -20% to +20%

Double storey house									
		-20%		-10%		10%		20%	
Zone	**Study**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**
1 - Akld	NPV	1.65	2,442	1.51	2,099	1.25	1,236	1.14	783
2 - Napr	NPV	2.44	5,228	2.23	4,897	1.85	4,062	1.69	3,625
3 - Wgtn	NPV	2.32	4,842	2.13	4,509	1.76	3,669	1.61	3,229
4 - Tngi	NPV	2.90	6,733	2.65	6,410	2.19	5,596	2.01	5,170
5 - Chch	NPV	2.55	5,719	2.34	5,385	1.94	4,542	1.77	4,101
6 - Qwtn	NPV	2.45	13,524	2.25	12,679	1.86	10,548	1.70	9,432
1 - Akld	Carbon	1.65	5,625	1.51	4,840	1.25	2,863	1.15	1,827
2 - Napr	Carbon	2.09	9,240	1.91	8,467	1.58	6,519	1.45	5,498
3 - Wgtn	Carbon	1.80	6,798	1.65	6,023	1.36	4,070	1.25	3,046
4 - Tngi	Carbon	2.07	9,022	1.90	8,257	1.57	6,330	1.44	5,320
5 - Chch	Carbon	1.54	7,771	1.42	6,472	1.17	3,198	1.07	1,483
6 - Qwtn	Carbon	2.07	16,684	1.90	15,267	1.57	11,696	1.44	9,826
1 - Akld	Equalise	2.32	2,113	2.13	1,968	1.76	1,601	1.61	1,409
2 - Napr	Equalise	2.91	4,784	2.67	4,557	2.21	3,984	2.02	3,684
3 - Wgtn	Equalise	2.32	4,842	2.13	4,509	1.76	3,669	1.61	3,229
4 - Tngi	Equalise	1.67	8,781	1.53	7,585	1.26	4,570	1.16	2,991
5 - Chch	Equalise	1.59	8,937	1.46	7,562	1.21	4,097	1.10	2,282
6 - Qwtn	Equalise	1.97	21,232	1.80	19,239	1.49	14,217	1.37	11,587

Table 28: Sensitivity study of material costs for the medium-density dwelling, from -20% to +20%

Medium density house									
		-20%		-10%		10%		20%	
Zone	**Study**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**
1 - Akld	NPV	1.44	6,422	1.32	5,091	1.09	1,737	1.00	-20
2 - Napr	NPV	2.26	17,781	2.07	16,496	1.71	13,259	1.57	11,563
3 - Wgtn	NPV	2.18	16,767	2.00	15,473	1.65	12,213	1.51	10,506
4 - Tngi	NPV	2.79	24,630	2.56	23,379	2.11	20,224	1.94	18,572
5 - Chch	NPV	2.48	21,138	2.27	19,840	1.88	16,569	1.72	14,855
6 - Qwtn	NPV	2.30	43,011	2.11	40,009	1.74	32,444	1.60	28,481
1 - Akld	Carbon	1.65	21,524	1.51	18,497	1.25	10,869	1.14	6,873
2 - Napr	Carbon	2.09	35,619	1.91	32,638	1.58	25,126	1.45	21,192
3 - Wgtn	Carbon	1.67	22,149	1.53	19,160	1.27	11,626	1.16	7,679
4 - Tngi	Carbon	2.03	33,365	1.86	30,418	1.54	22,989	1.41	19,098
5 - Chch	Carbon	1.40	20,891	1.28	16,144	1.06	4,180	0.97	-2,087
6 - Qwtn	Carbon	1.93	52,001	1.77	46,896	1.46	34,031	1.34	27,292
1 - Akld	Equalise	2.18	7,249	2.00	6,689	1.65	5,278	1.51	4,539
2 - Napr	Equalise	2.79	17,413	2.55	16,527	2.11	14,293	1.93	13,123
3 - Wgtn	Equalise	2.18	16,767	2.00	15,473	1.65	12,213	1.51	10,506
4 - Tngi	Equalise	1.57	27,807	1.44	23,365	1.19	12,171	1.09	6,308
5 - Chch	Equalise	1.46	25,523	1.34	20,471	1.11	7,742	1.01	1,074
6 - Qwtn	Equalise	1.81	63,415	1.66	56,259	1.37	38,226	1.25	28,780

Table 29: Sensitivity study of material costs for the apartment, from -20% to +20%

Apartment									
		-20%		-10%		10%		20%	
Zone	**Study**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**
1 - Akld	NPV	0.57	-33,171	0.52	-40,188	0.43	-57,872	0.40	-67,135
2 - Napr	NPV	1.18	14,046	1.08	6,985	0.89	-10,810	0.82	-20,131
3 - Wgtn	NPV	1.17	13,166	1.07	6,102	0.89	-11,701	0.81	-21,026
4 - Tngi	NPV	1.75	58,546	1.61	51,460	1.33	33,602	1.22	24,248
5 - Chch	NPV	1.67	52,001	1.53	44,990	1.27	27,322	1.16	18,067
6 - Qwtn	NPV	1.88	109,272	1.72	97,986	1.42	69,545	1.31	54,647
1 - Akld	Carbon	1.68	142,184	1.54	123,037	1.27	74,786	1.16	49,511
2 - Napr	Carbon	2.13	238,192	1.95	219,001	1.61	170,639	1.48	145,307
3 - Wgtn	Carbon	1.77	162,284	1.62	143,089	1.34	94,720	1.23	69,384
4 - Tngi	Carbon	2.14	240,148	1.96	220,932	1.62	172,507	1.48	147,142
5 - Chch	Carbon	1.59	150,118	1.45	126,801	1.20	68,039	1.10	37,260
6 - Qwtn	Carbon	2.38	354,996	2.18	331,580	1.80	272,571	1.65	241,662
1 - Akld	Equalise	1.64	27,243	1.50	23,383	1.24	13,655	1.14	8,559
2 - Napr	Equalise	2.09	50,329	1.91	46,117	1.58	35,504	1.45	29,944
3 - Wgtn	Equalise	1.17	13,166	1.07	6,102	0.89	-11,701	0.81	-21,026
4 - Tngi	Equalise	1.73	196,246	1.58	171,720	1.31	109,914	1.20	77,540
5 - Chch	Equalise	1.00	1,181	0.92	-22,236	0.76	-81,248	0.70	-112,159
6 - Qwtn	Equalise	1.31	103,642	1.20	73,302	0.99	-3,152	0.91	-43,200

Alternatively, the BCR and NPV metrics can be examined more visually, as Figure 34 and Figure 35 show. Here, dot-plots represent each of the five cost increments: -20%, -10%, Baseline, +10%, +20%. BCRs not achieving break-even (i.e. unity) are coded as red, as are negative NPVs.

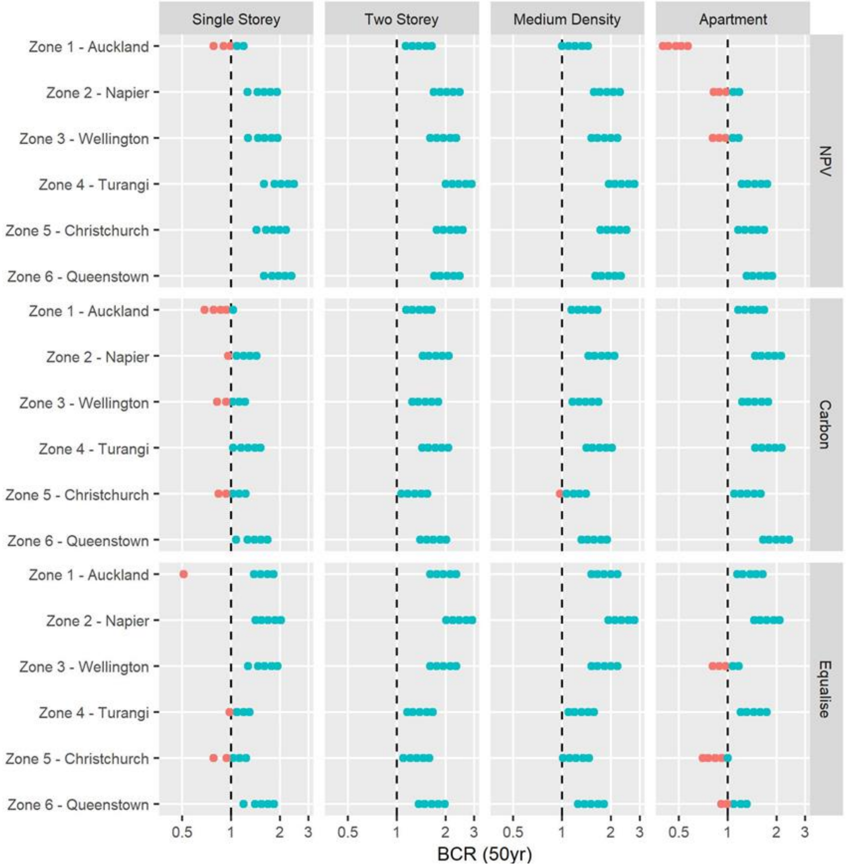


Figure 34: BCR sensitivity to altering costs between -20% to +20% of baseline

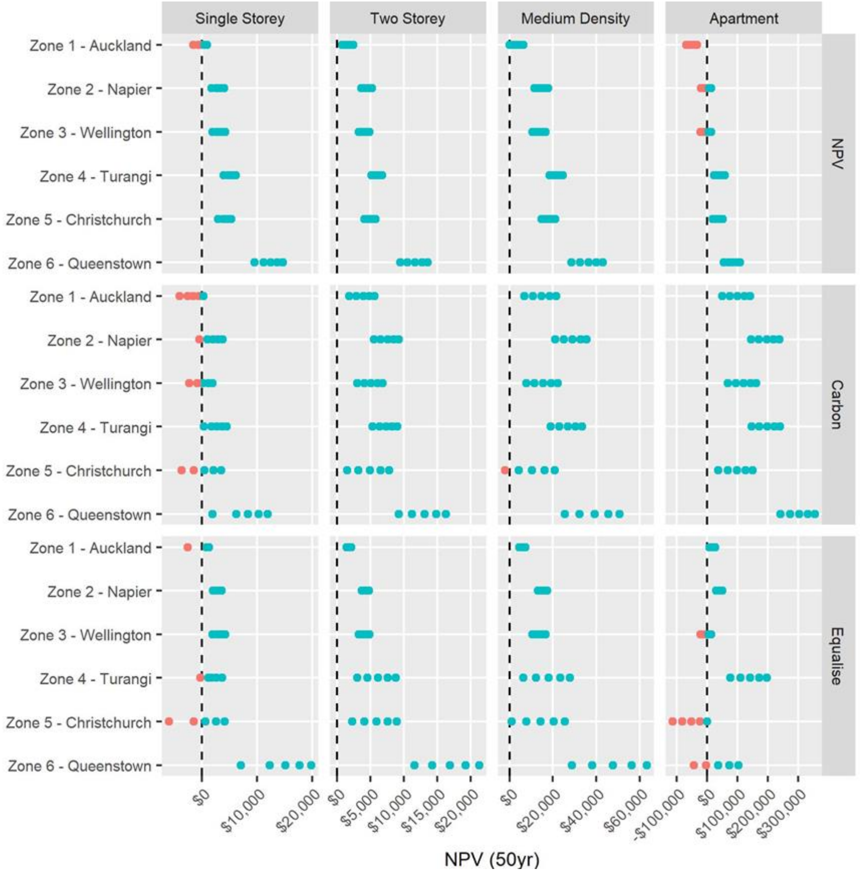


Figure 35: NPV sensitivity to altering costs between -20% to +20% of baseline

Appendix E: Summary CBAs of individual upgrades

Table 30 – Table 52 summarise the economic and carbon analysis of the cost/benefits of upgrading different parts of the building fabric past Code minimum. They are arranged so they progressively move through the climate zones, starting at Zone 1 – Auckland.

'Economics' includes the extra cost of applying the given upgrade, estimating the annual energy savings (combined space cooling and space heating) and the benefit/cost ratio and net present value over a 50-year life. 'Carbon' includes a stacked bar plot of the operational emissions (blue) and the material-related emissions (orange), along with the net CO_2 over a 50-year life and the ratio of operational to material emissions. 'Comfort' is summarised as the percentage of hours between 18–25°C in the main living space in the day and the master bedroom at night.

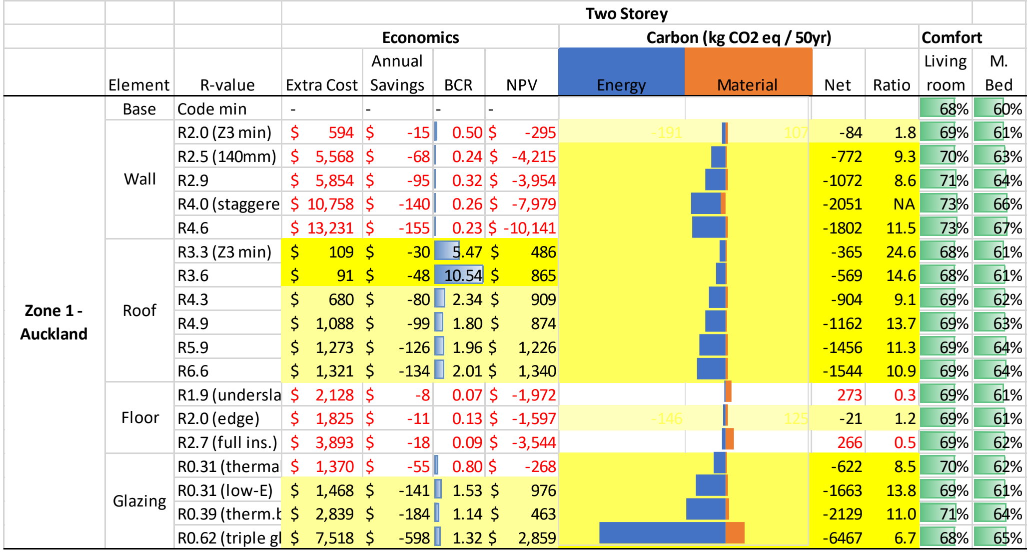
Note the graphs are not on the same scale between buildings. They are there for understanding the relative contributions of operational versus material carbon. Note also that all these figures are given as the marginal cost or benefit compared to Code minimum.

Formatting is as follows to assist identification of the most favourable choices:

Negative overall result/poor return
Technically positive overall result
Strong overall result (benefit/cost ratio >3, reasonable odds of staying positive even with less-optimistic energy-saving projections)

Results are only provided for the six newly defined climate zones at the building level. For the same results expressed in terms of conditioned floor area, see the Excel file **'net_carbon_static4.xls'**.

Table 30: CBA results for interim mini-study on individual upgrades – two storey (Zone 1)



			Two Storey									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					68%	60%
	Wall	R2.0 (Z3 min)	$ 594	$ -15	0.50	$ -295	-191	107	-84	1.8	69%	61%
		R2.5 (140mm)	$ 5,568	$ -68	0.24	$ -4,215			-772	9.3	70%	63%
		R2.9	$ 5,854	$ -95	0.32	$ -3,954			-1072	8.6	71%	64%
		R4.0 (staggere	$ 10,758	$ -140	0.26	$ -7,979			-2051	NA	73%	66%
		R4.6	$ 13,231	$ -155	0.23	$ -10,141			-1802	11.5	73%	67%
	Roof	R3.3 (Z3 min)	$ 109	$ -30	5.47	$ 486			-365	24.6	68%	61%
		R3.6	$ 91	$ -48	10.54	$ 865			-569	14.6	68%	61%
		R4.3	$ 680	$ -80	2.34	$ 909			-904	9.1	69%	62%
		R4.9	$ 1,088	$ -99	1.80	$ 874			-1162	13.7	69%	63%
		R5.9	$ 1,273	$ -126	1.96	$ 1,226			-1456	11.3	69%	64%
		R6.6	$ 1,321	$ -134	2.01	$ 1,340			-1544	10.9	69%	64%
	Floor	R1.9 (undersla	$ 2,128	$ -8	0.07	$ -1,972			273	0.3	69%	61%
		R2.0 (edge)	$ 1,825	$ -11	0.13	$ -1,597	-146	125	-21	1.2	69%	61%
		R2.7 (full ins.)	$ 3,893	$ -18	0.09	$ -3,544			266	0.5	69%	62%
	Glazing	R0.31 (therma	$ 1,370	$ -55	0.80	$ -268			-622	8.5	70%	62%
		R0.31 (low-E)	$ 1,468	$ -141	1.53	$ 976			-1663	13.8	69%	61%
		R0.39 (therm.b	$ 2,839	$ -184	1.14	$ 463			-2129	11.0	71%	64%
		R0.62 (triple gl	$ 7,518	$ -598	1.32	$ 2,859			-6467	6.7	68%	65%

Table 31: CBA results for interim mini-study on individual upgrades – MDH (Zone 1)

			Medium Density									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					75%	62%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -42	0.44	$ -1,037	-529	336	-194	1.6	75%	62%
		R2.5 (140mm)	$ 17,822	$ -193	0.22	$ -13,970			-2168	8.4	76%	65%
		R2.9	$ 19,863	$ -275	0.28	$ -14,380			-3037	7.5	77%	66%
		R4.0 (staggere	$ 37,269	$ -413	0.22	$ -29,049			-6036	NA	78%	69%
		R4.6	$ 45,804	$ -458	0.20	$ -36,684			-5001	7.1	79%	70%
	Roof	R3.3 (Z3 min)	$ 435	$ -100	4.56	$ 1,551			-1207	20.5	75%	63%
		R3.6	$ 363	$ -157	8.64	$ 2,770			-1833	11.9	75%	63%
		R4.3	$ 2,720	$ -262	1.92	$ 2,491			-2883	7.5	75%	65%
		R4.9	$ 4,352	$ -327	1.50	$ 2,160			-3793	11.3	75%	66%
		R5.9	$ 5,093	$ -420	1.64	$ 3,261			-4773	9.5	75%	66%
		R6.6	$ 5,284	$ -446	1.68	$ 3,598			-5050	9.1	75%	67%
	Floor	R1.9 (undersla	$ 6,557	$ -22	0.07	$ -6,113			864	0.2	74%	62%
		R2.0 (edge)	$ 5,596	$ -77	0.28	$ -4,056	-984	370	-614	2.7	75%	62%
		R2.7 (full ins.)	$ 12,083	$ -78	0.13	$ -10,524			512	0.7	75%	63%
	Glazing	R0.31 (therma	$ 5,259	$ -169	0.64	$ -1,900			-1828	6.8	76%	64%
		R0.31 (low-E)	$ 5,635	$ -517	1.46	$ 3,257			-6071	13.2	76%	63%
		R0.39 (therm.b	$ 10,894	$ -634	1.03	$ 338			-7249	9.9	78%	66%
		R0.62 (triple gl	$ 28,851	$ -2,305	1.32	$ 11,201			-24963	6.7	76%	65%

Table 32: CBA results for interim mini-study on individual upgrades – apartment (Zone 1)

			Apartment									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					79%	77%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -1	0.00	$ -7,287			1302	0.0	79%	77%
		R2.5 (140mm)	$ 68,520	$ -2	0.00	$ -68,490			1120	0.0	80%	78%
		R2.9	$ 72,031	$ 6					1817	0.0	80%	78%
		R4.0 (staggere	$ 132,373	$ 47			602	-3394	-2792	NA	80%	79%
		R4.6	$ 162,805	$ 70					3002	0.4	79%	79%
	Roof	R3.3 (Z3 min)	$ 207	$ -35	3.39	$ 494			-382	6.8	79%	77%
		R3.9	$ 703	$ -55	1.55	$ 384			-558	5.1	79%	77%
		R4.3	$ 620	$ -86	2.78	$ 1,101			-843	4.3	79%	77%
		R5.3	$ 3,307	$ -105	0.63	$ -1,216	-1336	574	-762	2.3	79%	77%
		R6.3	$ 4,428	$ -128	0.57	$ -1,888	-1622	1011	-611	1.6	79%	77%
		R7.3	$ 5,548	$ -134	0.48	$ -2,889	-1699	1635	-63	1.0	79%	77%
	Floor	R2.0	$ 1,090	$ 338					4479	23.1	79%	77%
		R2.0	$ 1,090	$ 338					4479	23.1	79%	77%
		R2.7	$ 1,201	$ 634					8303	34.3	79%	78%
	Glazing	R0.31 (therma	$ 37,613	$ 256					5529	1.4	79%	78%
		R0.31 (low-E)	$ 40,300	$ -3,430	1.36	$ 18,025			-40054	12.2	81%	80%
		R0.39 (therm.b	$ 77,913	$ -2,168	0.49	$ -44,707			-21735	4.7	80%	76%
		R0.62 (triple gl	$ 206,336	$ -17,606	1.41	$ 102,503			-192834	7.2	90%	79%

Table 33: CBA results for interim mini-study on individual upgrades – single storey (Zone 2)

			Single Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 2 - Napier	Base	Code min	-	-	-	-					65%	46%
	Wall	R2.0 (Z3 min)	$ 475	$ -15	0.64	$ -170	-180	85	-94	2.1	65%	46%
		R2.5 (140mm)	$ 4,403	$ -73	0.33	$ -2,950			-782	11.6	66%	47%
		R2.9	$ 4,631	$ -104	0.45	$ -2,555			-1111	10.8	66%	47%
		R4.0 (staggered stud)	$ 8,106	$ -153	0.38	$ -5,063			-2014	NA	67%	48%
		R4.6	$ 10,432	$ -170	0.32	$ -7,046			-1858	14.5	68%	48%
	Roof	R3.3 (Z3 min)	$ 217	$ -55	5.05	$ 878			-612	19.2	66%	47%
		R3.6	$ 177	$ -88	9.88	$ 1,575			-942	11.3	66%	47%
		R4.3	$ 1,795	$ -147	1.63	$ 1,133			-1483	7.1	67%	48%
		R4.9	$ 2,242	$ -183	1.63	$ 1,408			-1952	10.8	68%	48%
		R5.9	$ 2,584	$ -235	1.81	$ 2,103			-2456	9.0	69%	49%
		R6.6	$ 2,646	$ -251	1.89	$ 2,359			-2611	8.7	69%	49%
	Floor	R1.9 (underslab)	$ 4,069	$ -42	0.21	$ -3,225			172	0.7	65%	49%
		R2.0 (edge)	$ 2,556	$ -26	0.20	$ -2,045	-301	165	-136	1.8	66%	46%
		R2.7 (full ins.)	$ 6,625	$ -61	0.18	$ -5,407			116	0.9	65%	49%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -76	1.26	$ 311			-819	12.3	66%	48%
		R0.31 (low-E)	$ 1,288	$ -105	1.30	$ 486			-1119	10.8	66%	47%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -185	1.31	$ 873			-1983	11.6	67%	49%
		R0.62 (triple glaz.)	$ 6,594	$ -398	1.00	$ 3			-3680	4.7	65%	50%

Table 34: CBA results for interim mini-study on individual upgrades – two storey (Zone 2)

			Two Storey									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 2 - Napier	Base	Code min	-	-	-	-					62%	48%
	Wall	R2.0 (Z3 min)	$ 594	$ -26	0.86	$ -83	-301	107	-194	2.8	62%	49%
		R2.5 (140mm)	$ 5,503	$ -111	0.40	$ -3,297			-1208	14.0	63%	51%
		R2.9	$ 5,789	$ -158	0.54	$ -2,648			-1710	13.1	63%	52%
		R4.0 (staggere	$ 10,131	$ -238	0.47	$ -5,403			-3063	NA	65%	54%
		R4.6	$ 13,039	$ -263	0.40	$ -7,795			-2919	18.0	65%	54%
	Roof	R3.3 (Z3 min)	$ 100	$ -44	8.75	$ 773			-499	33.3	62%	50%
		R3.6	$ 82	$ -70	17.08	$ 1,312			-780	19.6	62%	50%
		R4.3	$ 825	$ -115	2.77	$ 1,462			-1236	12.1	62%	51%
		R4.9	$ 1,031	$ -143	2.76	$ 1,816			-1586	18.3	62%	52%
		R5.9	$ 1,188	$ -181	3.03	$ 2,416			-1983	15.1	63%	52%
		R6.6	$ 1,217	$ -194	3.18	$ 2,654			-2125	14.6	63%	53%
	Floor	R1.9 (undersla	$ 2,252	$ -6	0.05	$ -2,131			301	0.2	61%	49%
		R2.0 (edge)	$ 1,818	$ -20	0.22	$ -1,421	-234	125	-109	1.9	62%	50%
		R2.7 (full ins.)	$ 4,030	$ -22	0.11	$ -3,589			229	0.5	62%	50%
	Glazing	R0.31 (thermal	$ 1,370	$ -91	1.32	$ 435			-981	12.9	63%	50%
		R0.31 (low-E)	$ 1,468	$ -177	1.93	$ 1,695			-1948	16.0	62%	50%
		R0.39 (therm.b	$ 2,839	$ -259	1.61	$ 1,961			-2831	14.3	63%	52%
		R0.62 (triple gl	$ 7,518	$ -723	1.59	$ 5,349			-7347	7.5	61%	53%

Table 35: CBA results for interim mini-study on individual upgrades – MDH (Zone 2)

			Medium Density									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 2 - Napier	Base	Code min	-	-	-	-					65%	50%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -63	0.67	$ -616	-737	336	-401	2.2	66%	51%
		R2.5 (140mm)	$ 17,602	$ -315	0.36	$ -11,333			-3403	12.6	67%	53%
		R2.9	$ 19,847	$ -446	0.45	$ -10,962			-4772	11.3	67%	54%
		R4.0 (staggere	$ 35,318	$ -659	0.37	$ -22,191			-8522	NA	68%	56%
		R4.6	$ 45,410	$ -731	0.32	$ -30,852			-7756	10.4	69%	56%
	Roof	R3.3 (Z3 min)	$ 399	$ -158	7.86	$ 2,737			-1786	29.9	66%	51%
		R3.6	$ 326	$ -251	15.34	$ 4,680			-2783	17.6	66%	52%
		R4.3	$ 3,300	$ -418	2.52	$ 5,026			-4462	11.0	66%	52%
		R4.9	$ 4,123	$ -526	2.54	$ 6,356			-5809	16.8	66%	53%
		R5.9	$ 4,751	$ -679	2.84	$ 8,761			-7401	14.1	66%	54%
		R6.6	$ 4,866	$ -720	2.94	$ 9,461			-7821	13.5	66%	54%
	Floor	R1.9 (undersla	$ 6,967	$ -34	0.10	$ -6,295			752	0.3	65%	50%
		R2.0 (edge)	$ 5,596	$ -120	0.43	$ -3,216			-1033	3.8	66%	51%
		R2.7 (full ins.)	$ 12,516	$ -124	0.20	$ -10,053			56	1.0	65%	51%
	Glazing	R0.31 (thermal	$ 5,259	$ -296	1.12	$ 638			-3158	10.9	67%	52%
		R0.31 (low-E)	$ 5,635	$ -641	1.82	$ 5,729			-7020	15.1	66%	51%
		R0.39 (therm.b	$ 10,894	$ -903	1.46	$ 5,699			-9785	13.0	68%	54%
		R0.62 (triple gl	$ 28,851	$ -2,732	1.57	$ 19,718			-27718	7.4	65%	53%

Table 36: CBA results for interim mini-study on individual upgrades – apartment (Zone 2)

			Apartment									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 2 - Napier	Base	Code min	-	-	-	-					71%	61%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -48	0.13	$ -6,357			755	0.4	72%	61%
		R2.5 (140mm)	$ 67,718	$ -293	0.09	$ -61,894			-2293	3.0	72%	61%
		R2.9	$ 71,228	$ -403	0.11	$ -63,204	-4730	1739	-2991	2.7	73%	62%
		R4.0 (staggere	$ 124,664	$ -612	0.10	$ -112,489	-7176	-3394	-10570	NA	73%	62%
		R4.6	$ 160,448	$ -679	0.08	$ -146,923			-5858	3.8	74%	62%
	Roof	R3.3 (Z3 min)	$ 124	$ -58	9.38	$ 1,039			-620	10.5	71%	61%
		R3.9	$ 579	$ -123	4.22	$ 1,863			-1303	10.6	71%	61%
		R4.3	$ 496	$ -201	8.07	$ 3,509			-2104	9.2	71%	61%
		R5.3	$ 3,886	$ -246	1.26	$ 1,020			-2318	5.0	71%	61%
		R6.3	$ 5,007	$ -309	1.23	$ 1,144			-2614	3.6	71%	61%
		R7.3	$ 6,127	$ -328	1.07	$ 408	-3852	1635	-2216	2.4	71%	61%
	Floor	R2.0	$ 914	$ 450					5461	28.4	71%	62%
		R2.0	$ 914	$ 450					5461	28.4	71%	62%
		R2.7	$ 1,174	$ 824					9909	41.1	71%	62%
	Glazing	R0.31 (therma	$ 37,613	$ -737	0.39	$ -22,948			-6372	3.8	74%	62%
		R0.31 (low-E)	$ 40,300	$ -4,562	1.81	$ 40,562			-49966	15.0	74%	63%
		R0.39 (therm.b	$ 77,913	$ -4,379	0.99	$ -686			-45551	8.8	78%	65%
		R0.62 (triple gl	$ 206,336	$ -22,276	1.79	$ 195,455			-230314	8.4	88%	76%

Table 37: CBA results for interim mini-study on individual upgrades – single storey (Zone 3)

			Single Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					55%	30%
	Wall	R2.0 (Z3 min)	$ 475	$ -18	0.77	$ -110	-225	85	-139	2.6	55%	30%
		R2.5 (140mm)	$ 4,783	$ -91	0.38	$ -2,973			-1042	15.1	56%	31%
		R2.9	$ 5,012	$ -129	0.51	$ -2,435			-1475	14.1	56%	32%
		R4.0 (staggered stud)	$ 8,244	$ -194	0.47	$ -4,384			-2600	NA	57%	33%
		R4.6	$ 10,570	$ -216	0.41	$ -6,266			-2516	19.3	58%	33%
	Roof	R3.3 (Z3 min)	$ 217	$ -55	5.03	$ 874			-639	20.0	56%	31%
		R3.6	$ 177	$ -88	9.84	$ 1,570			-986	11.8	56%	31%
		R4.3	$ 1,814	$ -147	1.61	$ 1,104			-1557	7.4	57%	32%
		R4.9	$ 2,201	$ -184	1.67	$ 1,466			-2060	11.3	58%	33%
		R5.9	$ 2,542	$ -237	1.86	$ 2,179			-2604	9.5	58%	33%
		R6.6	$ 2,604	$ -253	1.94	$ 2,440			-2770	9.2	59%	34%
	Floor	R1.9 (underslab)	$ 3,633	$ -128	0.70	$ -1,084	-1	669	-903	2.3	57%	34%
		R2.0 (edge)	$ 2,524	$ -54	0.43	$ -1,444			-501	4.0	56%	30%
		R2.7 (full ins.)	$ 6,157	$ -161	0.52	$ -2,947		834	-1145	2.4	57%	34%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -91	1.51	$ 607			-1043	15.4	56%	32%
		R0.31 (low-E)	$ 1,288	$ -86	1.06	$ 97			-936	9.2	55%	31%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -190	1.34	$ 966			-2140	12.5	57%	33%
		R0.62 (triple glaz.)	$ 6,594	$ -294	0.74	$ -2,071			-2616	3.6	53%	34%

Table 38: CBA results for interim mini-study on individual upgrades – two storey (Zone 3)

			Two Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					53%	37%
	Wall	R2.0 (Z3 min)	$ 594	$ -27	0.90	$ -59			-223	3.1	53%	38%
		R2.5 (140mm)	$ 5,979	$ -124	0.41	$ -3,517			-1425	16.4	54%	40%
		R2.9	$ 6,264	$ -178	0.57	$ -2,718			-2045	15.5	55%	41%
		R4.0 (staggere	$ 10,304	$ -265	0.51	$ -5,031			-3526	NA	56%	44%
		R4.6	$ 13,212	$ -295	0.44	$ -7,339			-3449	21.1	56%	44%
	Roof	R3.3 (Z3 min)	$ 100	$ -39	7.72	$ 670			-459	30.7	53%	38%
		R3.6	$ 82	$ -61	14.81	$ 1,128			-703	17.8	53%	39%
		R4.3	$ 834	$ -101	2.42	$ 1,186			-1134	11.2	53%	40%
		R4.9	$ 1,012	$ -127	2.50	$ 1,522			-1471	17.0	54%	40%
		R5.9	$ 1,169	$ -165	2.81	$ 2,117			-1885	14.4	54%	42%
		R6.6	$ 1,198	$ -176	2.93	$ 2,312			-2007	13.9	54%	42%
	Floor	R1.9 (undersla	$ 2,020	$ -43	0.43	$ -1,161	-530	372	-157	1.4	55%	39%
		R2.0 (edge)	$ 1,799	$ -34	0.38	$ -1,119			-294	3.4	54%	39%
		R2.7 (full ins.)	$ 3,769	$ -69	0.37	$ -2,389	-850	489	-361	1.7	56%	40%
	Glazing	R0.31 (thermal	$ 1,370	$ -101	1.47	$ 644			-1159	15.0	54%	39%
		R0.31 (low-E)	$ 1,468	$ -159	1.72	$ 1,327			-1817	15.0	53%	39%
		R0.39 (therm.b	$ 2,839	$ -259	1.61	$ 1,958			-2968	15.0	54%	42%
		R0.62 (triple gl	$ 7,518	$ -617	1.36	$ 3,250			-6442	6.7	48%	42%

Table 39: CBA results for interim mini-study on individual upgrades – MDH (Zone 3)

			Medium Density									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					59%	39%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -66	0.70	$ -552	-810	336	-474	2.4	59%	39%
		R2.5 (140mm)	$ 19,097	$ -318	0.33	$ -12,761			-3613	13.4	60%	41%
		R2.9	$ 21,509	$ -457	0.42	$ -12,405			-5147	12.1	61%	43%
		R4.0 (staggere	$ 36,175	$ -695	0.38	$ -22,336			-9316	NA	62%	46%
		R4.6	$ 46,268	$ -774	0.33	$ -30,854			-8678	11.5	63%	47%
	Roof	R3.3 (Z3 min)	$ 399	$ -153	7.64	$ 2,648			-1816	30.4	59%	40%
		R3.6	$ 326	$ -243	14.84	$ 4,516			-2818	17.8	59%	40%
		R4.3	$ 3,337	$ -404	2.41	$ 4,713			-4517	11.1	59%	41%
		R4.9	$ 4,047	$ -508	2.50	$ 6,057			-5861	17.0	60%	42%
		R5.9	$ 4,675	$ -651	2.77	$ 8,293			-7431	14.2	60%	43%
		R6.6	$ 4,789	$ -696	2.89	$ 9,067			-7918	13.7	60%	44%
	Floor	R1.9 (undersla	$ 6,232	$ -164	0.52	$ -2,967	-2013	1148	-865	1.8	59%	39%
		R2.0 (edge)	$ 5,530	$ -235	0.84	$ -858			-2510	7.8	60%	39%
		R2.7 (full ins.)	$ 11,703	$ -314	0.53	$ -5,457	-3850	1508	-2342	2.6	60%	40%
	Glazing	R0.31 (therma	$ 5,259	$ -351	1.33	$ 1,734			-3993	13.6	61%	41%
		R0.31 (low-E)	$ 5,635	$ -536	1.52	$ 3,635			-6074	13.2	59%	40%
		R0.39 (therm.b	$ 10,894	$ -884	1.43	$ 5,317			-10036	13.3	61%	43%
		R0.62 (triple gl	$ 28,851	$ -2,084	1.20	$ 6,820			-21238	5.9	55%	42%

Table 40: CBA results for interim mini-study on individual upgrades – apartment (Zone 3)

			Apartment									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					69%	61%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -83	0.23	$ -5,647			292	0.8	69%	61%
		R2.5 (140mm)	$ 73,570	$ -373	0.10	$ -66,143			-3440	4.0	70%	61%
		R2.9	$ 77,081	$ -522	0.13	$ -66,695			-4664	3.7	71%	62%
		R4.0 (staggere	$ 126,788	$ -770	0.12	$ -111,457	-9451	-3394	-12845	NA	72%	62%
		R4.6	$ 162,571	$ -834	0.10	$ -145,973			-8119	4.8	72%	62%
	Roof	R3.3 (Z3 min)	$ 124	$ -72	11.62	$ 1,317			-823	13.6	69%	61%
		R3.9	$ 579	$ -112	3.84	$ 1,643			-1234	10.1	69%	61%
		R4.3	$ 496	$ -186	7.45	$ 3,198			-2021	8.9	69%	61%
		R5.3	$ 3,927	$ -227	1.15	$ 591			-2212	4.9	69%	61%
		R6.3	$ 5,048	$ -281	1.11	$ 550			-2439	3.4	69%	61%
		R7.3	$ 6,168	$ -298	0.96	$ -227	-3662	1635	-2027	2.2	69%	61%
	Floor	R2.0	$ 969	$ 331					4248	21.9	69%	61%
		R2.0	$ 969	$ 331					4248	21.9	69%	61%
		R2.7	$ 1,117	$ 626					7922	32.6	69%	62%
	Glazing	R0.31 (therma	$ 37,613	$ -1,122	0.59	$ -15,274			-11500	6.1	73%	63%
		R0.31 (low-E)	$ 40,300	$ -3,960	1.57	$ 28,573			-45032	13.6	73%	63%
		R0.39 (therm.b	$ 77,913	$ -4,389	0.99	$ -490			-48030	9.2	79%	66%
		R0.62 (triple gl	$ 206,336	$ -18,507	1.49	$ 120,441			-196066	7.3	90%	79%

Table 41: CBA results for interim mini-study on individual upgrades – single storey (Zone 4)

			Single Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 4 - Turangi	Base	Code min	-	-	-	-					50%	23%
	Wall	R2.0 (Z3 min)	-	-	-	-					50%	23%
		R2.5 (140mm)	$ 4,329	$ -95	0.44	$ -2,440			-1109	NA	50%	23%
		R2.9	$ 4,557	$ -147	0.64	$ -1,640			-1668	61.5	51%	24%
		R4.0 (staggered stud)	$ 7,449	$ -234	0.63	$ -2,784			-3017	NA	51%	25%
		R4.6	$ 9,971	$ -263	0.53	$ -4,726			-2996	58.7	52%	25%
	Roof	R3.3 (Z3 min)	-	-	-	-					50%	24%
		R3.6	$ -39	$ -46	NA	$ 962			-478	9.3	51%	24%
		R4.3	$ 1,775	$ -129	1.45	$ 798			-1287	7.2	51%	25%
		R4.9	$ 1,964	$ -182	1.84	$ 1,658			-1939	12.7	52%	25%
		R5.9	$ 2,325	$ -256	2.19	$ 2,775			-2691	10.9	52%	26%
		R6.6	$ 2,304	$ -279	2.41	$ 3,254			-2924	10.6	52%	26%
	Floor	R1.9 (underslab)	$ 3,986	$ -172	0.86	$ -556	-1993	669	-1324	3.0	51%	28%
		R2.0 (edge)	$ 2,545	$ -49	0.38	$ -1,569			-402	3.4	50%	23%
		R2.7 (full ins.)	$ 6,530	$ -202	0.62	$ -2,505	-234	834	-1506	2.8	52%	28%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -120	1.99	$ 1,191			-1318	19.1	51%	24%
		R0.31 (low-E)	$ 1,288	$ -113	1.40	$ 643			-1193	11.5	50%	24%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -250	1.77	$ 2,162			-2702	15.5	51%	26%
		R0.62 (triple glaz.)	$ 6,594	$ -395	0.99	$ -58			-3579	4.6	46%	25%

Table 42. CBA results for interim mini-study on individual upgrades – two storey (Zone 4)

			Two Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 4 - Turangi	Base	Code min	-	-	-	-					48%	31%
	Wall	R2.0 (Z3 min)	-	-	-	-					49%	32%
		R2.5 (140mm)	$ 5,411	$ -135	0.50	$ -2,717			-1579	NA	49%	33%
		R2.9	$ 5,696	$ -210	0.73	$ -1,510			-2398	70.6	50%	35%
		R4.0 (staggere	$ 9,310	$ -334	0.71	$ -2,658			-4249	NA	51%	37%
		R4.6	$ 12,463	$ -376	0.60	$ -4,974			-4287	67.1	51%	38%
	Roof	R3.3 (Z3 min)	-	-	-	-					48%	32%
		R3.6	$ (18)	$ -32	NA	$ 658			-346	14.0	49%	32%
		R4.3	$ 816	$ -90	2.19	$ 974			-944	10.8	49%	33%
		R4.9	$ 903	$ -126	2.77	$ 1,599			-1378	19.0	49%	34%
		R5.9	$ 1,069	$ -178	3.32	$ 2,484			-1939	16.5	49%	35%
		R6.6	$ 1,060	$ -195	3.65	$ 2,812			-2110	16.0	49%	35%
	Floor	R1.9 (undersla	$ 2,196	$ -63	0.58	$ -933	-734	372	-362	2.0	50%	32%
		R2.0 (edge)	$ 1,799	$ -36	0.40	$ -1,086			-289	3.3	49%	32%
		R2.7 (full ins.)	$ 3,977	$ -92	0.46	$ -2,149	-1062	489	-573	2.2	50%	33%
	Glazing	R0.31 (therma	$ 1,370	$ -137	1.98	$ 1,349			-1497	19.1	49%	33%
		R0.31 (low-E)	$ 1,468	$ -185	2.01	$ 1,854			-2011	16.5	48%	32%
		R0.39 (therm.b	$ 2,839	$ -327	2.03	$ 3,300			-3566	17.8	50%	34%
		R0.62 (triple gl	$ 7,518	$ -706	1.56	$ 5,023			-7038	7.2	44%	35%

Table 43: CBA results for interim mini-study on individual upgrades – MDH (Zone 4)

			Medium Density									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 4 - Turangi	Base	Code min	-	-	-	-					51%	30%
	Wall	R2.0 (Z3 min)	-	-	-	-					52%	30%
		R2.5 (140mm)	$ 17,391	$ -355	0.41	$ -10,330			-4147	NA	53%	33%
		R2.9	$ 19,721	$ -552	0.56	$ -8,733			-6256	49.3	53%	34%
		R4.0 (staggere	$ 32,987	$ -887	0.54	$ -15,323			-11385	NA	54%	36%
		R4.6	$ 43,943	$ -1,001	0.45	$ -24,017			-11091	23.7	55%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					52%	31%
		R3.6	$ (73)	$ -135	NA	$ 2,767			-1460	14.8	52%	32%
		R4.3	$ 3,264	$ -379	2.31	$ 4,290			-4006	11.4	52%	32%
		R4.9	$ 3,612	$ -534	2.94	$ 7,016			-5871	20.2	52%	33%
		R5.9	$ 4,276	$ -748	3.48	$ 10,623			-8156	17.3	52%	34%
		R6.6	$ 4,238	$ -815	3.83	$ 11,982			-8863	16.8	52%	34%
	Floor	R1.9 (undersla	$ 6,813	$ -187	0.55	$ -3,095	-2161	1148	-1013	1.9	52%	31%
		R2.0 (edge)	$ 5,559	$ -208	0.74	$ -1,422			-2034	6.5	52%	30%
		R2.7 (full ins.)	$ 12,351	$ -327	0.53	$ -5,848	-3779	1508	-2271	2.5	52%	31%
	Glazing	R0.31 (thermal	$ 5,259	$ -476	1.80	$ 4,207			-5183	17.3	53%	32%
		R0.31 (low-E)	$ 5,635	$ -643	1.82	$ 5,770			-6939	14.9	51%	31%
		R0.39 (therm.b	$ 10,894	$ -1,139	1.85	$ 10,395			-12365	16.2	53%	34%
		R0.62 (triple gl	$ 28,851	$ -2,525	1.45	$ 15,584			-24864	6.7	49%	33%

Table 44: CBA results for interim mini-study on individual upgrades – apartment (Zone 4)

			Apartment									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 4 - Turangi	Base	Code min	-	-	-	-					62%	56%
	Wall	R2.0 (Z3 min)	-	-	-	-					62%	56%
		R2.5 (140mm)	$ 66,578	$ -562	0.17	$ -55,388			-6679	NA	63%	57%
		R2.9	$ 70,089	$ -871	0.25	$ -52,750			-9652	23.8	63%	57%
		R4.0 (staggere	$ 114,565	$ -1,376	0.24	$ -87,164			-20632	NA	64%	57%
		R4.6	$ 153,358	$ -1,552	0.20	$ -122,468			-17153	22.5	65%	58%
	Roof	R3.3 (Z3 min)	-	-	-	-					62%	56%
		R3.9	$ 496	$ -68	2.71	$ 849			-711	11.1	62%	56%
		R4.3	$ 413	$ -218	10.51	$ 3,930			-2333	13.2	62%	56%
		R5.3	$ 4,217	$ -302	1.42	$ 1,790			-2982	6.9	62%	56%
		R6.3	$ 5,337	$ -418	1.56	$ 2,981			-3888	5.1	62%	56%
		R7.3	$ 6,458	$ -453	1.40	$ 2,564			-3673	3.3	62%	56%
	Floor	R2.0	$ 735	$ 466					5572	29.0	62%	56%
		R2.0	$ 735	$ 466					5572	29.0	62%	56%
		R2.7	$ 1,182	$ 859					10176	42.2	62%	56%
	Glazing	R0.31 (thermal	$ 37,613	$ -2,116	1.12	$ 4,503			-22203	10.8	66%	58%
		R0.31 (low-E)	$ 40,300	$ -4,989	1.98	$ 49,054			-54148	16.2	65%	58%
		R0.39 (therm.b	$ 77,913	$ -6,548	1.48	$ 42,488			-69918	13.0	70%	61%
		R0.62 (triple gl	$ 206,336	$ -22,304	1.79	$ 196,009			-226960	8.3	77%	67%

Table 45: CBA results for interim mini-study on individual upgrades – single storey (Zone 5)

			Single Storey									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					44%	23%
	Wall	R2.0 (Z3 min)	-	-	-	-					45%	24%
		R2.5 (140mm)	$ 3,286	$ -95	0.57	$ -1,405			-1245	NA	45%	25%
		R2.9	$ 3,515	$ -146	0.83	$ -610			-1876	69.1	45%	25%
		R4.0 (staggered stud)	$ 8,349	$ -233	0.55	$ -3,717			-3343	NA	46%	26%
		R4.6	$ 10,393	$ -262	0.50	$ -5,173			-3370	65.9	46%	26%
	Roof	R3.3 (Z3 min)	-	-	-	-					45%	24%
		R3.6	$ -39	$ -45	NA	$ 930			-526	10.1	45%	25%
		R4.3	$ 1,321	$ -125	1.89	$ 1,171			-1425	7.8	46%	25%
		R4.9	$ 2,150	$ -176	1.63	$ 1,356			-2132	13.8	46%	26%
		R5.9	$ 2,553	$ -249	1.94	$ 2,395			-2971	11.9	46%	27%
		R6.6	$ 2,637	$ -271	2.05	$ 2,762			-3233	11.6	46%	27%
	Floor	R1.9 (underslab)	$ 4,526	$ -189	0.83	$ -754			-1804	3.7	46%	28%
		R2.0 (edge)	$ 2,486	$ -53	0.43	$ -1,421			-533	4.2	45%	24%
		R2.7 (full ins.)	$ 7,012	$ -221	0.63	$ -2,618			-2046	3.5	46%	28%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -112	1.85	$ 1,027			-1389	20.1	45%	25%
		R0.31 (low-E)	$ 1,288	$ -99	1.22	$ 360			-1175	11.3	44%	24%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -229	1.62	$ 1,743			-2797	16.0	45%	27%
		R0.62 (triple glaz.)	$ 6,594	$ -352	0.89	$ -908			-3608	4.6	41%	27%

Table 46: CBA results for interim mini-study on individual upgrades – two storey (Zone 5)

			Two Storey									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					43%	31%
	Wall	R2.0 (Z3 min)	-	-	-	-					43%	31%
		R2.5 (140mm)	$ 4,107	$ -136	0.66	$ -1,392			-1794	NA	44%	33%
		R2.9	$ 4,393	$ -209	0.95	$ -223			-2699	79.4	45%	34%
		R4.0 (staggere	$ 10,436	$ -334	0.64	$ -3,780			-4746	NA	46%	36%
		R4.6	$ 12,990	$ -376	0.58	$ -5,499			-4846	75.7	46%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					43%	32%
		R3.6	$ (18)	$ -29	NA	$ 599			-354	14.4	43%	32%
		R4.3	$ 608	$ -82	2.69	$ 1,026			-975	11.2	43%	33%
		R4.9	$ 988	$ -116	2.33	$ 1,319			-1436	19.8	44%	34%
		R5.9	$ 1,174	$ -163	2.77	$ 2,079			-2007	17.0	44%	35%
		R6.6	$ 1,212	$ -178	2.92	$ 2,328			-2181	16.5	44%	35%
	Floor	R1.9 (undersla	$ 2,509	$ -71	0.57	$ -1,091	-929	372	-557	2.5	44%	32%
		R2.0 (edge)	$ 1,780	$ -38	0.42	$ -1,034			-364	3.9	44%	32%
		R2.7 (full ins.)	$ 4,234	$ -101	0.48	$ -2,221	-1320	489	-831	2.7	45%	33%
	Glazing	R0.31 (thermal	$ 1,370	$ -129	1.87	$ 1,189			-1595	20.3	44%	33%
		R0.31 (low-E)	$ 1,468	$ -163	1.77	$ 1,404			-1991	16.3	43%	32%
		R0.39 (therm.b	$ 2,839	$ -300	1.86	$ 2,762			-3697	18.4	44%	34%
		R0.62 (triple gl	$ 7,518	$ -652	1.44	$ 3,954			-7384	7.5	39%	34%

Table 47: CBA results for interim mini-study on individual upgrades – MDH (Zone 5)

			Medium Density									
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					48%	31%
	Wall	R2.0 (Z3 min)	-	-	-	-					48%	31%
		R2.5 (140mm)	$ 13,217	$ -337	0.51	$ -6,507			-4442	NA	48%	33%
		R2.9	$ 15,391	$ -525	0.68	$ -4,943			-6720	52.9	49%	34%
		R4.0 (staggere	$ 36,068	$ -842	0.46	$ -19,302			-12112	NA	50%	36%
		R4.6	$ 44,895	$ -949	0.42	$ -26,002			-11897	25.3	50%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					48%	32%
		R3.6	$ (73)	$ -128	NA	$ 2,614			-1560	15.7	48%	32%
		R4.3	$ 2,430	$ -355	2.90	$ 4,627			-4242	12.0	48%	34%
		R4.9	$ 3,953	$ -498	2.51	$ 5,955			-6190	21.3	48%	34%
		R5.9	$ 4,696	$ -698	2.96	$ 9,208			-8613	18.2	48%	35%
		R6.6	$ 4,848	$ -762	3.13	$ 10,323			-9383	17.7	48%	35%
	Floor	R1.9 (undersla	$ 7,754	$ -217	0.56	$ -3,426	-2837	1148	-1689	2.5	48%	32%
		R2.0 (edge)	$ 5,457	$ -211	0.77	$ -1,264			-2379	7.4	48%	31%
		R2.7 (full ins.)	$ 13,146	$ -354	0.54	$ -6,092			-3116	3.1	48%	32%
	Glazing	R0.31 (thermal	$ 5,259	$ -446	1.69	$ 3,624			-5506	18.3	49%	33%
		R0.31 (low-E)	$ 5,635	$ -562	1.59	$ 4,156			-6833	14.7	48%	32%
		R0.39 (therm.b	$ 10,894	$ -1,040	1.68	$ 8,409			-12751	16.6	49%	34%
		R0.62 (triple gl	$ 28,851	$ -2,186	1.25	$ 8,841			-24184	6.6	45%	34%

Table 48: CBA results for interim mini-study on individual upgrades – apartment (Zone 5)

			Apartment									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					59%	54%
	Wall	R2.0 (Z3 min)	-	-	-	-					59%	54%
		R2.5 (140mm)	$ 50,542	$ -576	0.23	$ -39,084			-7687	NA	59%	55%
		R2.9	$ 54,053	$ -882	0.32	$ -36,494			-11087	27.2	60%	55%
		R4.0 (staggere	$ 128,410	$ -1,420	0.22	$ -100,139			-23242	NA	60%	56%
		R4.6	$ 159,846	$ -1,605	0.20	$ -127,903			-20142	26.2	60%	56%
	Roof	R3.3 (Z3 min)	-	-	-	-					59%	54%
		R3.9	$ 455	$ -75	3.26	$ 1,030			-903	13.8	59%	54%
		R4.3	$ 372	$ -203	10.84	$ 3,662			-2454	13.8	59%	54%
		R5.3	$ 3,225	$ -280	1.73	$ 2,354			-3149	7.2	59%	54%
		R6.3	$ 4,345	$ -387	1.77	$ 3,353			-4101	5.3	59%	54%
		R7.3	$ 5,465	$ -418	1.52	$ 2,863			-3890	3.5	59%	54%
	Floor	R2.0	$ 1,082	$ 357					4844	25.1	59%	53%
		R2.0	$ 1,082	$ 357					4844	25.1	59%	53%
		R2.7	$ 1,268	$ 647					8683	35.9	59%	53%
	Glazing	R0.31 (therma	$ 37,613	$ -2,203	1.17	$ 6,237			-26474	12.7	61%	57%
		R0.31 (low-E)	$ 40,300	$ -4,345	1.72	$ 36,243			-53141	15.9	60%	57%
		R0.39 (therm.b	$ 77,913	$ -6,199	1.40	$ 35,527			-75058	13.9	65%	59%
		R0.62 (triple gl	$ 206,336	$ -19,287	1.55	$ 135,963			-220644	8.1	69%	63%

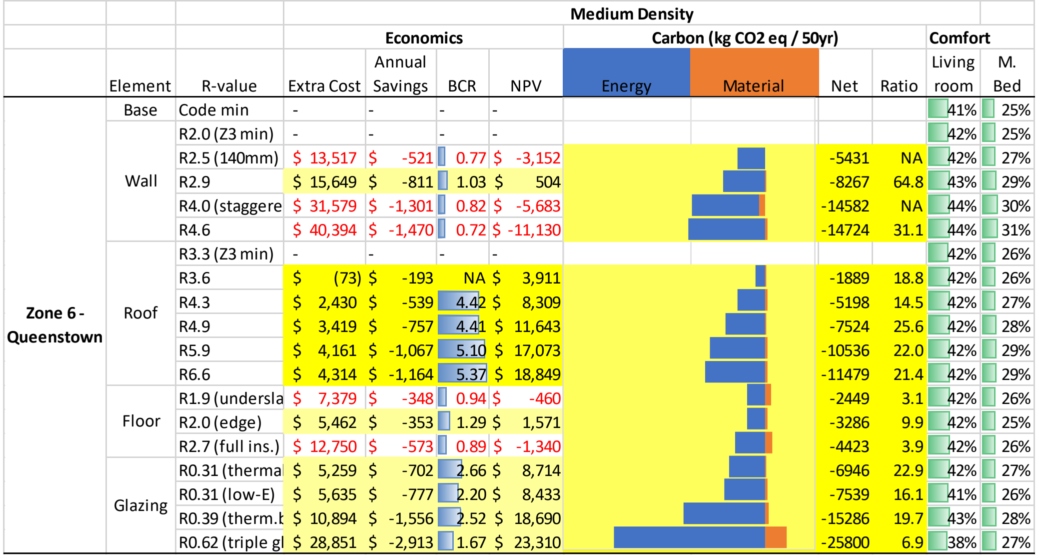
Table 49: CBA results for interim mini-study on individual upgrades – single storey (Zone 6)

			Single Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 6 - Queenstown	Base	Code min	-	-	-	-					39%	15%
	Wall	R2.0 (Z3 min)	-	-	-	-					39%	16%
		R2.5 (140mm)	$ 3,359	$ -149	0.88	$ -397			-1551	NA	39%	16%
		R2.9	$ 3,587	$ -228	1.27	$ 961			-2337	85.8	39%	16%
		R4.0 (staggered stud)	$ 7,202	$ -365	1.01	$ 73			-4088	NA	40%	17%
		R4.6	$ 9,246	$ -413	0.89	$ -1,023			-4223	82.4	40%	17%
	Roof	R3.3 (Z3 min)	-	-	-	-					39%	16%
		R3.6	$ -39	$ -67	NA	$ 1,368			-633	12.0	39%	16%
		R4.3	$ 1,321	$ -188	2.83	$ 2,420			-1736	9.3	40%	17%
		R4.9	$ 1,859	$ -264	2.83	$ 3,402			-2569	16.5	40%	18%
		R5.9	$ 2,263	$ -371	3.26	$ 5,114			-3562	14.1	40%	18%
		R6.6	$ 2,346	$ -404	3.43	$ 5,692			-3872	13.7	40%	19%
	Floor	R1.9 (underslab)	$ 4,297	$ -315	1.46	$ 1,980			-2594	4.9	40%	21%
		R2.0 (edge)	$ 2,482	$ -87	0.70	$ -743			-739	5.5	39%	16%
		R2.7 (full ins.)	$ 6,780	$ -367	1.08	$ 517			-2959	4.5	40%	21%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -174	2.88	$ 2,266			-1730	24.8	39%	17%
		R0.31 (low-E)	$ 1,288	$ -141	1.75	$ 1,197			-1343	12.8	38%	16%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -345	2.45	$ 4,067			-3388	19.2	39%	18%
		R0.62 (triple glaz.)	$ 6,594	$ -473	1.19	$ 1,499			-3906	4.9	34%	17%

Table 50: CBA results for interim mini-study on individual upgrades – two storey (Zone 6)

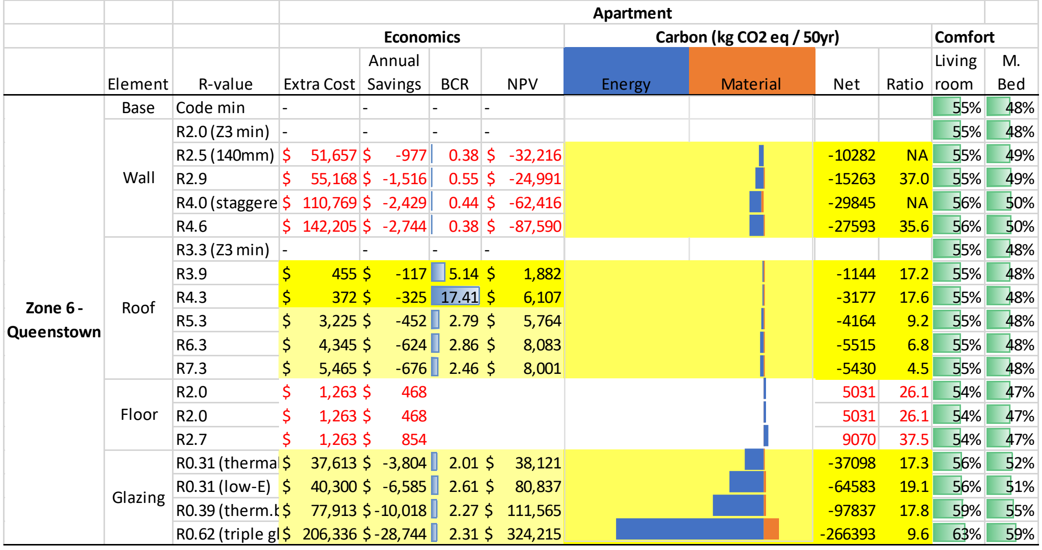
			Two Storey									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 6 - Queenstown	Base	Code min	-	-	-	-					37%	25%
	Wall	R2.0 (Z3 min)	-	-	-	-					37%	25%
		R2.5 (140mm)	$ 4,198	$ -212	1.01	$ 27			-2210	NA	38%	27%
		R2.9	$ 4,483	$ -329	1.46	$ 2,065			-3370	98.9	38%	28%
		R4.0 (staggere	$ 9,002	$ -524	1.16	$ 1,422			-5801	NA	39%	30%
		R4.6	$ 11,557	$ -591	1.02	$ 206			-6050	94.3	40%	30%
	Roof	R3.3 (Z3 min)	-	-	-	-					37%	26%
		R3.6	$ (18)	$ -44	NA	$ 898			-431	17.3	37%	26%
		R4.3	$ 608	$ -122	4.01	$ 1,826			-1169	13.2	37%	27%
		R4.9	$ 855	$ -172	4.01	$ 2,574			-1706	23.3	38%	28%
		R5.9	$ 1,041	$ -242	4.62	$ 3,771			-2376	19.9	38%	29%
		R6.6	$ 1,079	$ -264	4.87	$ 4,176			-2591	19.4	38%	29%
	Floor	R1.9 (undersla	$ 2,397	$ -121	1.01	$ 13			-880	3.4	39%	26%
		R2.0 (edge)	$ 1,789	$ -63	0.70	$ -544			-522	5.2	38%	26%
		R2.7 (full ins.)	$ 4,107	$ -171	0.83	$ -704			-1280	3.6	39%	27%
	Glazing	R0.31 (thermal	$ 1,370	$ -199	2.88	$ 2,582			-1972	24.8	38%	26%
		R0.31 (low-E)	$ 1,468	$ -225	2.44	$ 2,639			-2194	17.9	37%	26%
		R0.39 (therm.b	$ 2,839	$ -445	2.77	$ 5,654			-4391	21.7	38%	28%
		R0.62 (triple gl	$ 7,518	$ -852	1.88	$ 7,918			-7681	7.8	32%	27%

Table 51: CBA results for interim mini-study on individual upgrades – MDH (Zone 6)



			Medium Density									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 6 - Queenstown	Base	Code min	-	-	-	-					41%	25%
	Wall	R2.0 (Z3 min)	-	-	-	-					42%	25%
		R2.5 (140mm)	$ 13,517	$ -521	0.77	$ -3,152			-5431	NA	42%	27%
		R2.9	$ 15,649	$ -811	1.03	$ 504			-8267	64.8	43%	29%
		R4.0 (staggere	$ 31,579	$ -1,301	0.82	$ -5,683			-14582	NA	44%	30%
		R4.6	$ 40,394	$ -1,470	0.72	$ -11,130			-14724	31.1	44%	31%
	Roof	R3.3 (Z3 min)	-	-	-	-					42%	26%
		R3.6	$ (73)	$ -193	NA	$ 3,911			-1889	18.8	42%	26%
		R4.3	$ 2,430	$ -539	4.42	$ 8,309			-5198	14.5	42%	27%
		R4.9	$ 3,419	$ -757	4.41	$ 11,643			-7524	25.6	42%	28%
		R5.9	$ 4,161	$ -1,067	5.10	$ 17,073			-10536	22.0	42%	29%
		R6.6	$ 4,314	$ -1,164	5.37	$ 18,849			-11479	21.4	42%	29%
	Floor	R1.9 (undersla	$ 7,379	$ -348	0.94	$ -460			-2449	3.1	42%	26%
		R2.0 (edge)	$ 5,462	$ -353	1.29	$ 1,571			-3286	9.9	42%	25%
		R2.7 (full ins.)	$ 12,750	$ -573	0.89	$ -1,340			-4423	3.9	42%	26%
	Glazing	R0.31 (thermal	$ 5,259	$ -702	2.66	$ 8,714			-6946	22.9	42%	27%
		R0.31 (low-E)	$ 5,635	$ -777	2.20	$ 8,433			-7539	16.1	41%	26%
		R0.39 (therm.b	$ 10,894	$ -1,556	2.52	$ 18,690			-15286	19.7	43%	28%
		R0.62 (triple gl	$ 28,851	$ -2,913	1.67	$ 23,310			-25800	6.9	38%	27%

Table 52: CBA results for interim mini-study on individual upgrades – apartment (Zone 6)



			Apartment									
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 6 - Queenstown	Base	Code min	-	-	-	-					55%	48%
	Wall	R2.0 (Z3 min)	-	-	-	-					55%	48%
		R2.5 (140mm)	$ 51,657	$ -977	0.38	$ -32,216			-10282	NA	55%	49%
		R2.9	$ 55,168	$ -1,516	0.55	$ -24,991			-15263	37.0	55%	49%
		R4.0 (staggere	$ 110,769	$ -2,429	0.44	$ -62,416			-29845	NA	56%	50%
		R4.6	$ 142,205	$ -2,744	0.38	$ -87,590			-27593	35.6	56%	50%
	Roof	R3.3 (Z3 min)	-	-	-	-					55%	48%
		R3.9	$ 455	$ -117	5.14	$ 1,882			-1144	17.2	55%	48%
		R4.3	$ 372	$ -325	17.41	$ 6,107			-3177	17.6	55%	48%
		R5.3	$ 3,225	$ -452	2.79	$ 5,764			-4164	9.2	55%	48%
		R6.3	$ 4,345	$ -624	2.86	$ 8,083			-5515	6.8	55%	48%
		R7.3	$ 5,465	$ -676	2.46	$ 8,001			-5430	4.5	55%	48%
	Floor	R2.0	$ 1,263	$ 468					5031	26.1	54%	47%
		R2.0	$ 1,263	$ 468					5031	26.1	54%	47%
		R2.7	$ 1,263	$ 854					9070	37.5	54%	47%
	Glazing	R0.31 (thermal	$ 37,613	$ -3,804	2.01	$ 38,121			-37098	17.3	56%	52%
		R0.31 (low-E)	$ 40,300	$ -6,585	2.61	$ 80,837			-64583	19.1	56%	51%
		R0.39 (therm.b	$ 77,913	$ -10,018	2.27	$ 111,565			-97837	17.8	59%	55%
		R0.62 (triple gl	$ 206,336	$ -28,744	2.31	$ 324,215			-266393	9.6	63%	59%

Appendix F: Combination sensitivity studies

Table 53 to Table 55 examine the impact of eight variations to the building design and operation on space conditioning needs. The details of the changes and how to interpret the tables can be viewed in section 3.6, where the single-storey dwelling result is displayed.

Table 53: Various sensitivity studies, both individual and combined savings, on the two-storey house

						Two Storey House (percent savings)							
Climate	Set	Roof	Wall	Floor	Glaz.	Curtains	0.3ACH	0.16ACH	10m ground water	Better oriented (+90)	"Realistic " heating schedule	Combined 2	Combined 1
Akld	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Napr	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Wtn	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Trngi	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Chch	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Qtwn	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Akld	NPV	R2.9	R1.9	R1.3	R0.26	90%	95%	91%	99%	100%	31%	18%	35%
Napr	NPV	R2.9	R1.9	R1.3	R0.26	89%	96%	93%	100%	101%	29%	19%	41%
Wtn	NPV	R2.9	R1.9	R1.3	R0.26	87%	97%	94%	100%	99%	28%	17%	44%
Trngi	NPV	R3.3	R2.0	R1.3	R0.26	87%	97%	94%	100%	100%	30%	20%	46%
Chch	NPV	R3.3	R2.0	R1.3	R0.26	86%	97%	94%	100%	99%	31%	22%	52%
Qtwn	NPV	R3.3	R2.0	R1.3	R0.26	91%	96%	93%	97%	100%	33%	28%	61%
Akld	Carbon	R2.9	R1.9	R1.3	R0.26	95%	100%	99%	101%	96%	49%	22%	24%
Napr	Carbon	R2.9	R1.9	R1.3	R0.26	93%	100%	100%	101%	98%	42%	20%	30%
Wtn	Carbon	R2.9	R1.9	R1.3	R0.26	90%	101%	101%	101%	90%	39%	13%	29%
Trngi	Carbon	R3.3	R2.0	R1.3	R0.26	89%	101%	101%	102%	97%	38%	18%	34%
Chch	Carbon	R3.3	R2.0	R1.3	R0.26	91%	98%	96%	98%	95%	38%	23%	46%
Qtwn	Carbon	R3.3	R2.0	R1.3	R0.26	90%	99%	97%	100%	99%	39%	26%	52%
Akld	Equalise	R2.9	R1.9	R1.3	R0.26	92%	98%	97%	100%	99%	43%	22%	29%
Napr	Equalise	R2.9	R1.9	R1.3	R0.26	94%	97%	96%	100%	100%	33%	19%	38%
Wtn	Equalise	R2.9	R1.9	R1.3	R0.26	87%	97%	94%	100%	99%	28%	17%	44%
Trngi	Equalise	R3.3	R2.0	R1.3	R0.26	91%	99%	98%	101%	98%	35%	19%	40%
Chch	Equalise	R3.3	R2.0	R1.3	R0.26	91%	97%	95%	98%	96%	38%	23%	47%
Qtwn	Equalise	R3.3	R2.0	R1.3	R0.26	92%	97%	94%	98%	100%	38%	27%	55%

Table 54: Various sensitivity studies, both individual and combined savings, on the MDH

						MDH (percent savings)							
Climate	Set	Roof	Wall	Floor	Glaz.	Curtains	0.3ACH	0.16ACH	10m ground water	Better oriented (+90)	"Realistic" heating schedule	Combined 2	Combined 1
Akld	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Napr	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Wtn	Base	R2.9	R1.9	R1.3	R0.26	-	-	-	-	-	-	-	-
Trngi	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Chch	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Qtwn	Base	R3.3	R2.0	R1.3	R0.26	-	-	-	-	-	-	-	-
Akld	NPV	R2.9	R1.9	R1.3	R0.26	89%	92%	83%	99%	97%	17%	7%	26%
Napr	NPV	R2.9	R1.9	R1.3	R0.26	88%	92%	87%	99%	96%	18%	8%	37%
Wtn	NPV	R2.9	R1.9	R1.3	R0.26	86%	93%	87%	100%	99%	18%	11%	43%
Trngi	NPV	R3.3	R2.0	R1.3	R0.26	85%	95%	90%	99%	98%	23%	14%	44%
Chch	NPV	R3.3	R2.0	R1.3	R0.26	85%	95%	91%	99%	97%	25%	16%	47%
Qtwn	NPV	R3.3	R2.0	R1.3	R0.26	89%	95%	91%	99%	100%	27%	22%	53%
Akld	Carbon	R2.9	R1.9	R1.3	R0.26	95%	101%	100%	101%	76%	44%	11%	14%
Napr	Carbon	R2.9	R1.9	R1.3	R0.26	93%	100%	100%	101%	80%	36%	9%	21%
Wtn	Carbon	R2.9	R1.9	R1.3	R0.26	89%	101%	101%	100%	78%	30%	8%	25%
Trngi	Carbon	R3.3	R2.0	R1.3	R0.26	88%	101%	102%	101%	81%	31%	11%	28%
Chch	Carbon	R3.3	R2.0	R1.3	R0.26	89%	99%	98%	99%	86%	34%	15%	37%
Qtwn	Carbon	R3.3	R2.0	R1.3	R0.26	89%	100%	100%	104%	88%	33%	19%	43%
Akld	Equalise	R2.9	R1.9	R1.3	R0.26	92%	99%	96%	100%	88%	35%	10%	18%
Napr	Equalise	R2.9	R1.9	R1.3	R0.26	92%	94%	91%	100%	93%	23%	8%	33%
Wtn	Equalise	R2.9	R1.9	R1.3	R0.26	86%	93%	87%	100%	99%	18%	11%	43%
Trngi	Equalise	R3.3	R2.0	R1.3	R0.26	90%	100%	99%	100%	83%	30%	12%	32%
Chch	Equalise	R3.3	R2.0	R1.3	R0.26	90%	98%	96%	99%	88%	33%	16%	39%
Qtwn	Equalise	R3.3	R2.0	R1.3	R0.26	90%	98%	96%	100%	92%	32%	20%	46%

Table 55: Various sensitivity studies, both individual and combined savings, on the apartment

						Apartment (percent savings)							
Climate	**Set**	**Roof**	**Wall**	**Floor**	**Glaz.**	**Curtains**	**0.3ACH**	**0.16ACH**	**10m ground water**	**Better oriented (+90)**	**"Realistic" heating schedule**	**Combined 2**	**Combined 1**
Akld	Base	R2.9	R1.9	R1.3	R0.26	-	-	-		-	-	-	-
Napr	Base	R2.9	R1.9	R1.3	R0.26	-	-	-		-	-	-	-
Wtn	Base	R2.9	R1.9	R1.3	R0.26	-	-	-		-	-	-	-
Trngi	Base	R3.3	R2.0	R1.3	R0.26	-	-	-		-	-	-	-
Chch	Base	R3.3	R2.0	R1.3	R0.26	-	-	-		-	-	-	-
Qtwn	Base	R3.3	R2.0	R1.3	R0.26	-	-	-		-	-	-	-
Akld	NPV	R2.9	R1.9	R1.3	R0.26	69%	70%	47%		105%	-24%	27%	28%
Napr	NPV	R2.9	R1.9	R1.3	R0.26	73%	84%	69%		102%	2%	18%	36%
Wtn	NPV	R2.9	R1.9	R1.3	R0.26	64%	82%	67%		101%	6%	15%	40%
Trngi	NPV	R3.3	R2.0	R1.3	R0.26	69%	88%	77%		101%	18%	19%	42%
Chch	NPV	R3.3	R2.0	R1.3	R0.26	69%	89%	79%		101%	23%	24%	46%
Qtwn	NPV	R3.3	R2.0	R1.3	R0.26	71%	90%	82%		102%	26%	28%	52%
Akld	Carbon	R2.9	R1.9	R1.3	R0.26	98%	97%	95%		96%	47%	31%	30%
Napr	Carbon	R2.9	R1.9	R1.3	R0.26	94%	97%	94%		93%	43%	25%	32%
Wtn	Carbon	R2.9	R1.9	R1.3	R0.26	90%	97%	93%		94%	39%	19%	28%
Trngi	Carbon	R3.3	R2.0	R1.3	R0.26	89%	98%	94%		95%	39%	22%	32%
Chch	Carbon	R3.3	R2.0	R1.3	R0.26	87%	97%	93%		98%	39%	27%	36%
Qtwn	Carbon	R3.3	R2.0	R1.3	R0.26	86%	98%	95%		97%	41%	27%	37%
Akld	Equalise	R2.9	R1.9	R1.3	R0.26	92%	94%	88%		98%	35%	31%	32%
Napr	Equalise	R2.9	R1.9	R1.3	R0.26	88%	95%	91%		97%	33%	26%	36%
Wtn	Equalise	R2.9	R1.9	R1.3	R0.26	64%	82%	67%		101%	6%	15%	40%
Trngi	Equalise	R3.3	R2.0	R1.3	R0.26	88%	96%	92%		96%	38%	21%	33%
Chch	Equalise	R3.3	R2.0	R1.3	R0.26	73%	84%	70%		102%	21%	25%	46%
Qtwn	Equalise	R3.3	R2.0	R1.3	R0.26	73%	86%	73%		103%	25%	28%	50%

Appendix G: Grid emission sensitivity study

An examination of grid carbon emission factors on a seasonal basis was assessed. As can be seen in Table 56 , the difference between quarterly ('Qrtly') and yearly ('Basic') grid emissions factors is very slight (5% or less). As a result, MBIE chose to utilise the yearly model emission figures for this study.

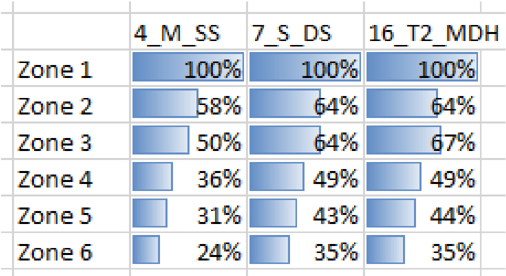
Table 56: Significance of yearly versus quarterly grid emissions differences

						Single Storey			**Two Storey**			**Medium Density**			**Apartment**		
						Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)		
	Climate	**Roof**	**Wall**	**Floor**	**Glaz.**	**Basic model**	**Qrtly Model**	**Diff.**	**Basic model**	**Qrtly Model**	**Diff.**	**Basic model**	**Qrtly Model**	**Diff.**	**Basic model**	**Qrtly Model**	**Diff.**
Base	**Akld**	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Napr	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Wgtn	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Trngi	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Chch	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Qnstn	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
NPV	**Akld**	R6.6	R1.9	R1.3	R0.39	-3,591	-3,555	-1%	-3,967	-4,005	1%	-13,456	-13,511	0%	-28,121	-28,368	1%
	Napr	R6.6	R1.9	R1.3	R0.39	-5,024	-4,933	-2%	-5,228	-5,231	0%	-18,811	-18,690	-1%	-54,062	-53,068	-2%
	Wgtn	R6.6	R1.9	R1.3	R0.39	-5,374	-5,240	-2%	-5,245	-5,200	-1%	-19,108	-18,736	-2%	-56,022	-53,479	-5%
	Trngi	R6.6	R2.0	R1.3	R0.39	-6,040	-5,924	-2%	-5,976	-5,943	-1%	-22,316	-22,035	-1%	-79,323	-76,896	-3%
	Chch	R6.6	R2.0	R1.3	R0.39	-6,455	-6,315	-2%	-6,160	-6,097	-1%	-23,218	-22,768	-2%	-84,650	-81,375	-4%
	Qnstn	R6.6	R2.9	R1.9	R0.39	-13,268	-12,911	-3%	-11,865	-11,614	-2%	-39,526	-38,615	-2%	-121,342	-116,461	-4%
Carbon	**Akld**	R6.6	R1.9	R1.3	R0.62	-5,907	-6,112	3%	-9,106	-9,556	5%	-35,021	-36,949	6%	-225,374	-236,312	5%
	Napr	R6.6	R1.9	R1.3	R0.62	-7,345	-7,414	1%	-10,458	-10,780	3%	-40,321	-41,674	3%	-264,825	-272,699	3%
	Wgtn	R6.6	R1.9	R1.3	R0.62	-6,605	-6,551	-1%	-9,448	-9,656	2%	-33,928	-34,695	2%	-230,205	-235,296	2%
	Trngi	R6.6	R2.0	R1.3	R0.62	-7,543	-7,528	0%	-10,131	-10,358	2%	-38,234	-39,261	3%	-262,398	-268,103	2%
	Chch	R6.6	R2.9	R1.9	R0.62	-12,463	-12,210	-2%	-14,463	-14,456	0%	-47,931	-48,099	0%	-266,564	-268,467	1%
	Qnstn	R6.6	R2.9	R2.7	R0.62	-15,423	-15,112	-2%	-16,776	-16,707	0%	-56,224	-56,314	0%	-318,440	-319,738	0%
Equalise	**Akld**	R3.6	R1.9	R1.3	R0.31	-1,751	-1,785	2%	-2,373	-2,455	3%	-8,564	-8,872	4%	-44,529	-46,193	4%
	Napr	R6.6	R1.9	R1.3	R0.31	-4,133	-4,089	-1%	-4,293	-4,354	1%	-16,010	-16,127	1%	-56,973	-57,969	2%
	Wgtn	R6.6	R1.9	R1.3	R0.39	-5,374	-5,240	-2%	-5,245	-5,200	-1%	-19,108	-18,736	-2%	-56,022	-53,479	-5%
	Trngi	R6.6	R2.9	R1.3	R0.62	-9,284	-9,200	-1%	-12,750	-12,885	1%	-44,554	-45,406	2%	-270,827	-275,824	2%
	Chch	R8.4	R2.9	R1.9	R0.76	-14,033	-13,720	-2%	-15,776	-15,713	0%	-53,159	-53,080	0%	-169,643	-163,121	-4%
	Qnstn	R9.4	R4.6	R3.4	R0.76	-22,573	-22,001	-3%	-22,433	-22,135	-1%	-73,885	-73,251	-1%	-227,364	-218,390	-4%

Appendix H: Equalising performance across climates

A mini study examined what levels of insulation would be needed if houses across all climate zones require approximately equal space conditioning needs annually – see section 2.5.

The first point to note is that the performance of the various house typologies varies significantly across New Zealand's climate zones. Overall heating/cooling energy use in the South Island may be ~3–4 times as much as that in Auckland/Northland. Also, the drop from Zone 1 (Auckland) to the rest of the North island is significant. The difference between Napier (Zone 2) and Wellington (Zone 3) is much less so, and depending on the house, the increased space heating requirements in Wellington may be cancelled out by increased cooling requirements in Napier.



	4_M_SS	7_S_DS	16_T2_MDH
Zone 1	100%	100%	100%
Zone 2	58%	64%	64%
Zone 3	50%	64%	67%
Zone 4	36%	49%	49%
Zone 5	31%	43%	44%
Zone 6	24%	35%	35%

Figure 36: Total energy use across climate zones relative to Auckland for the three houses

The second point to note in this analysis is that a 'one size fits all' solution does not really exist as different elements have different importance. For example, in a single-storey house, the roof and floor are considerably more important parts of the envelope than in a multi-storey house. Similarly, a house that is more prone to overheating may see much greater gains from glazing upgrades that reduce solar heat gain, such as high-performance triple glazing. Thus, we cannot equalise performance across all houses simultaneously with the same constructions – the best we can achieve is an approximate average equalisation.

Taking Zone 3 (Wellington) with R6.6 roof and R0.39 (thermally broken frame with a low-E) glazing as our target performance level (i.e. the thermally neutral climate), we might suggest the following rough constructions for the different climates:

	Roof	Walls	Floor	Glazing
Zone 1	R2.9	R1.9	R1.3	R0.26
Zone 2	R6.6	R1.9	R1.3	R0.31 (low-E)
Zone 3	R6.6	R1.9	R1.3	R0.39
Zone 4	R6.6	R2.9 (140mm)	R1.3	R0.62 (triple-glazing)
Zone 5	R8.4	R2.9	R2.0 (underslab, not edge)	R0.76 (triple glazing, uPVC frame)
Zone 6	R9.4	R4.6 (staggered stud)	~R5.0	R0.76

Zone 1 (Auckland) can be equal – if not better – than the targeted level of performance in Wellington with current Code levels of insulation (although as has been discussed, increasing roof R-values to R3.6 has a very good financial return).

Zone 2 (Napier) may be able to get away with slightly lower glazing than Wellington. It should be noted that low-E coatings are probably better than thermally broken frames due to the warmer climate and cooling issues up north.

Zone 4 (central North Island) is where significant upgrades are needed. Suggested is further upgrading the walls to 140 mm framing and moving up to triple glazing. The overall effect of this may be very variable depending on the house, with the 2-storey and medium-density developments here benefiting substantially from the triple glazing due to how it reduces their overheating problems (Table 57**Error! Reference source not found.** below).

In Zone 5 (Christchurch), it becomes difficult to avoid adding underslab insulation. Roof insulation is pushed up to R8.4 (R5.0 layer over top of joists) which will likely pose difficulties for skillion roofs but is probably a cost-effective option. Triple glazing also really needs to be pushed up to uPVC framing at this point. Note also that the marginal gains from roof insulation upgrades are getting increasingly small, and it would be difficult to avoid underslab insulation (despite its extra expense).

Zone 6 (Queenstown) requires very substantial upgrades. It is difficult to avoid upgrading the walls and floor at this point – something like staggered stud walls and a fully enclosed slab system like MAXRaft would be needed.

Table 57: Relative space conditioning needs for Wellington (Zone 3) normalisations

	Single storey	**Double storey**	**MDH**
Zone 1	87%	104%	105%
Zone 2	90%	108%	112%
Zone 3	100%	100%	100%
Zone 4	113%	83%	98%
Zone 5	106%	88%	104%
Zone 6	101%	85%	118%

Note that airtightness considerations have not been included here, with all models being run at 0.5 ach infiltration. 0.3 ach infiltration (the average observed in post-1994 New Zealand houses and the lower limit of what could be considered acceptable fresh air) would result in ~12–15% less energy use, while ~0.16 ach (such as might be effectively achieved by an airtight house and installing a heat recovery system) would result in ~20–24% less energy use. This option may offer another route to achieving these targets in the colder regions, although the cost-benefit ratio and carbon returns for such systems would need to be considered first.

Final_results_static2 - Sheet: Base

model	climate	Set	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Single storey detached	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	22.7	0	0	-	-	-	0	0	0	-	0.73	2010	231	0	0
Single storey detached	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	32.6	0	0	-	-	-	0	0	0	-	0.65	4240	342	0	0
Single storey detached	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	37.7	0	0	-	-	-	0	0	0	-	0.55	7240	5	0	0
Single storey detached	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	49.8	0	0	-	-	-	0	0	0	-	0.5	9700	98	0	0
Single storey detached	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	58.1	0	0	-	-	-	0	0	0	-	0.45	13200	362	0	0
Single storey detached	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	74.3	0	0	-	-	-	0	0	0	-	0.39	18500	58	0	0
Two storey detached	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	33	0	0	-	-	-	0	0	0	-	0.68	2510	134	0	0
Two storey detached	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	43.8	0	0	-	-	-	0	0	0	-	0.62	5270	227	0	0
Two storey detached	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	43.3	0	0	-	-	-	0	0	0	-	0.53	8530	2	0	0
Two storey detached	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	54	0	0	-	-	-	0	0	0	-	0.49	11200	70	0	0
Two storey detached	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	62.6	0	0	-	-	-	0	0	0	-	0.43	15200	265	0	0
Two storey detached	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	75.7	0	0	-	-	-	0	0	0	-	0.38	21300	39	0	0
Medium density development	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	27.5	0	0	-	-	-	0	0	0	-	0.75	1670	253	0	0
Medium density development	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	36.7	0	0	-	-	-	0	0	0	-	0.65	4230	380	0	0
Medium density development	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	35.2	0	0	-	-	-	0	0	0	-	0.59	6860	11	0	0
Medium density development	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	46.5	0	0	-	-	-	0	0	0	-	0.52	9690	164	0	0
Medium density development	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	52.3	0	0	-	-	-	0	0	0	-	0.48	12600	368	0	0
Medium density development	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	65.5	0	0	-	-	-	0	0	0	-	0.42	18300	118	0	0
Apartment building	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	37.2	0	0	-	-	-	0	0	0	-	0.79	44	1370	0	0
Apartment building	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	43.3	0	0	-	-	-	0	0	0	-	0.71	591	1640	0	0
Apartment building	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	35.3	0	0	-	-	-	0	0	0	-	0.69	1760	645	0	0
Apartment building	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	42.2	0	0	-	-	-	0	0	0	-	0.62	2910	836	0	0
Apartment building	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	43.3	0	0	-	-	-	0	0	0	-	0.59	5820	996	0	0
Apartment building	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	52.1	0	0	-	-	-	0	0	0	-	0.55	9920	551	0	0

Final_results_static2 - Sheet: Single

model	climate	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	21.9	0	0 -	-	-				0	-	73%	2010	231	0%	0%
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	31.4	0	0 -	-	-				0	-	65%	4240	342	0%	0%
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	36.3	0	0 -	-	-				0	-	55%	7240	5	0%	0%
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	48.0	0	0 -	-	-				0	-	50%	9700	98	0%	0%
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	56.0	0	0 -	-	-				0	-	45%	13200	362	0%	0%
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	71.6	0	0 -	-	-				0	-	39%	18500	58	0%	0%
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	14.5	$ 5,360	-$ 278	19.3	0.99	$ -61	-3590	526	-3060	6.8	82%	1210	142	-40%	-39%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	21.0	$ 5,030	-$ 421	11.9	1.59	$ 3,175	-5020	526	-4500	9.6	71%	2870	256	-32%	-25%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	25.2	$ 5,090	-$ 433	11.8	1.61	$ 3,305	-5370	526	-4850	10.2	60%	5430	2	-25%	-60%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	35.5	$ 4,790	-$ 526	9.1	2.03	$ 5,281	-6040	526	-5510	11.5	54%	7990	69	-18%	-30%
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	42.7	$ 5,130	-$ 500	10.3	1.81	$ 4,402	-6460	526	-5930	12.3	48%	11400	307	-14%	-15%
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	44.1	$ 12,700	-$ 1,280	9.9	1.96	$ 12,486	-13300	1220	-12000	10.9	45%	14800	56	-20%	-3%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	9.7	$ 9,470	-$ 457	20.7	0.86	$ -1,551	-5910	1330	-4580	4.4	81%	1400	41	-30%	-82%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	16.2	$ 9,140	-$ 616	14.8	1.19	$ 1,995	-7340	1330	-6010	5.5	69%	3280	136	-23%	-60%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	22.7	$ 9,200	-$ 533	17.3	1.02	$ 185	-6600	1330	-5270	5	55%	6100	0	-16%	-100%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	32.4	$ 8,900	-$ 657	13.5	1.27	$ 2,750	-7540	1330	-6210	5.7	48%	9180	36	-5%	-63%
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	30.3	$ 17,300	-$ 965	17.9	1.02	$ 409	-12500	2030	-10400	6.1	48%	11200	230	-15%	-36%
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	39.7	$ 19,300	-$ 1,490	12.9	1.44	$ 9,030	-15400	2190	-13200	7	40%	16300	26	-12%	-55%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	18.3	$ 1,490	-$ 136	11	1.52	$ 939	-1750	453	-1300	3.9	76%	1770	170	-12%	-26%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	22.8	$ 3,830	-$ 347	11	1.69	$ 2,865	-4130	453	-3680	9.1	69%	3260	252	-23%	-26%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	25.2	$ 5,090	-$ 433	11.8	1.61	$ 3,305	-5370	526	-4850	10.2	60%	5430	2	-25%	-60%
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	28.7	$ 13,500	-$ 808	16.6	1.08	$ 1,190	-9280	1360	-7920	6.8	50%	8530	35	-12%	-64%
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	27.0	$ 19,500	-$ 1,090	17.9	1.03	$ 622	-14000	4360	-9670	3.2	49%	10300	228	-22%	-37%
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	24.9	$ 27,000	-$ 2,180	12.3	1.54	$ 15,141	-22600	5330	-17200	4.2	47%	12400	35	-33%	-40%

Final_results_static2 - Sheet: Double

model	climate	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	33	0	0 -	-	-				0	-	68%	2510	134	0%	0%
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	43.8	0	0 -	-	-				0	-	62%	5270	227	0%	0%
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	43.3	0	0 -	-	-				0	-	53%	8530	2	0%	0%
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	54	0	0 -	-	-				0	-	49%	11200	70	0%	0%
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	62.6	0	0 -	-	-				0	-	43%	15200	265	0%	0%
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	75.7	0	0 -	-	-				0	-	38%	21300	39	0%	0%
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	24.4	$ 4,160	-$ 307	13.5	1.37	$ 1,688	-3970	369	-3600	10.8	72%	1960	99	-22%	-26%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	32.4	$ 4,010	-$ 438	9.1	2.03	$ 4,499	-5230	369	-4860	14.2	64%	4540	191	-14%	-16%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	31.9	$ 4,040	-$ 423	9.5	1.93	$ 4,109	-5250	369	-4880	14.2	55%	7550	0	-11%	-100%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	41	$ 3,900	-$ 520	7.5	2.41	$ 6,023	-5980	369	-5610	16.2	51%	10200	58	-9%	-17%
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	49.2	$ 4,050	-$ 477	8.5	2.13	$ 4,983	-6160	369	-5790	16.7	45%	14300	236	-6%	-11%
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	49.9	$ 10,800	-$ 1,150	9.4	2.05	$ 11,664	-11900	776	-11100	15.3	43%	18300	56	-14%	44%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	13.2	$ 8,840	-$ 705	12.5	1.38	$ 3,898	-9110	1290	-7820	7.1	69%	2590	22	3%	-84%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	21.1	$ 8,690	-$ 877	9.9	1.74	$ 7,539	-10500	1290	-9170	8.1	61%	5350	93	2%	-59%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	22.7	$ 8,720	-$ 762	11.4	1.50	$ 5,093	-9450	1290	-8160	7.3	49%	8520	0	0%	-100%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	32	$ 8,580	-$ 882	9.7	1.73	$ 7,339	-10100	1290	-8840	7.9	45%	11800	25	5%	-64%
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	31.2	$ 15,600	-$ 1,120	14	1.29	$ 4,913	-14500	1690	-12800	8.5	45%	13800	172	-9%	-35%
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	39.2	$ 17,200	-$ 1,620	10.6	1.73	$ 13,566	-16800	1810	-15000	9.3	38%	19800	20	-7%	-49%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	27.9	$ 1,560	-$ 184	8.5	1.93	$ 1,793	-2370	286	-2090	8.3	69%	2440	98	-3%	-27%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	34.5	$ 2,640	-$ 360	7.3	2.43	$ 4,284	-4290	286	-4010	15	63%	5020	189	-5%	-17%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	31.9	$ 4,040	-$ 423	9.5	1.93	$ 4,109	-5250	369	-4880	14.2	55%	7550	0	-11%	-100%
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	26.3	$ 14,300	-$ 1,110	12.9	1.39	$ 6,149	-12700	1320	-11400	9.6	47%	10800	23	-4%	-67%
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	28.3	$ 16,600	-$ 1,220	13.6	1.33	$ 5,912	-15800	4030	-11700	3.9	47%	13000	178	-14%	-33%
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	26.9	$ 24,800	-$ 2,170	11.4	1.64	$ 16,848	-22400	4450	-18000	5	45%	16100	30	-24%	-23%

Final_results_static2 - Sheet: MDH

model	climate	R	W	F	G	Total Energy (kWh/m2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/50yr)	Material carbon (kgCO2eq/50yr)	Net carbon (kgCO2eq/50yr)	Energy/Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	27.5	0	0	-	-	-			0	-	75%	1670	253	0%	0%
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	36.7	0	0	-	-	-			0	-	65%	4230	380	0%	0%
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	35.2	0	0	-	-	-			0	-	59%	6860	11	0%	0%
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	46.5	0	0	-	-	-			0	-	52%	9690	164	0%	0%
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	52.3	0	0	-	-	-			0	-	48%	12600	368	0%	0%
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	65.5	0	0	-	-	-			0	-	42%	18300	118	0%	0%
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	21.3	$ 16,200	-$ 1,040	15.5	1.20	$ 3,494	-13500	1440	-12000	9.3	79%	1200	209	-28%	-17%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	27.9	$ 15,600	-$ 1,580	9.9	1.88	$ 14,955	-18800	1440	-17400	13.1	69%	3490	341	-17%	-10%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	26.3	$ 15,700	-$ 1,540	10.2	1.82	$ 13,921	-19100	1440	-17700	13.3	62%	5820	7	-15%	-36%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	36.1	$ 15,100	-$ 1,940	7.8	2.32	$ 21,876	-22300	1440	-20900	15.5	54%	8650	142	-11%	-13%
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	41.5	$ 15,700	-$ 1,800	8.8	2.07	$ 18,282	-23200	1440	-21800	16.1	50%	11500	340	-9%	-8%
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	47.2	$ 38,200	-$ 3,820	10	1.92	$ 36,407	-39500	2720	-36800	14.5	46%	16000	108	-13%	-8%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	11.3	$ 34,100	-$ 2,710	12.6	1.37	$ 14,864	-35000	4970	-30100	7.1	78%	1560	60	-7%	-76%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	17.9	$ 33,500	-$ 3,380	9.9	1.74	$ 29,061	-40300	4970	-35400	8.1	66%	4200	182	-1%	-52%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	19.4	$ 33,600	-$ 2,740	12.3	1.39	$ 15,572	-33900	4970	-29000	6.8	57%	6730	0	-2%	-100%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	28.7	$ 33,100	-$ 3,330	9.9	1.69	$ 26,880	-38200	4970	-33300	7.7	50%	10100	68	4%	-59%
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	30.1	$ 56,800	-$ 3,710	15.3	1.17	$ 10,447	-47900	6240	-41700	7.7	49%	11900	218	-6%	-41%
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	39.4	$ 61,600	-$ 5,440	11.3	1.61	$ 40,769	-56200	6600	-49600	8.5	42%	17800	44	-3%	-63%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	23.6	$ 6,000	-$ 663	9	1.81	$ 6,017	-8560	1120	-7440	7.6	76%	1580	203	-5%	-20%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	29.2	$ 10,300	-$ 1,340	7.7	2.32	$ 15,463	-16000	1120	-14900	14.3	67%	3940	330	-7%	-13%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	26.3	$ 15,700	-$ 1,540	10.2	1.82	$ 13,921	-19100	1440	-17700	13.3	62%	5820	7	-15%	-36%
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	25.8	$ 52,800	-$ 3,880	13.6	1.31	$ 18,035	-44600	5100	-39500	8.7	52%	9230	65	-5%	-60%
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	27.6	$ 60,900	-$ 4,120	14.8	1.22	$ 14,410	-53200	15300	-37900	3.5	50%	11200	224	-11%	-39%
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	31.2	$ 88,600	-$ 7,150	12.4	1.50	$ 47,671	-73900	16900	-56900	4.4	46%	15400	52	-16%	-56%

Final_results_static2 - Sheet: AP

model	climate	R	W	F	G	Total Energy (kWh/m 2/yr)	Extra cost ($)	Annual savings ($)	Simple payback period (yrs)	BCR	NPV	Carbon energy savings (kgCO2eq/ 50yr)	Material carbon (kgCO2eq/ 50yr)	Net carbon (kgCO2eq/ 50yr)	Energy/Material carbon ratio	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	37.2	0	0	-	-	-			0	-	79%	44	1370	0%	0%
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	43.3	0	0	-	-	-			0	-	71%	591	1640	0%	0%
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	35.3	0	0	-	-	-			0	-	69%	1760	645	0%	0%
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	42.2	0	0	-	-	-			0	-	62%	2910	836	0%	0%
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	43.3	0	0	-	-	-			0	-	59%	5820	996	0%	0%
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	52.1	0	0	-	-	-			0	-	55%	9920	551	0%	0%
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	34.3	$ 82,700	-$ 2,180	38	0.48	$ -48,609	-28100	6850	-21300	4.1	80%	4	1310	-91%	-4%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	37.7	$ 83,300	-$ 4,530	18.4	0.98	$ -1,489	-54100	6850	-47200	7.9	78%	141	1610	-76%	-2%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	29.5	$ 83,300	-$ 4,520	18.4	0.97	$ -2,376	-56000	6850	-49200	8.2	79%	527	649	-70%	1%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	34	$ 83,600	-$ 6,910	12.1	1.46	$ 42,956	-79300	6850	-72500	11.6	70%	1370	820	-53%	-2%
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	34.6	$ 82,600	-$ 6,550	12.6	1.40	$ 36,577	-84600	6850	-77800	12.4	65%	3820	981	-34%	-2%
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	39.5	$ 139,000	-$ 11,700	11.8	1.57	$ 84,442	-121000	7460	-114000	16.3	60%	6790	542	-32%	-2%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	13.9	$ 211,000	-$ 17,400	12.1	1.40	$ 100,060	-225000	32100	-193000	7	90%	1	411	-98%	-70%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	16	$ 212,000	-$ 22,200	9.5	1.77	$ 195,971	-265000	32100	-233000	8.3	88%	87	625	-85%	-62%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	11.5	$ 212,000	-$ 18,600	11.4	1.47	$ 120,056	-230000	32100	-198000	7.2	90%	257	137	-85%	-79%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	15.1	$ 212,000	-$ 22,900	9.3	1.78	$ 197,873	-262000	32100	-230000	8.2	77%	1240	206	-57%	-75%
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	15.8	$ 266,000	-$ 20,600	12.9	1.32	$ 98,819	-267000	32700	-234000	8.2	71%	2940	486	-49%	-51%
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	19.2	$ 267,000	-$ 30,800	8.7	1.98	$ 303,480	-318000	32700	-286000	9.7	65%	6390	121	-36%	-78%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	32.6	$ 41,000	-$ 3,450	11.9	1.37	$ 18,751	-44500	4570	-40000	9.7	81%	24	1180	-45%	-14%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	37.4	$ 45,600	-$ 4,780	9.6	1.74	$ 41,063	-57000	4570	-52400	12.5	74%	408	1480	-31%	-10%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	29.5	$ 83,300	-$ 4,520	18.4	0.97	$ -2,376	-56000	6850	-49200	8.2	79%	527	649	-70%	1%
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	14.2	$ 282,000	-$ 23,600	12	1.44	$ 142,289	-271000	32500	-238000	8.3	81%	848	209	-71%	-75%
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	25.8	$ 267,000	-$ 13,100	20.4	0.84	$ -50,337	-170000	90900	-78800	1.9	77%	932	922	-84%	-7%
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	28.6	$ 359,000	-$ 22,000	16.3	1.09	$ 36,895	-227000	89200	-138000	2.6	70%	2490	481	-75%	-13%

Final_results_static2 - Sheet: Carbon_sensitivity

						Single Storey			Two Storey			Medium Density			Apartment		
						Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)			Total carbon savings (kgCO2/50yr)		
	climate	R	W	F	G	Basic model	Quarterly Model	Diff.	Basic model	Quarterly Model	Diff.	Basic model	Quarterly Model	Diff.	Basic model	Quarterly Model	Diff.
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	-	-		-	-		-	-		-	-	
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	-3,591	-3,555	-1%	-3,967	-4,005	1%	-13,456	-13,511	0%	-28,121	-28,368	1%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	-5,024	-4,933	-2%	-5,228	-5,231	0%	-18,811	-18,690	-1%	-54,062	-53,068	-2%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	-5,374	-5,240	-2%	-5,245	-5,200	-1%	-19,108	-18,736	-2%	-56,022	-53,479	-5%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	-6,040	-5,924	-2%	-5,976	-5,943	-1%	-22,316	-22,035	-1%	-79,323	-76,896	-3%
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	-6,455	-6,315	-2%	-6,160	-6,097	-1%	-23,218	-22,768	-2%	-84,650	-81,375	-4%
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	-13,268	-12,911	-3%	-11,865	-11,614	-2%	-39,526	-38,615	-2%	-121,342	-116,461	-4%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	-5,907	-6,112	3%	-9,106	-9,556	5%	-35,021	-36,949	6%	-225,374	-236,312	5%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	-7,345	-7,414	1%	-10,458	-10,780	3%	-40,321	-41,674	3%	-264,825	-272,699	3%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	-6,605	-6,551	-1%	-9,448	-9,656	2%	-33,928	-34,695	2%	-230,205	-235,296	2%
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	-7,543	-7,528	0%	-10,131	-10,358	2%	-38,234	-39,261	3%	-262,398	-268,103	2%
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	-12,463	-12,210	-2%	-14,463	-14,456	0%	-47,931	-48,099	0%	-266,564	-268,467	1%
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	-15,423	-15,112	-2%	-16,776	-16,707	0%	-56,224	-56,314	0%	-318,440	-319,738	0%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	-1,751	-1,785	2%	-2,373	-2,455	3%	-8,564	-8,872	4%	-44,529	-46,193	4%
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	-4,133	-4,089	-1%	-4,293	-4,354	1%	-16,010	-16,127	1%	-56,973	-57,969	2%
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	-5,374	-5,240	-2%	-5,245	-5,200	-1%	-19,108	-18,736	-2%	-56,022	-53,479	-5%
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	-9,284	-9,200	-1%	-12,750	-12,885	1%	-44,554	-45,406	2%	-270,827	-275,824	2%
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	-14,033	-13,720	-2%	-15,776	-15,713	0%	-53,159	-53,080	0%	-169,643	-163,121	-4%
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	-22,573	-22,001	-3%	-22,433	-22,135	-1%	-73,885	-73,251	-1%	-227,364	-218,390	-4%

Final_results_static2 - Sheet: BCR_cost_sens

						Single Storey									
						BCR					NPV				
	climate	R	W	F	G	+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
NPV	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.39	0.82	0.90	0.99	1.09	1.19	-1197	-629	-61	456	886
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.39	1.33	1.45	1.59	1.75	1.91	2105	2640	3175	3661	4066
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	1.34	1.46	1.61	1.77	1.93	2222	2763	3305	3797	4207
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.39	1.69	1.85	2.03	2.24	2.44	4259	4770	5281	5746	6133
	Zone 5 - Christchurch	R6.6	R2.0	R1.3	R0.39	1.51	1.64	1.81	1.99	2.17	3313	3858	4402	4897	5310
	Zone 6 - Queenstown	R6.6	R2.9	R1.9	R0.39	1.63	1.78	1.96	2.15	2.35	9878	11182	12486	13671	14659
						+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Carbon	Zone 1 - Auckland	R6.6	R1.9	R1.3	R0.62	0.71	0.78	0.86	0.94	1.03	-3711	-2631	-1551	-569	249
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.62	0.99	1.08	1.19	1.31	1.43	-98	949	1995	2947	3740
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.62	0.85	0.93	1.02	1.12	1.22	-1921	-868	185	1142	1940
	Zone 4 - Turangi	R6.6	R2.0	R1.3	R0.62	1.06	1.15	1.27	1.40	1.52	705	1728	2750	3680	4455
	Zone 5 - Christchurch	R6.6	R2.9	R1.9	R0.62	0.85	0.93	1.02	1.12	1.23	-3311	-1451	409	2100	3509
	Zone 6 - Queenstown	R6.6	R2.9	R2.7	R0.62	1.20	1.31	1.44	1.58	1.73	4903	6967	9030	10907	12470
						+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Equalise	Zone 1 - Auckland	R3.6	R1.9	R1.3	R0.31	1.27	1.38	1.52	1.67	1.82	578	758	939	1103	1239
	Zone 2 - Napier	R6.6	R1.9	R1.3	R0.31	1.41	1.54	1.69	1.86	2.03	2035	2450	2865	3242	3556
	Zone 3 - Wellington	R6.6	R1.9	R1.3	R0.39	1.34	1.46	1.61	1.77	1.93	2222	2763	3305	3797	4207
	Zone 4 - Turangi	R6.6	R2.9	R1.3	R0.62	0.90	0.98	1.08	1.19	1.30	-1768	-289	1190	2534	3654
	Zone 5 - Christchurch	R8.4	R2.9	R1.9	R0.76	0.86	0.94	1.03	1.13	1.24	-3534	-1456	622	2512	4086
	Zone 6 - Queenstown	R9.4	R4.6	R3.4	R0.76	1.28	1.40	1.54	1.69	1.84	9484	12313	15141	17712	19854
						+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%

		Two Storey									
		BCR					NPV				
	climate	+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
NPV	Zone 1 - Auckland	1.14	1.25	1.37	1.51	1.65	783	1236	1688	2099	2442
	Zone 2 - Napier	1.69	1.85	2.03	2.23	2.44	3625	4062	4499	4897	5228
	Zone 3 - Wellington	1.61	1.76	1.93	2.13	2.32	3229	3669	4109	4509	4842
	Zone 4 - Turangi	2.01	2.19	2.41	2.65	2.90	5170	5596	6023	6410	6733
	Zone 5 - Christchurch	1.77	1.94	2.13	2.34	2.55	4101	4542	4983	5385	5719
	Zone 6 - Queenstown	1.70	1.86	2.05	2.25	2.45	9432	10548	11664	12679	13524
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Carbon	Zone 1 - Auckland	1.15	1.25	1.38	1.51	1.65	1827	2863	3898	4840	5625
	Zone 2 - Napier	1.45	1.58	1.74	1.91	2.09	5498	6519	7539	8467	9240
	Zone 3 - Wellington	1.25	1.36	1.50	1.65	1.80	3046	4070	5093	6023	6798
	Zone 4 - Turangi	1.44	1.57	1.73	1.90	2.07	5320	6330	7339	8257	9022
	Zone 5 - Christchurch	1.07	1.17	1.29	1.42	1.54	1483	3198	4913	6472	7771
	Zone 6 - Queenstown	1.44	1.57	1.73	1.90	2.07	9826	11696	13566	15267	16684
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Equalise	Zone 1 - Auckland	1.61	1.76	1.93	2.13	2.32	1409	1601	1793	1968	2113
	Zone 2 - Napier	2.02	2.21	2.43	2.67	2.91	3684	3984	4284	4557	4784
	Zone 3 - Wellington	1.61	1.76	1.93	2.13	2.32	3229	3669	4109	4509	4842
	Zone 4 - Turangi	1.16	1.26	1.39	1.53	1.67	2991	4570	6149	7585	8781
	Zone 5 - Christchurch	1.10	1.21	1.33	1.46	1.59	2282	4097	5912	7562	8937
	Zone 6 - Queenstown	1.37	1.49	1.64	1.80	1.97	11587	14217	16848	19239	21232
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%

		Medium Density									
		BCR					NPV				
	climate	+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
NPV	Zone 1 - Auckland	1.00	1.09	1.20	1.32	1.44	-20	1737	3494	5091	6422
	Zone 2 - Napier	1.57	1.71	1.88	2.07	2.26	11563	13259	14955	16496	17781
	Zone 3 - Wellington	1.51	1.65	1.82	2.00	2.18	10506	12213	13921	15473	16767
	Zone 4 - Turangi	1.94	2.11	2.32	2.56	2.79	18572	20224	21876	23379	24630
	Zone 5 - Christchurch	1.72	1.88	2.07	2.27	2.48	14855	16569	18282	19840	21138
	Zone 6 - Queenstown	1.60	1.74	1.92	2.11	2.30	28481	32444	36407	40009	43011
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Carbon	Zone 1 - Auckland	1.14	1.25	1.37	1.51	1.65	6873	10869	14864	18497	21524
	Zone 2 - Napier	1.45	1.58	1.74	1.91	2.09	21192	25126	29061	32638	35619
	Zone 3 - Wellington	1.16	1.27	1.39	1.53	1.67	7679	11626	15572	19160	22149
	Zone 4 - Turangi	1.41	1.54	1.69	1.86	2.03	19098	22989	26880	30418	33365
	Zone 5 - Christchurch	0.97	1.06	1.17	1.28	1.40	-2087	4180	10447	16144	20891
	Zone 6 - Queenstown	1.34	1.46	1.61	1.77	1.93	27292	34031	40769	46896	52001
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Equalise	Zone 1 - Auckland	1.51	1.65	1.81	2.00	2.18	4539	5278	6017	6689	7249
	Zone 2 - Napier	1.93	2.11	2.32	2.55	2.79	13123	14293	15463	16527	17413
	Zone 3 - Wellington	1.51	1.65	1.82	2.00	2.18	10506	12213	13921	15473	16767
	Zone 4 - Turangi	1.09	1.19	1.31	1.44	1.57	6308	12171	18035	23365	27807
	Zone 5 - Christchurch	1.01	1.11	1.22	1.34	1.46	1074	7742	14410	20471	25523
	Zone 6 - Queenstown	1.25	1.37	1.50	1.66	1.81	28780	38226	47671	56259	63415
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%

		Apartment									
		BCR					NPV				
	climate	+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
NPV	Zone 1 - Auckland	0.40	0.43	0.48	0.52	0.57	-67135	-57872	-48609	-40188	-33171
	Zone 2 - Napier	0.82	0.89	0.98	1.08	1.18	-20131	-10810	-1489	6985	14046
	Zone 3 - Wellington	0.81	0.89	0.97	1.07	1.17	-21026	-11701	-2376	6102	13166
	Zone 4 - Turangi	1.22	1.33	1.46	1.61	1.75	24248	33602	42956	51460	58546
	Zone 5 - Christchurch	1.16	1.27	1.40	1.53	1.67	18067	27322	36577	44990	52001
	Zone 6 - Queenstown	1.31	1.42	1.57	1.72	1.88	54647	69545	84442	97986	109272
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Carbon	Zone 1 - Auckland	1.16	1.27	1.40	1.54	1.68	49511	74786	100060	123037	142184
	Zone 2 - Napier	1.48	1.61	1.77	1.95	2.13	145307	170639	195971	219001	238192
	Zone 3 - Wellington	1.23	1.34	1.47	1.62	1.77	69384	94720	120056	143089	162284
	Zone 4 - Turangi	1.48	1.62	1.78	1.96	2.14	147142	172507	197873	220932	240148
	Zone 5 - Christchurch	1.10	1.20	1.32	1.45	1.59	37260	68039	98819	126801	150118
	Zone 6 - Queenstown	1.65	1.80	1.98	2.18	2.38	241662	272571	303480	331580	354996
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%
Equalise	Zone 1 - Auckland	1.14	1.24	1.37	1.50	1.64	8559	13655	18751	23383	27243
	Zone 2 - Napier	1.45	1.58	1.74	1.91	2.09	29944	35504	41063	46117	50329
	Zone 3 - Wellington	0.81	0.89	0.97	1.07	1.17	-21026	-11701	-2376	6102	13166
	Zone 4 - Turangi	1.20	1.31	1.44	1.58	1.73	77540	109914	142289	171720	196246
	Zone 5 - Christchurch	0.70	0.76	0.84	0.92	1.00	-112159	-81248	-50337	-22236	1181
	Zone 6 - Queenstown	0.91	0.99	1.09	1.20	1.31	-43200	-3152	36895	73302	103642
		+20%	+10%	Base	-10%	-20%	+20%	+10%	Base	-10%	-20%

R-values for mass walls for the different construction sets

NPV

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Heavy (190mm concrete)	1	1.1	1.2	1.2	1.3	2
75mm timber on external walls, none on internal	1.4	1.4	1.5	1.5	1.5	2.2
60mm timber on external walls, 45mm on internal	1.2	1.2	1.3	1.3	1.4	2.1
60mm timber on external walls, 60mm on internal	1.2	1.2	1.3	1.3	1.4	2
90mm timber on external walls, 45mm on internal	1.2	1.2	1.4	1.5	1.5	2.1

Carbon

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Heavy (190mm concrete)	1.2	1.2	1.4	1.4	2.1	2.2
75mm timber on external walls, none on internal	1.4	1.4	1.5	1.6	2.3	2.4
60mm timber on external walls, 45mm on internal	1.3	1.3	1.4	1.5	2.2	2.3
60mm timber on external walls, 60mm on internal	1.3	1.3	1.4	1.4	2.2	2.3
90mm timber on external walls, 45mm on internal	1.4	1.4	1.5	1.5	2.2	2.3

	Equalise					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Heavy (190mm concrete)	1	1	1.2	1.9	2.2	3.5
75mm timber on external walls, none on internal	1.4	1.4	1.4	2.2	2.4	3.8
60mm timber on external walls, 45mm on internal	1.2	1.2	1.3	2	2.2	3.6
60mm timber on external walls, 60mm on internal	1.2	1.2	1.3	2	2.2	3.6
90mm timber on external walls, 45mm on internal	1.1	1.2	1.4	2.1	2.3	3.6

Heating energy use relative to the standard light timber frame

	Heavy	4_M_SS	7_S_DS	16_T2_MD	18_T2_AP
NPV	Zone 1 - Auckland	100%	100%	79%	88%
	Zone 2 - Napier	95%	94%	83%	87%
	Zone 3 - Wellington	99%	98%	91%	96%
	Zone 4 - Turangi	100%	98%	91%	91%
	Zone 5 - Christchurch	100%	99%	93%	94%
	Zone 6 - Queenstown	99%	98%	94%	92%
Carbon	Zone 1 - Auckland	98%	99%	85%	87%
	Zone 2 - Napier	98%	98%	89%	93%
	Zone 3 - Wellington	97%	96%	92%	95%
	Zone 4 - Turangi	99%	98%	93%	93%
	Zone 5 - Christchurch	100%	100%	95%	96%
	Zone 6 - Queenstown	100%	100%	96%	95%
Equalise	Zone 1 - Auckland	97%	96%	80%	85%
	Zone 2 - Napier	100%	99%	87%	91%
	Zone 3 - Wellington	99%	98%	91%	96%
	Zone 4 - Turangi	100%	100%	95%	96%
	Zone 5 - Christchurch	99%	98%	94%	90%
	Zone 6 - Queenstown	100%	100%	96%	91%

	Ext 60/Int 45	4_M_SS	7_S_DS	16_T2_MD	18_T2_AP
NPV	Zone 1 - Auckland	96%	94%	78%	86%
	Zone 2 - Napier	98%	97%	86%	92%
	Zone 3 - Wellington	99%	98%	91%	98%
	Zone 4 - Turangi	100%	98%	91%	94%
	Zone 5 - Christchurch	100%	98%	92%	96%
	Zone 6 - Queenstown	99%	99%	92%	95%
Carbon	Zone 1 - Auckland	98%	98%	84%	93%
	Zone 2 - Napier	99%	98%	89%	96%
	Zone 3 - Wellington	99%	99%	92%	101%
	Zone 4 - Turangi	98%	96%	91%	94%
	Zone 5 - Christchurch	100%	99%	93%	97%
	Zone 6 - Queenstown	99%	99%	93%	97%
Equalise	Zone 1 - Auckland	95%	93%	81%	85%
	Zone 2 - Napier	98%	96%	87%	92%
	Zone 3 - Wellington	99%	98%	91%	98%
	Zone 4 - Turangi	100%	100%	93%	98%
	Zone 5 - Christchurch	100%	100%	93%	94%
	Zone 6 - Queenstown	100%	100%	93%	94%

	Ext 75/Int 0	4_M_SS	7_S_DS	16_T2_MD	18_T2_AP
NPV	Zone 1 - Auckland	93%	89%	79%	92%
	Zone 2 - Napier	95%	92%	86%	95%
	Zone 3 - Wellington	97%	94%	90%	99%
	Zone 4 - Turangi	98%	94%	90%	97%
	Zone 5 - Christchurch	100%	98%	93%	99%
	Zone 6 - Queenstown	100%	99%	94%	98%
Carbon	Zone 1 - Auckland	99%	97%	87%	103%
	Zone 2 - Napier	99%	98%	90%	102%
	Zone 3 - Wellington	100%	98%	93%	104%
	Zone 4 - Turangi	98%	95%	92%	98%
	Zone 5 - Christchurch	100%	99%	94%	100%
	Zone 6 - Queenstown	100%	99%	94%	99%
Equalise	Zone 1 - Auckland	94%	89%	82%	92%
	Zone 2 - Napier	95%	92%	87%	95%
	Zone 3 - Wellington	100%	99%	92%	103%
	Zone 4 - Turangi	100%	97%	93%	100%
	Zone 5 - Christchurch	99%	98%	93%	97%
	Zone 6 - Queenstown	100%	100%	93%	97%

	Ext 60/Int 60	4_M_SS	7_S_DS	16_T2_MD	18_T2_AP
NPV	Zone 1 - Auckland	94%	92%	76%	82%
	Zone 2 - Napier	96%	95%	85%	89%
	Zone 3 - Wellington	98%	97%	90%	97%
	Zone 4 - Turangi	100%	97%	90%	93%
	Zone 5 - Christchurch	99%	98%	91%	94%
	Zone 6 - Queenstown	100%	100%	92%	95%
Carbon	Zone 1 - Auckland	97%	96%	83%	91%
	Zone 2 - Napier	98%	97%	88%	94%
	Zone 3 - Wellington	99%	98%	91%	100%
	Zone 4 - Turangi	100%	99%	92%	97%
	Zone 5 - Christchurch	99%	99%	92%	97%
	Zone 6 - Queenstown	99%	99%	92%	96%
Equalise	Zone 1 - Auckland	94%	91%	79%	82%
	Zone 2 - Napier	96%	95%	85%	90%
	Zone 3 - Wellington	98%	97%	90%	97%
	Zone 4 - Turangi	100%	99%	92%	97%
	Zone 5 - Christchurch	100%	100%	92%	93%
	Zone 6 - Queenstown	100%	100%	92%	93%

	Ext 90/Int 45	4_M_SS	7_S_DS	16_T2_MD	18_T2_AP
NPV	Zone 1 - Auckland	97%	95%	74%	86%
	Zone 2 - Napier	98%	97%	84%	92%
	Zone 3 - Wellington	100%	99%	89%	99%
	Zone 4 - Turangi	95%	90%	85%	88%
	Zone 5 - Christchurch	98%	95%	89%	93%
	Zone 6 - Queenstown	100%	99%	91%	95%
Carbon	Zone 1 - Auckland	99%	98%	81%	94%
	Zone 2 - Napier	99%	98%	87%	96%
	Zone 3 - Wellington	97%	95%	89%	98%
	Zone 4 - Turangi	99%	96%	89%	95%
	Zone 5 - Christchurch	100%	100%	91%	97%
	Zone 6 - Queenstown	100%	99%	92%	97%
Equalise	Zone 1 - Auckland	100%	100%	81%	92%
	Zone 2 - Napier	98%	96%	84%	91%
	Zone 3 - Wellington	100%	99%	89%	99%
	Zone 4 - Turangi	99%	97%	90%	95%
	Zone 5 - Christchurch	99%	98%	90%	92%
	Zone 6 - Queenstown	100%	100%	91%	94%

Summary spreadsheet of cost/benefit analysis of individual element upgrades for MBIE H1 project

This spreadsheet has summary tables of the economic and carbon analysis of the cost/benefits of upgrading different parts of the building fabric past code minimum
Tables are arranged with the different case studies dwellings running across, and different climate zones running down

Economics includes the extra cost of applying the given upgrade, the estimated annual energy savings (combined cooling and heating), and the benefit/cost ratio and net present value over a 50 year life

Carbon includes a stacked bar plot of the operational emissions and the material-related emissions to show how they compare, the net co2 over a 50 year life, and the ratio of operational to material emissions

Note the graphs are not on the same scale - they are there for understanding the relative contributions of operational vs. material carbon, not for comparisons between buildingsn (which operate on different scales anyway)

Note also that all these figures are given as the marginal cost or benefit compared to code minimum

"Comfort" is summarised as the % of hours between 18-25 degrees in the main living space in the day, and in the master bedroom over night

Formatting is as follows to assist identification of the best choices:

Negative overall result/poor return
Technically positive overall result

Strong overall result (benefit/cost ratio > 3, reasonable odds of
staying positive even with less optimistic energy saving projections)

Results are given on both building level and in terms of conditioned floor area (see tabs)

Construction details

Walls

Table 5 External timber wall constructions and R-values

R1.9	R2.0	R2.5	R2.9	R4.0	R4.6
R2.2 pink batts, 90mm framing (24%)	R2.6 pink batts, 90mm framing (24%)	R2.8 pink batts, 140mm framing (24%)	R4.0 pink batts ultra, 140mm framing (24%)	R2.2 + R2.2 pink batts, 2 x 90mm staggered stud (24%)	R2.8 x 2 pink batts, 2 x 90mm staggered stud (24%)
HIG p66	HIG p66	HIG p67	HIG p67	HIG p71	HIG p71

Table 6 Retaining wall insulation and R-values. Note here that the lowest R-value option here is ~R2.1 using typical masonry wall batt insulation.

~R2.1	~R2.1	~R2.5	~R2.9	~R4.0	~R4.5
R1.0 pink batts masonry, 45mm framing (10%)	R1.0 pink batts masonry, 45mm framing (10%)	R1.2 pink batts masonry, 75mm framing (10%)	R1.8 pink batts, 90mm framing (10%)	R3.2 pink batts, 140mm framing (10%)	R4.0 pink batts, 140mm framing (10%)

Floor

Table 7 Slab construction scenarios and rough R-values. Note these R-values do not include internal linings such as carpet, though they have been

~R1.3	~R1.9	~R2.0	~R2.7
Uninsulated slab	R1.2 underslab insulation (50mm polystyrene)	R1.0 edge insulation (30mm polystyrene)	R1.0 edge insulation + R1.2 underslab insulation
HIG p127	HIG p127	HIG p127	HIG p127

Table 9 Batts between floor joist insulation and R-values

R1.5	R2.0	R2.0	R2.8
R1.0 40mm masonry batts strapped, 11% timber framing	R1.6 batts strapped, 11% timber framing	R1.6 batts strapped, 11% timber framing	R2.6 batts strapped, 11% timber framing
HIG p118	HIG p118	HIG p118	HIG p118

Roof

Table 5 Ceiling insulation and overall roof R-values

R2.9	R3.3	R3.6	R4.3	R4.9	R5.9	R6.6
R3.2 pink batts, 5% framing. Assumed installed slightly inefficiently to bring R-value down to code min (HIG: R3.1)	R3.6 pink batts, 5% framing. Assumed installed slightly inefficiently to bring R-value down to code min (HIG: R3.4)	R4.0 pink batts, 5% framing	R5.0 pink batts, 5% framing	R3.2 batts between chords + R1.8 batts over top	R3.6 batts between chords + R2.6 batts over top	R3.6 batts between chords + R3.2 batts over top
HIG p29	HIG p29	HIG p29	HIG p29			

Table 5 Apartment building ceiling insulation and overall roof R-values

R2.9	R3.3	R3.9	R4.3	R5.3	R6.3	R7.3
R2.6 batts	R3.2 batts, assumed effectively R3.0 due to poor installation in order to provide code min R-value	R3.6 batts	R4.0 batts	R5.0 batts	R6.0 batts	R7.0 batts

Glazing

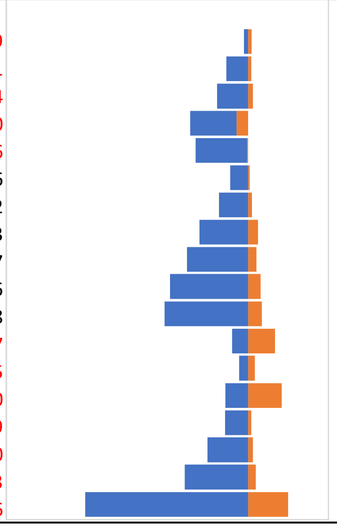
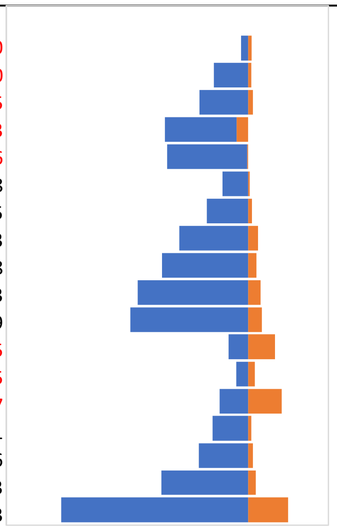
R0.26 SHGC: 0.74	R0.31 SHGC: 0.74	R0.31 SHGC: 0.7	R0.39 SHGC: 0.7	R0.62 SHGC: 0.4
Double glazing in al. frame	Double glazing in thermally broken al. frame	Double glazing in al. frame w. low-E coating	Double glazing in thermally broken al. frame w. low-E coating	Triple glazing in thermally broken al. frame w. low-E coating + argon fill
HIG Table 6	HIG Table 6	HIG Table 6	HIG Table 6	Expert estimate

Later additions

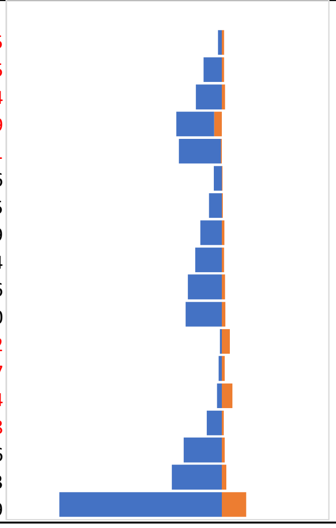
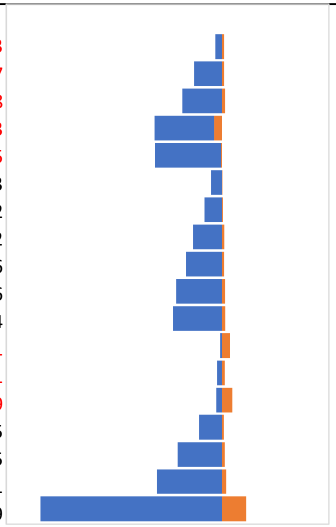
Glazing	Floor		Apartment Roof
R0.76 **SHGC: 0.4**	**~R3.4-3.9**	**R3.6**	**R6.6**
Triple glazing in uPVC frame w. low-E coating + argon fill	High performance fully enclosed insulated slab system such as MaxRaft	R3.6 batts strapped, 10% timber framing	R6.3 batts to align R-value with selected insulation level in houses
Expert estimate	Expert estimate	HIG p118	

net_carbon_static3 - Sheet: Building_level - Page 1

Single Storey

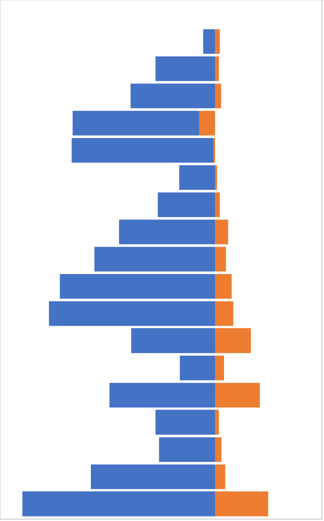
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
				Annual							Living	
	Element	R-value	Extra Cost	Savings	BCR	NPV	Energy	Material	Net	Ratio	room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					73%	56%
	Wall	R2.0 (Z3 min)	$ 475	$ -9	0.37	$ -299			-27	1.3	73%	56%
		R2.5 (140mm)	$ 4,455	$ -43	0.19	$ -3,591			-478	7.5	74%	57%
		R2.9	$ 4,683	$ -61	0.26	$ -3,464			-666	6.9	75%	58%
		R4.0 (staggered stud)	$ 8,607	$ -91	0.21	$ -6,790			-1455	NA	75%	59%
		R4.6	$ 10,586	$ -101	0.19	$ -8,576			-1315	NA	76%	60%
	Roof	R3.3 (Z3 min)	$ 237	$ -36	3.01	$ 476			-422	13.6	74%	56%
		R3.6	$ 197	$ -58	5.83	$ 952			-643	8.0	75%	57%
		R4.3	$ 1,479	$ -96	1.29	$ 433			-979	5.0	76%	58%
		R4.9	$ 2,367	$ -121	1.02	$ 37			-1336	7.7	76%	59%
		R5.9	$ 2,769	$ -154	1.11	$ 296			-1652	6.4	77%	60%
		R6.6	$ 2,873	$ -164	1.14	$ 398			-1750	6.2	78%	60%
	Floor	R1.9 (underslab)	$ 3,820	$ -32	0.17	$ -3,187			265	0.6	74%	59%
		R2.0 (edge)	$ 2,550	$ -18	0.14	$ -2,195			-62	1.4	74%	56%
		R2.7 (full ins.)	$ 6,370	$ -45	0.14	$ -5,480			265	0.7	75%	60%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -46	0.76	$ -289			-511	8.0	75%	57%
		R0.31 (low-E)	$ 1,288	$ -81	1.00	$ -0			-912	9.0	74%	57%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -125	0.88	$ -323			-1401	8.5	76%	59%
		R0.62 (triple glaz.)	$ 6,594	$ -320	0.80	$ -1,556			-3076	4.1	75%	60%
Zone 2 - Napier	Base	Code min	-	-	-	-					65%	46%
	Wall	R2.0 (Z3 min)	$ 475	$ -15	0.64	$ -170			-94	2.1	65%	46%
		R2.5 (140mm)	$ 4,403	$ -73	0.33	$ -2,950			-782	11.6	66%	47%
		R2.9	$ 4,631	$ -104	0.45	$ -2,555			-1111	10.8	66%	47%
		R4.0 (staggered stud)	$ 8,106	$ -153	0.38	$ -5,063			-2088	NA	67%	48%
		R4.6	$ 10,432	$ -170	0.32	$ -7,046			-2027	NA	68%	48%
	Roof	R3.3 (Z3 min)	$ 217	$ -55	5.05	$ 878			-612	19.2	66%	47%
		R3.6	$ 177	$ -88	9.88	$ 1,575			-942	11.3	66%	47%
		R4.3	$ 1,795	$ -147	1.63	$ 1,133			-1483	7.1	67%	48%
		R4.9	$ 2,242	$ -183	1.63	$ 1,408			-1952	10.8	68%	48%
		R5.9	$ 2,584	$ -235	1.81	$ 2,103			-2456	9.0	69%	49%
		R6.6	$ 2,646	$ -251	1.89	$ 2,359			-2611	8.7	69%	49%
	Floor	R1.9 (underslab)	$ 4,069	$ -42	0.21	$ -3,225			172	0.7	65%	49%
		R2.0 (edge)	$ 2,556	$ -26	0.20	$ -2,045			-136	1.8	66%	46%
		R2.7 (full ins.)	$ 6,625	$ -61	0.18	$ -5,407			116	0.9	65%	49%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -76	1.26	$ 311			-819	12.3	66%	48%
		R0.31 (low-E)	$ 1,288	$ -105	1.30	$ 486			-1119	10.8	66%	47%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -185	1.31	$ 873			-1983	11.6	67%	49%
		R0.62 (triple glaz.)	$ 6,594	$ -398	1.00	$ 3			-3680	4.7	65%	50%

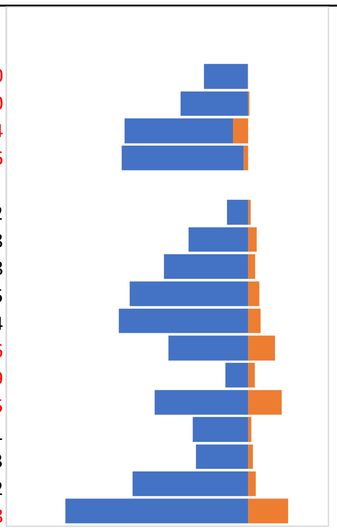
Two Storey

			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
				Annual							Living	
	Element	R-value	Extra Cost	Savings	BCR	NPV	Energy	Material	Net	Ratio	room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					68%	60%
	Wall	R2.0 (Z3 min)	$ 594	$ -15	0.50	$ -295			-84	1.8	69%	61%
		R2.5 (140mm)	$ 5,568	$ -68	0.24	$ -4,215			-772	9.3	70%	63%
		R2.9	$ 5,854	$ -95	0.32	$ -3,954			-1072	8.6	71%	64%
		R4.0 (staggered	$ 10,758	$ -140	0.26	$ -7,979			-2143	NA	73%	66%
		R4.6	$ 13,231	$ -155	0.23	$ -10,141			-2013	NA	73%	67%
	Roof	R3.3 (Z3 min)	$ 109	$ -30	5.47	$ 486			-365	24.6	68%	61%
		R3.6	$ 91	$ -48	10.54	$ 865			-569	14.6	68%	61%
		R4.3	$ 680	$ -80	2.34	$ 909			-904	9.1	69%	62%
		R4.9	$ 1,088	$ -99	1.80	$ 874			-1162	13.7	69%	63%
		R5.9	$ 1,273	$ -126	1.96	$ 1,226			-1456	11.3	69%	64%
		R6.6	$ 1,321	$ -134	2.01	$ 1,340			-1544	10.9	69%	64%
	Floor	R1.9 (underslab	$ 2,128	$ -8	0.07	$ -1,972			273	0.3	69%	61%
		R2.0 (edge)	$ 1,825	$ -11	0.13	$ -1,597			-21	1.2	69%	61%
		R2.7 (full ins.)	$ 3,893	$ -18	0.09	$ -3,544			266	0.5	69%	62%
	Glazing	R0.31 (thermall	$ 1,370	$ -55	0.80	$ -268			-622	8.5	70%	62%
		R0.31 (low-E)	$ 1,468	$ -141	1.53	$ 976			-1663	13.8	69%	61%
		R0.39 (therm.br	$ 2,839	$ -184	1.14	$ 463			-2129	11.0	71%	64%
		R0.62 (triple gla	$ 7,518	$ -598	1.32	$ 2,859			-6467	6.7	68%	65%
Zone 2 - Napier	Base	Code min	-	-	-	-					62%	48%
	Wall	R2.0 (Z3 min)	$ 594	$ -26	0.86	$ -83			-194	2.8	62%	49%
		R2.5 (140mm)	$ 5,503	$ -111	0.40	$ -3,297			-1208	14.0	63%	51%
		R2.9	$ 5,789	$ -158	0.54	$ -2,648			-1710	13.1	63%	52%
		R4.0 (staggered	$ 10,131	$ -238	0.47	$ -5,403			-3155	NA	65%	54%
		R4.6	$ 13,039	$ -263	0.40	$ -7,795			-3130	NA	65%	54%
	Roof	R3.3 (Z3 min)	$ 100	$ -44	8.75	$ 773			-499	33.3	62%	50%
		R3.6	$ 82	$ -70	17.08	$ 1,312			-780	19.6	62%	50%
		R4.3	$ 825	$ -115	2.77	$ 1,462			-1236	12.1	62%	51%
		R4.9	$ 1,031	$ -143	2.76	$ 1,816			-1586	18.3	62%	52%
		R5.9	$ 1,188	$ -181	3.03	$ 2,416			-1983	15.1	63%	52%
		R6.6	$ 1,217	$ -194	3.18	$ 2,654			-2125	14.6	63%	53%
	Floor	R1.9 (underslab	$ 2,252	$ -6	0.05	$ -2,131			301	0.2	61%	49%
		R2.0 (edge)	$ 1,818	$ -20	0.22	$ -1,421			-109	1.9	62%	50%
		R2.7 (full ins.)	$ 4,030	$ -22	0.11	$ -3,589			229	0.5	62%	50%
	Glazing	R0.31 (thermall	$ 1,370	$ -91	1.32	$ 435			-981	12.9	63%	50%
		R0.31 (low-E)	$ 1,468	$ -177	1.93	$ 1,695			-1948	16.0	62%	50%
		R0.39 (therm.br	$ 2,839	$ -259	1.61	$ 1,961			-2831	14.3	63%	52%
		R0.62 (triple gla	$ 7,518	$ -723	1.59	$ 5,349			-7347	7.5	61%	53%

net_carbon_static3 - Sheet: Building_level - Page 2

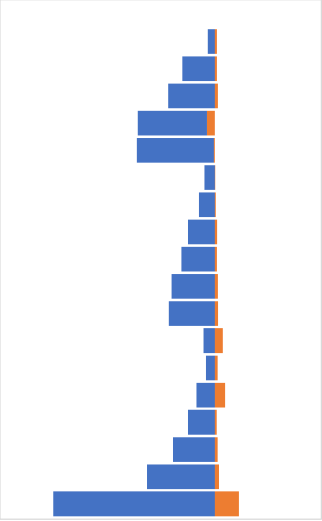
Single Storey

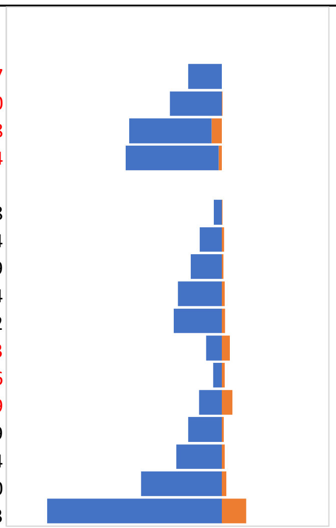




			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					55%	30%
	Wall	R2.0 (Z3 min)	$ 475	$ -18	0.77	$ -110			-139	2.6	55%	30%
		R2.5 (140mm)	$ 4,783	$ -91	0.38	$ -2,973			-1042	15.1	56%	31%
		R2.9	$ 5,012	$ -129	0.51	$ -2,435			-1475	14.1	56%	32%
		R4.0 (staggered stud)	$ 8,244	$ -194	0.47	$ -4,384			-2674	NA	57%	33%
		R4.6	$ 10,570	$ -216	0.41	$ -6,266			-2685	NA	58%	33%
	Roof	R3.3 (Z3 min)	$ 217	$ -55	5.03	$ 874			-639	20.0	56%	31%
		R3.6	$ 177	$ -88	9.84	$ 1,570			-986	11.8	56%	31%
		R4.3	$ 1,814	$ -147	1.61	$ 1,104			-1557	7.4	57%	32%
		R4.9	$ 2,201	$ -184	1.67	$ 1,466			-2060	11.3	58%	33%
		R5.9	$ 2,542	$ -237	1.86	$ 2,179			-2604	9.5	58%	33%
		R6.6	$ 2,604	$ -253	1.94	$ 2,440			-2770	9.2	59%	34%
	Floor	R1.9 (underslab)	$ 3,633	$ -128	0.70	$ -1,084			-903	2.3	57%	34%
		R2.0 (edge)	$ 2,524	$ -54	0.43	$ -1,444			-501	4.0	56%	30%
		R2.7 (full ins.)	$ 6,157	$ -161	0.52	$ -2,947			-1145	2.4	57%	34%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -91	1.51	$ 607			-1043	15.4	56%	32%
		R0.31 (low-E)	$ 1,288	$ -86	1.06	$ 97			-936	9.2	55%	31%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -190	1.34	$ 966			-2140	12.5	57%	33%
		R0.62 (triple glaz.)	$ 6,594	$ -294	0.74	$ -2,071			-2616	3.6	53%	34%
Zone 4 - Turangi	Base	Code min	-	-	-	-					50%	23%
	Wall	R2.0 (Z3 min)	-	-	-	-					50%	23%
		R2.5 (140mm)	$ 4,329	$ -95	0.44	$ -2,440			-1109	NA	50%	23%
		R2.9	$ 4,557	$ -147	0.64	$ -1,640			-1668	61.5	51%	24%
		R4.0 (staggered stud)	$ 7,449	$ -234	0.63	$ -2,784			-3091	NA	51%	25%
		R4.6	$ 9,971	$ -263	0.53	$ -4,726			-3165	NA	52%	25%
	Roof	R3.3 (Z3 min)	-	-	-	-					50%	24%
		R3.6	$ -39	$ -46	NA	$ 962			-478	9.3	51%	24%
		R4.3	$ 1,775	$ -129	1.45	$ 798			-1287	7.2	51%	25%
		R4.9	$ 1,964	$ -182	1.84	$ 1,658			-1939	12.7	52%	25%
		R5.9	$ 2,325	$ -256	2.19	$ 2,775			-2691	10.9	52%	26%
		R6.6	$ 2,304	$ -279	2.41	$ 3,254			-2924	10.6	52%	26%
	Floor	R1.9 (underslab)	$ 3,986	$ -172	0.86	$ -556			-1324	3.0	51%	28%
		R2.0 (edge)	$ 2,545	$ -49	0.38	$ -1,569			-402	3.4	50%	23%
		R2.7 (full ins.)	$ 6,530	$ -202	0.62	$ -2,505			-1506	2.8	52%	28%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -120	1.99	$ 1,191			-1318	19.1	51%	24%
		R0.31 (low-E)	$ 1,288	$ -113	1.40	$ 643			-1193	11.5	50%	24%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -250	1.77	$ 2,162			-2702	15.5	51%	26%
		R0.62 (triple glaz.)	$ 6,594	$ -395	0.99	$ -58			-3579	4.6	46%	25%

Two Storey

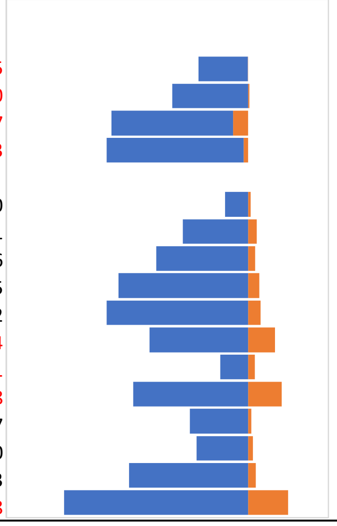


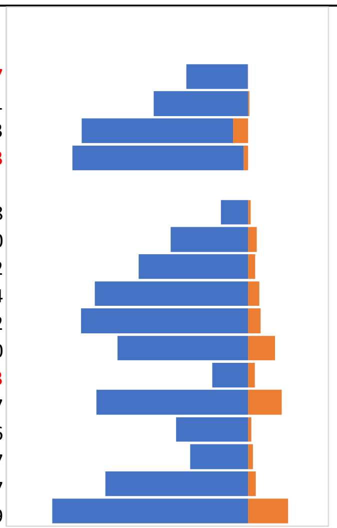


			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					53%	37%
	Wall	R2.0 (Z3 min)	$ 594	$ -27	0.90	$ -59			-223	3.1	53%	38%
		R2.5 (140mm)	$ 5,979	$ -124	0.41	$ -3,517			-1425	16.4	54%	40%
		R2.9	$ 6,264	$ -178	0.57	$ -2,718			-2045	15.5	55%	41%
		R4.0 (staggered	$ 10,304	$ -265	0.51	$ -5,031			-3618	NA	56%	44%
		R4.6	$ 13,212	$ -295	0.44	$ -7,339			-3660	NA	56%	44%
	Roof	R3.3 (Z3 min)	$ 100	$ -39	7.72	$ 670			-459	30.7	53%	38%
		R3.6	$ 82	$ -61	14.81	$ 1,128			-703	17.8	53%	39%
		R4.3	$ 834	$ -101	2.42	$ 1,186			-1134	11.2	53%	40%
		R4.9	$ 1,012	$ -127	2.50	$ 1,522			-1471	17.0	54%	40%
		R5.9	$ 1,169	$ -165	2.81	$ 2,117			-1885	14.4	54%	42%
		R6.6	$ 1,198	$ -176	2.93	$ 2,312			-2007	13.9	54%	42%
	Floor	R1.9 (underslab	$ 2,020	$ -43	0.43	$ -1,161			-157	1.4	55%	39%
		R2.0 (edge)	$ 1,799	$ -34	0.38	$ -1,119			-294	3.4	54%	39%
		R2.7 (full ins.)	$ 3,769	$ -69	0.37	$ -2,389			-361	1.7	56%	40%
	Glazing	R0.31 (thermall	$ 1,370	$ -101	1.47	$ 644			-1159	15.0	54%	39%
		R0.31 (low-E)	$ 1,468	$ -159	1.72	$ 1,327			-1817	15.0	53%	39%
		R0.39 (therm.br	$ 2,839	$ -259	1.61	$ 1,958			-2968	15.0	54%	42%
		R0.62 (triple gla	$ 7,518	$ -617	1.36	$ 3,250			-6442	6.7	48%	42%
Zone 4 - Turangi	Base	Code min	-	-	-	-					48%	31%
	Wall	R2.0 (Z3 min)	-	-	-	-					49%	32%
		R2.5 (140mm)	$ 5,411	$ -135	0.50	$ -2,717			-1579	NA	49%	33%
		R2.9	$ 5,696	$ -210	0.73	$ -1,510			-2398	70.6	50%	35%
		R4.0 (staggered	$ 9,310	$ -334	0.71	$ -2,658			-4341	NA	51%	37%
		R4.6	$ 12,463	$ -376	0.60	$ -4,974			-4498	NA	51%	38%
	Roof	R3.3 (Z3 min)	-	-	-	-					48%	32%
		R3.6	$ (18)	$ -32	NA	$ 658			-346	14.0	49%	32%
		R4.3	$ 816	$ -90	2.19	$ 974			-944	10.8	49%	33%
		R4.9	$ 903	$ -126	2.77	$ 1,599			-1378	19.0	49%	34%
		R5.9	$ 1,069	$ -178	3.32	$ 2,484			-1939	16.5	49%	35%
		R6.6	$ 1,060	$ -195	3.65	$ 2,812			-2110	16.0	49%	35%
	Floor	R1.9 (underslab	$ 2,196	$ -63	0.58	$ -933			-362	2.0	50%	32%
		R2.0 (edge)	$ 1,799	$ -36	0.40	$ -1,086			-289	3.3	49%	32%
		R2.7 (full ins.)	$ 3,977	$ -92	0.46	$ -2,149			-573	2.2	50%	33%
	Glazing	R0.31 (thermall	$ 1,370	$ -137	1.98	$ 1,349			-1497	19.1	49%	33%
		R0.31 (low-E)	$ 1,468	$ -185	2.01	$ 1,854			-2011	16.5	48%	32%
		R0.39 (therm.br	$ 2,839	$ -327	2.03	$ 3,300			-3566	17.8	50%	34%
		R0.62 (triple gla	$ 7,518	$ -706	1.56	$ 5,023			-7038	7.2	44%	35%

net_carbon_static3 - Sheet: Building_level - Page 3

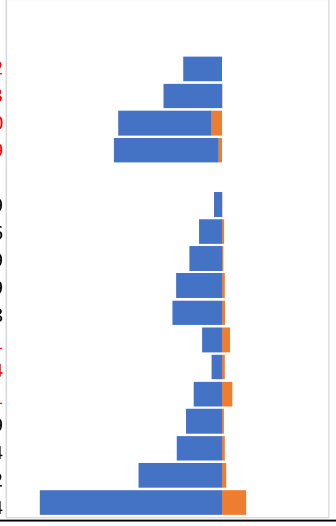
Single Storey

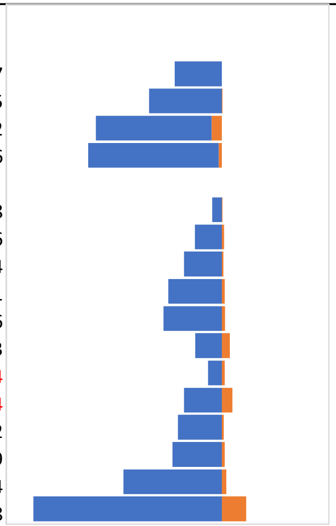




			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					44%	23%
		R2.0 (Z3 min)	-	-	-	-					45%	24%
	Wall	R2.5 (140mm)	$ 3,286	$ -95	0.57	$ -1,405			-1245	NA	45%	25%
		R2.9	$ 3,515	$ -146	0.83	$ -610			-1876	69.1	45%	25%
		R4.0 (staggered stud)	$ 8,349	$ -233	0.55	$ -3,717			-3417	NA	46%	26%
		R4.6	$ 10,393	$ -262	0.50	$ -5,173			-3539	NA	46%	26%
	Roof	R3.3 (Z3 min)	-	-	-	-					45%	24%
		R3.6	$ -39	$ -45	NA	$ 930			-526	10.1	45%	25%
		R4.3	$ 1,321	$ -125	1.89	$ 1,171			-1425	7.8	46%	25%
		R4.9	$ 2,150	$ -176	1.63	$ 1,356			-2132	13.8	46%	26%
		R5.9	$ 2,553	$ -249	1.94	$ 2,395			-2971	11.9	46%	27%
		R6.6	$ 2,637	$ -271	2.05	$ 2,762			-3233	11.6	46%	27%
	Floor	R1.9 (underslab)	$ 4,526	$ -189	0.83	$ -754			-1804	3.7	46%	28%
		R2.0 (edge)	$ 2,486	$ -53	0.43	$ -1,421			-533	4.2	45%	24%
		R2.7 (full ins.)	$ 7,012	$ -221	0.63	$ -2,618			-2046	3.5	46%	28%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -112	1.85	$ 1,027			-1389	20.1	45%	25%
		R0.31 (low-E)	$ 1,288	$ -99	1.22	$ 360			-1175	11.3	44%	24%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -229	1.62	$ 1,743			-2797	16.0	45%	27%
		R0.62 (triple glaz.)	$ 6,594	$ -352	0.89	$ -908			-3608	4.6	41%	27%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					39%	15%
		R2.0 (Z3 min)	-	-	-	-					39%	16%
	Wall	R2.5 (140mm)	$ 3,359	$ -149	0.88	$ -397			-1551	NA	39%	16%
		R2.9	$ 3,587	$ -228	1.27	$ 961			-2337	85.8	39%	16%
		R4.0 (staggered stud)	$ 7,202	$ -365	1.01	$ 73			-4162	NA	40%	17%
		R4.6	$ 9,246	$ -413	0.89	$ -1,023			-4392	NA	40%	17%
	Roof	R3.3 (Z3 min)	-	-	-	-					39%	16%
		R3.6	$ -39	$ -67	NA	$ 1,368			-633	12.0	39%	16%
		R4.3	$ 1,321	$ -188	2.83	$ 2,420			-1736	9.3	40%	17%
		R4.9	$ 1,859	$ -264	2.83	$ 3,402			-2569	16.5	40%	18%
		R5.9	$ 2,263	$ -371	3.26	$ 5,114			-3562	14.1	40%	18%
		R6.6	$ 2,346	$ -404	3.43	$ 5,692			-3872	13.7	40%	19%
	Floor	R1.9 (underslab)	$ 4,297	$ -315	1.46	$ 1,980			-2594	4.9	40%	21%
		R2.0 (edge)	$ 2,482	$ -87	0.70	$ -743			-739	5.5	39%	16%
		R2.7 (full ins.)	$ 6,780	$ -367	1.08	$ 517			-2959	4.5	40%	21%
	Glazing	R0.31 (thermally broken)	$ 1,202	$ -174	2.88	$ 2,266			-1730	24.8	39%	17%
		R0.31 (low-E)	$ 1,288	$ -141	1.75	$ 1,197			-1343	12.8	38%	16%
		R0.39 (therm.brk + low-E)	$ 2,490	$ -345	2.45	$ 4,067			-3388	19.2	39%	18%
		R0.62 (triple glaz.)	$ 6,594	$ -473	1.19	$ 1,499			-3906	4.9	34%	17%

Two Storey

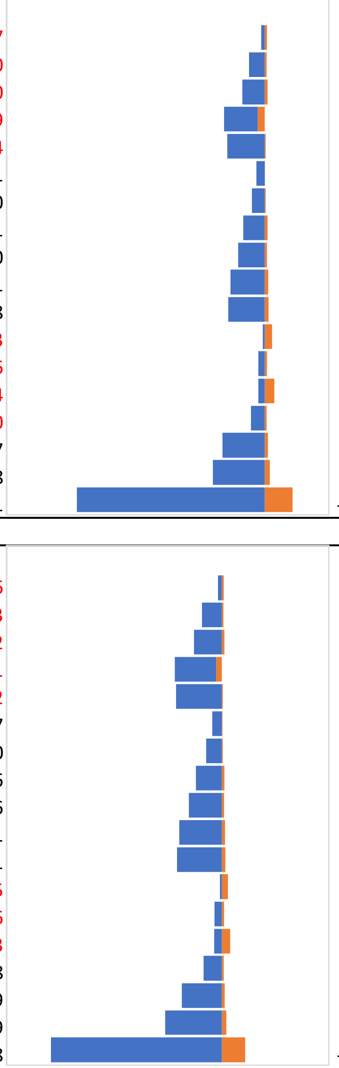




			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					43%	31%
		R2.0 (Z3 min)	-	-	-	-					43%	31%
	Wall	R2.5 (140mm)	$ 4,107	$ -136	0.66	$ -1,392			-1794	NA	44%	33%
		R2.9	$ 4,393	$ -209	0.95	$ -223			-2699	79.4	45%	34%
		R4.0 (staggered	$ 10,436	$ -334	0.64	$ -3,780			-4838	NA	46%	36%
		R4.6	$ 12,990	$ -376	0.58	$ -5,499			-5057	NA	46%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					43%	32%
		R3.6	$ (18)	$ -29	NA	$ 599			-354	14.4	43%	32%
		R4.3	$ 608	$ -82	2.69	$ 1,026			-975	11.2	43%	33%
		R4.9	$ 988	$ -116	2.33	$ 1,319			-1436	19.8	44%	34%
		R5.9	$ 1,174	$ -163	2.77	$ 2,079			-2007	17.0	44%	35%
		R6.6	$ 1,212	$ -178	2.92	$ 2,328			-2181	16.5	44%	35%
	Floor	R1.9 (underslab	$ 2,509	$ -71	0.57	$ -1,091			-557	2.5	44%	32%
		R2.0 (edge)	$ 1,780	$ -38	0.42	$ -1,034			-364	3.9	44%	32%
		R2.7 (full ins.)	$ 4,234	$ -101	0.48	$ -2,221			-831	2.7	45%	33%
	Glazing	R0.31 (thermall	$ 1,370	$ -129	1.87	$ 1,189			-1595	20.3	44%	33%
		R0.31 (low-E)	$ 1,468	$ -163	1.77	$ 1,404			-1991	16.3	43%	32%
		R0.39 (therm.br	$ 2,839	$ -300	1.86	$ 2,762			-3697	18.4	44%	34%
		R0.62 (triple gla	$ 7,518	$ -652	1.44	$ 3,954			-7384	7.5	39%	34%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					37%	25%
		R2.0 (Z3 min)	-	-	-	-					37%	25%
	Wall	R2.5 (140mm)	$ 4,198	$ -212	1.01	$ 27			-2210	NA	38%	27%
		R2.9	$ 4,483	$ -329	1.46	$ 2,065			-3370	98.9	38%	28%
		R4.0 (staggered	$ 9,002	$ -524	1.16	$ 1,422			-5894	NA	39%	30%
		R4.6	$ 11,557	$ -591	1.02	$ 206			-6261	NA	40%	30%
	Roof	R3.3 (Z3 min)	-	-	-	-					37%	26%
		R3.6	$ (18)	$ -44	NA	$ 898			-431	17.3	37%	26%
		R4.3	$ 608	$ -122	4.01	$ 1,826			-1169	13.2	37%	27%
		R4.9	$ 855	$ -172	4.01	$ 2,574			-1706	23.3	38%	28%
		R5.9	$ 1,041	$ -242	4.62	$ 3,771			-2376	19.9	38%	29%
		R6.6	$ 1,079	$ -264	4.87	$ 4,176			-2591	19.4	38%	29%
	Floor	R1.9 (underslab	$ 2,397	$ -121	1.01	$ 13			-880	3.4	39%	26%
		R2.0 (edge)	$ 1,789	$ -63	0.70	$ -544			-522	5.2	38%	26%
		R2.7 (full ins.)	$ 4,107	$ -171	0.83	$ -704			-1280	3.6	39%	27%
	Glazing	R0.31 (thermall	$ 1,370	$ -199	2.88	$ 2,582			-1972	24.8	38%	26%
		R0.31 (low-E)	$ 1,468	$ -225	2.44	$ 2,639			-2194	17.9	37%	26%
		R0.39 (therm.br	$ 2,839	$ -445	2.77	$ 5,654			-4391	21.7	38%	28%
		R0.62 (triple gla	$ 7,518	$ -852	1.88	$ 7,918			-7681	7.8	32%	27%

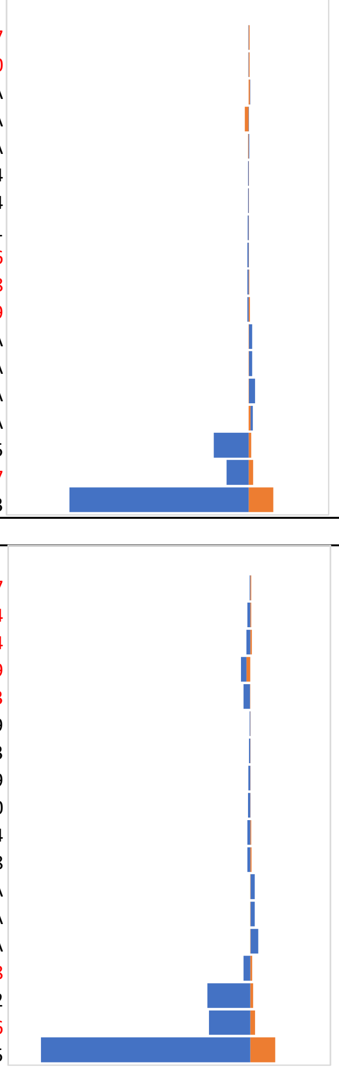
net_carbon_static3 - Sheet: Building_level - Page 4

Medium Density



			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					75%	62%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -42	0.44	$ -1,037			-194	1.6	75%	62%
		R2.5 (140mm)	$ 17,822	$ -193	0.22	$ -13,970			-2168	8.4	76%	65%
		R2.9	$ 19,863	$ -275	0.28	$ -14,380			-3037	7.5	77%	66%
		R4.0 (staggered	$ 37,269	$ -413	0.22	$ -29,049			-6325	NA	78%	69%
		R4.6	$ 45,804	$ -458	0.20	$ -36,684			-5664	36.0	79%	70%
	Roof	R3.3 (Z3 min)	$ 435	$ -100	4.56	$ 1,551			-1207	20.5	75%	63%
		R3.6	$ 363	$ -157	8.64	$ 2,770			-1833	11.9	75%	63%
		R4.3	$ 2,720	$ -262	1.92	$ 2,491			-2883	7.5	75%	65%
		R4.9	$ 4,352	$ -327	1.50	$ 2,160			-3793	11.3	75%	66%
		R5.9	$ 5,093	$ -420	1.64	$ 3,261			-4773	9.5	75%	66%
		R6.6	$ 5,284	$ -446	1.68	$ 3,598			-5050	9.1	75%	67%
	Floor	R1.9 (underslab	$ 6,557	$ -22	0.07	$ -6,113			864	0.2	74%	62%
		R2.0 (edge)	$ 5,596	$ -77	0.28	$ -4,056			-614	2.7	75%	62%
		R2.7 (full ins.)	$ 12,083	$ -78	0.13	$ -10,524			512	0.7	75%	63%
	Glazing	R0.31 (thermall	$ 5,259	$ -169	0.64	$ -1,900			-1828	6.8	76%	64%
		R0.31 (low-E)	$ 5,635	$ -517	1.46	$ 3,257			-6071	13.2	76%	63%
		R0.39 (therm.br	$ 10,894	$ -634	1.03	$ 338			-7249	9.9	78%	66%
		R0.62 (triple gla	$ 28,851	$ -2,305	1.32	$ 11,201			-24963	6.7	76%	65%
Zone 2 - Napier	Base	Code min	-	-	-	-					65%	50%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -63	0.67	$ -616			-401	2.2	66%	51%
		R2.5 (140mm)	$ 17,602	$ -315	0.36	$ -11,333			-3403	12.6	67%	53%
		R2.9	$ 19,847	$ -446	0.45	$ -10,962			-4772	11.3	67%	54%
		R4.0 (staggered	$ 35,318	$ -659	0.37	$ -22,191			-8811	NA	68%	56%
		R4.6	$ 45,410	$ -731	0.32	$ -30,852			-8419	53.0	69%	56%
	Roof	R3.3 (Z3 min)	$ 399	$ -158	7.86	$ 2,737			-1786	29.9	66%	51%
		R3.6	$ 326	$ -251	15.34	$ 4,680			-2783	17.6	66%	52%
		R4.3	$ 3,300	$ -418	2.52	$ 5,026			-4462	11.0	66%	52%
		R4.9	$ 4,123	$ -526	2.54	$ 6,356			-5809	16.8	66%	53%
		R5.9	$ 4,751	$ -679	2.84	$ 8,761			-7401	14.1	66%	54%
		R6.6	$ 4,866	$ -720	2.94	$ 9,461			-7821	13.5	66%	54%
	Floor	R1.9 (underslab	$ 6,967	$ -34	0.10	$ -6,295			752	0.3	65%	50%
		R2.0 (edge)	$ 5,596	$ -120	0.43	$ -3,216			-1033	3.8	66%	51%
		R2.7 (full ins.)	$ 12,516	$ -124	0.20	$ -10,053			56	1.0	65%	51%
	Glazing	R0.31 (thermall	$ 5,259	$ -296	1.12	$ 638			-3158	10.9	67%	52%
		R0.31 (low-E)	$ 5,635	$ -641	1.82	$ 5,729			-7020	15.1	66%	51%
		R0.39 (therm.br	$ 10,894	$ -903	1.46	$ 5,699			-9785	13.0	68%	54%
		R0.62 (triple gla	$ 28,851	$ -2,732	1.57	$ 19,718			-27718	7.4	65%	53%

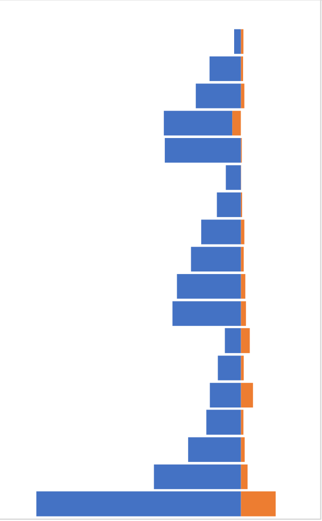
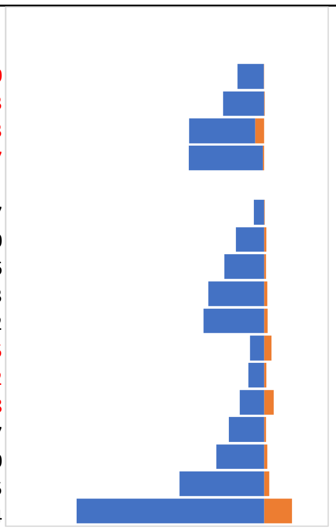
Apartment



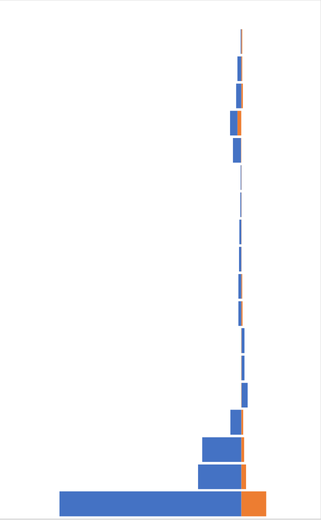
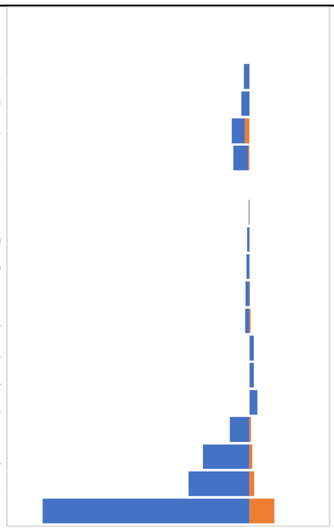
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 1 - Auckland	Base	Code min	-	-	-	-					79%	77%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -1	0.00	$ -7,287			1302	0.0	79%	77%
		R2.5 (140mm)	$ 68,520	$ -2	0.00	$ -68,490			1120	0.0	80%	78%
		R2.9	$ 72,031	$ 6	NA	NA			1817	0.0	80%	78%
		R4.0 (staggered	$ 132,373	$ 47	NA	NA			-3924	NA	80%	79%
		R4.6	$ 162,805	$ 70	NA	NA			406	NA	79%	79%
	Roof	R3.3 (Z3 min)	$ 207	$ -35	3.39	$ 494			-382	6.8	79%	77%
		R3.9	$ 703	$ -55	1.55	$ 384			-558	5.1	79%	77%
		R4.3	$ 620	$ -86	2.78	$ 1,101			-843	4.3	79%	77%
		R5.3	$ 3,307	$ -105	0.63	$ -1,216			-762	2.3	79%	77%
		R6.3	$ 4,428	$ -128	0.57	$ -1,888			-611	1.6	79%	77%
		R7.3	$ 5,548	$ -134	0.48	$ -2,889			-63	1.0	79%	77%
	Floor	R2.0	$ 1,090	$ 338	NA	NA			4479	23.1	79%	77%
		R2.0	$ 1,090	$ 338	NA	NA			4479	23.1	79%	77%
		R2.7	$ 1,201	$ 634	NA	NA			8303	34.3	79%	78%
	Glazing	R0.31 (thermall	$ 37,613	$ 256	NA	NA			5529	1.4	79%	78%
		R0.31 (low-E)	$ 40,300	$ -3,430	1.36	$ 18,025			-40054	12.2	81%	80%
		R0.39 (therm.br	$ 77,913	$ -2,168	0.49	$ -44,707			-21735	4.7	80%	76%
		R0.62 (triple gla	$ 206,336	$ -17,606	1.41	$ 102,503			-192834	7.2	90%	79%
Zone 2 - Napier	Base	Code min	-	-	-	-					71%	61%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -48	0.13	$ -6,357			755	0.4	72%	61%
		R2.5 (140mm)	$ 67,718	$ -293	0.09	$ -61,894			-2293	3.0	72%	61%
		R2.9	$ 71,228	$ -403	0.11	$ -63,204			-2991	2.7	73%	62%
		R4.0 (staggered	$ 124,664	$ -612	0.10	$ -112,489			-11703	NA	73%	62%
		R4.6	$ 160,448	$ -679	0.08	$ -146,923			-8455	NA	74%	62%
	Roof	R3.3 (Z3 min)	$ 124	$ -58	9.38	$ 1,039			-620	10.5	71%	61%
		R3.9	$ 579	$ -123	4.22	$ 1,863			-1303	10.6	71%	61%
		R4.3	$ 496	$ -201	8.07	$ 3,509			-2104	9.2	71%	61%
		R5.3	$ 3,886	$ -246	1.26	$ 1,020			-2318	5.0	71%	61%
		R6.3	$ 5,007	$ -309	1.23	$ 1,144			-2614	3.6	71%	61%
		R7.3	$ 6,127	$ -328	1.07	$ 408			-2216	2.4	71%	61%
	Floor	R2.0	$ 914	$ 450	NA	NA			5461	28.4	71%	62%
		R2.0	$ 914	$ 450	NA	NA			5461	28.4	71%	62%
		R2.7	$ 1,174	$ 824	NA	NA			9909	41.1	71%	62%
	Glazing	R0.31 (thermall	$ 37,613	$ -737	0.39	$ -22,948			-6372	3.8	74%	62%
		R0.31 (low-E)	$ 40,300	$ -4,562	1.81	$ 40,562			-49966	15.0	74%	63%
		R0.39 (therm.br	$ 77,913	$ -4,379	0.99	$ -686			-45551	8.8	78%	65%
		R0.62 (triple gla	$ 206,336	$ -22,276	1.79	$ 195,455			-230314	8.4	88%	76%

net_carbon_static3 - Sheet: Building_level - Page 5

Medium Density

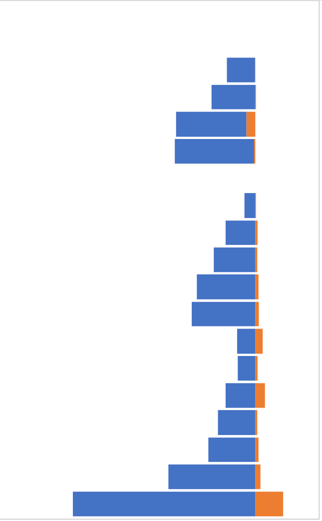
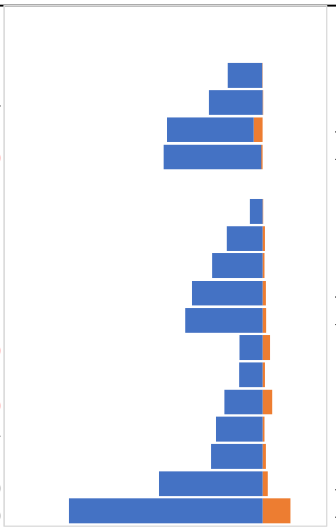
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					59%	39%
	Wall	R2.0 (Z3 min)	$ 1,866	$ -66	0.70	$ -552			-474	2.4	59%	39%
		R2.5 (140mm)	$ 19,097	$ -318	0.33	$ -12,761			-3613	13.4	60%	41%
		R2.9	$ 21,509	$ -457	0.42	$ -12,405			-5147	12.1	61%	43%
		R4.0 (staggered	$ 36,175	$ -695	0.38	$ -22,336			-9606	NA	62%	46%
		R4.6	$ 46,268	$ -774	0.33	$ -30,854			-9341	58.7	63%	47%
	Roof	R3.3 (Z3 min)	$ 399	$ -153	7.64	$ 2,648			-1816	30.4	59%	40%
		R3.6	$ 326	$ -243	14.84	$ 4,516			-2818	17.8	59%	40%
		R4.3	$ 3,337	$ -404	2.41	$ 4,713			-4517	11.1	59%	41%
		R4.9	$ 4,047	$ -508	2.50	$ 6,057			-5861	17.0	60%	42%
		R5.9	$ 4,675	$ -651	2.77	$ 8,293			-7431	14.2	60%	43%
		R6.6	$ 4,789	$ -696	2.89	$ 9,067			-7918	13.7	60%	44%
	Floor	R1.9 (underslab	$ 6,232	$ -164	0.52	$ -2,967			-865	1.8	59%	39%
		R2.0 (edge)	$ 5,530	$ -235	0.84	$ -858			-2510	7.8	60%	39%
		R2.7 (full ins.)	$ 11,703	$ -314	0.53	$ -5,457			-2342	2.6	60%	40%
	Glazing	R0.31 (thermall	$ 5,259	$ -351	1.33	$ 1,734			-3993	13.6	61%	41%
		R0.31 (low-E)	$ 5,635	$ -536	1.52	$ 3,635			-6074	13.2	59%	40%
		R0.39 (therm.br	$ 10,894	$ -884	1.43	$ 5,317			-10036	13.3	61%	43%
		R0.62 (triple gla	$ 28,851	$ -2,084	1.20	$ 6,820			-21238	5.9	55%	42%
Zone 4 - Turangi	Base	Code min	-	-	-	-					51%	30%
	Wall	R2.0 (Z3 min)	-	-	-	-					52%	30%
		R2.5 (140mm)	$ 17,391	$ -355	0.41	$ -10,330			-4147	NA	53%	33%
		R2.9	$ 19,721	$ -552	0.56	$ -8,733			-6256	49.3	53%	34%
		R4.0 (staggered	$ 32,987	$ -887	0.54	$ -15,323			-11674	NA	54%	36%
		R4.6	$ 43,943	$ -1,001	0.45	$ -24,017			-11754	NA	55%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					52%	31%
		R3.6	$ (73)	$ -135	NA	$ 2,767			-1460	14.8	52%	32%
		R4.3	$ 3,264	$ -379	2.31	$ 4,290			-4006	11.4	52%	32%
		R4.9	$ 3,612	$ -534	2.94	$ 7,016			-5871	20.2	52%	33%
		R5.9	$ 4,276	$ -748	3.48	$ 10,623			-8156	17.3	52%	34%
		R6.6	$ 4,238	$ -815	3.83	$ 11,982			-8863	16.8	52%	34%
	Floor	R1.9 (underslab	$ 6,813	$ -187	0.55	$ -3,095			-1013	1.9	52%	31%
		R2.0 (edge)	$ 5,559	$ -208	0.74	$ -1,422			-2034	6.5	52%	30%
		R2.7 (full ins.)	$ 12,351	$ -327	0.53	$ -5,848			-2271	2.5	52%	31%
	Glazing	R0.31 (thermall	$ 5,259	$ -476	1.80	$ 4,207			-5183	17.3	53%	32%
		R0.31 (low-E)	$ 5,635	$ -643	1.82	$ 5,770			-6939	14.9	51%	31%
		R0.39 (therm.br	$ 10,894	$ -1,139	1.85	$ 10,395			-12365	16.2	53%	34%
		R0.62 (triple gla	$ 28,851	$ -2,525	1.45	$ 15,584			-24864	6.7	49%	33%

Apartment

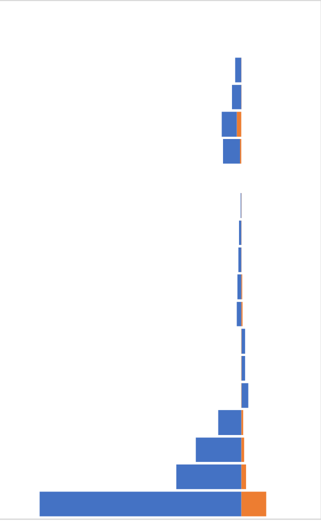
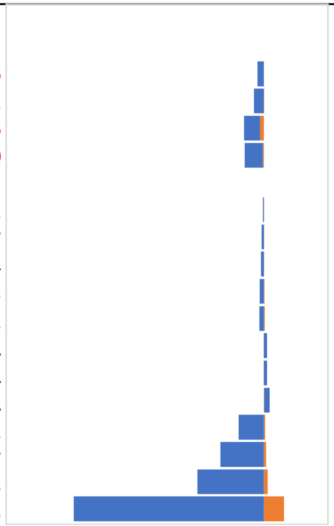
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 3 - Wellington	Base	Code min	-	-	-	-					69%	61%
	Wall	R2.0 (Z3 min)	$ 7,307	$ -83	0.23	$ -5,647			292	0.8	69%	61%
		R2.5 (140mm)	$ 73,570	$ -373	0.10	$ -66,143			-3440	4.0	70%	61%
		R2.9	$ 77,081	$ -522	0.13	$ -66,695			-4664	3.7	71%	62%
		R4.0 (staggered	$ 126,788	$ -770	0.12	$ -111,457			-13978	NA	72%	62%
		R4.6	$ 162,571	$ -834	0.10	$ -145,973			-10716	NA	72%	62%
	Roof	R3.3 (Z3 min)	$ 124	$ -72	11.62	$ 1,317			-823	13.6	69%	61%
		R3.9	$ 579	$ -112	3.84	$ 1,643			-1234	10.1	69%	61%
		R4.3	$ 496	$ -186	7.45	$ 3,198			-2021	8.9	69%	61%
		R5.3	$ 3,927	$ -227	1.15	$ 591			-2212	4.9	69%	61%
		R6.3	$ 5,048	$ -281	1.11	$ 550			-2439	3.4	69%	61%
		R7.3	$ 6,168	$ -298	0.96	$ -227			-2027	2.2	69%	61%
	Floor	R2.0	$ 969	$ 331	NA	NA			4248	21.9	69%	61%
		R2.0	$ 969	$ 331	NA	NA			4248	21.9	69%	61%
		R2.7	$ 1,117	$ 626	NA	NA			7922	32.6	69%	62%
	Glazing	R0.31 (thermall	$ 37,613	$ -1,122	0.59	$ -15,274			-11500	6.1	73%	63%
		R0.31 (low-E)	$ 40,300	$ -3,960	1.57	$ 28,573			-45032	13.6	73%	63%
		R0.39 (therm.br	$ 77,913	$ -4,389	0.99	$ -490			-48030	9.2	79%	66%
		R0.62 (triple gla	$ 206,336	$ -18,507	1.49	$ 120,441			-196066	7.3	90%	79%
Zone 4 - Turangi	Base	Code min	-	-	-	-					62%	56%
	Wall	R2.0 (Z3 min)	-	-	-	-					62%	56%
		R2.5 (140mm)	$ 66,578	$ -562	0.17	$ -55,388			-6679	NA	63%	57%
		R2.9	$ 70,089	$ -871	0.25	$ -52,750			-9652	23.8	63%	57%
		R4.0 (staggered	$ 114,565	$ -1,376	0.24	$ -87,164			-21765	NA	64%	57%
		R4.6	$ 153,358	$ -1,552	0.20	$ -122,468			-19750	NA	65%	58%
	Roof	R3.3 (Z3 min)	-	-	-	-					62%	56%
		R3.9	$ 496	$ -68	2.71	$ 849			-711	11.1	62%	56%
		R4.3	$ 413	$ -218	10.51	$ 3,930			-2333	13.2	62%	56%
		R5.3	$ 4,217	$ -302	1.42	$ 1,790			-2982	6.9	62%	56%
		R6.3	$ 5,337	$ -418	1.56	$ 2,981			-3888	5.1	62%	56%
		R7.3	$ 6,458	$ -453	1.40	$ 2,564			-3673	3.3	62%	56%
	Floor	R2.0	$ 735	$ 466	NA	NA			5572	29.0	62%	56%
		R2.0	$ 735	$ 466	NA	NA			5572	29.0	62%	56%
		R2.7	$ 1,182	$ 859	NA	NA			10176	42.2	62%	56%
	Glazing	R0.31 (thermall	$ 37,613	$ -2,116	1.12	$ 4,503			-22203	10.8	66%	58%
		R0.31 (low-E)	$ 40,300	$ -4,989	1.98	$ 49,054			-54148	16.2	65%	58%
		R0.39 (therm.br	$ 77,913	$ -6,548	1.48	$ 42,488			-69918	13.0	70%	61%
		R0.62 (triple gla	$ 206,336	$ -22,304	1.79	$ 196,009			-226960	8.3	77%	67%

net_carbon_static3 - Sheet: Building_level - Page 6

Medium Density

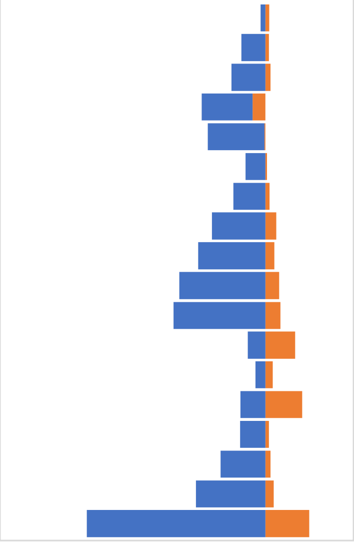
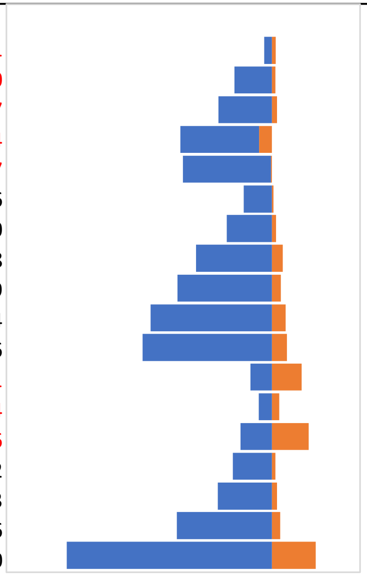
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					48%	31%
		R2.0 (Z3 min)	-	-	-	-					48%	31%
	Wall	R2.5 (140mm)	$ 13,217	$ -337	0.51	$ -6,507			-4442	NA	48%	33%
		R2.9	$ 15,391	$ -525	0.68	$ -4,943			-6720	52.9	49%	34%
		R4.0 (staggered	$ 36,068	$ -842	0.46	$ -19,302			-12401	NA	50%	36%
		R4.6	$ 44,895	$ -949	0.42	$ -26,002			-12560	NA	50%	37%
	Roof	R3.3 (Z3 min)	-	-	-	-					48%	32%
		R3.6	$ (73)	$ -128	NA	$ 2,614			-1560	15.7	48%	32%
		R4.3	$ 2,430	$ -355	2.90	$ 4,627			-4242	12.0	48%	34%
		R4.9	$ 3,953	$ -498	2.51	$ 5,955			-6190	21.3	48%	34%
		R5.9	$ 4,696	$ -698	2.96	$ 9,208			-8613	18.2	48%	35%
		R6.6	$ 4,848	$ -762	3.13	$ 10,323			-9383	17.7	48%	35%
	Floor	R1.9 (underslab	$ 7,754	$ -217	0.56	$ -3,426			-1689	2.5	48%	32%
		R2.0 (edge)	$ 5,457	$ -211	0.77	$ -1,264			-2379	7.4	48%	31%
		R2.7 (full ins.)	$ 13,146	$ -354	0.54	$ -6,092			-3116	3.1	48%	32%
	Glazing	R0.31 (thermall	$ 5,259	$ -446	1.69	$ 3,624			-5506	18.3	49%	33%
		R0.31 (low-E)	$ 5,635	$ -562	1.59	$ 4,156			-6833	14.7	48%	32%
		R0.39 (therm.br	$ 10,894	$ -1,040	1.68	$ 8,409			-12751	16.6	49%	34%
		R0.62 (triple gla	$ 28,851	$ -2,186	1.25	$ 8,841			-24184	6.6	45%	34%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					41%	25%
		R2.0 (Z3 min)	-	-	-	-					42%	25%
	Wall	R2.5 (140mm)	$ 13,517	$ -521	0.77	$ -3,152			-5431	NA	42%	27%
		R2.9	$ 15,649	$ -811	1.03	$ 504			-8267	64.8	43%	29%
		R4.0 (staggered	$ 31,579	$ -1,301	0.82	$ -5,683			-14872	NA	44%	30%
		R4.6	$ 40,394	$ -1,470	0.72	$ -11,130			-15386	NA	44%	31%
	Roof	R3.3 (Z3 min)	-	-	-	-					42%	26%
		R3.6	$ (73)	$ -193	NA	$ 3,911			-1889	18.8	42%	26%
		R4.3	$ 2,430	$ -539	4.42	$ 8,309			-5198	14.5	42%	27%
		R4.9	$ 3,419	$ -757	4.41	$ 11,643			-7524	25.6	42%	28%
		R5.9	$ 4,161	$ -1,067	5.10	$ 17,073			-10536	22.0	42%	29%
		R6.6	$ 4,314	$ -1,164	5.37	$ 18,849			-11479	21.4	42%	29%
	Floor	R1.9 (underslab	$ 7,379	$ -348	0.94	$ -460			-2449	3.1	42%	26%
		R2.0 (edge)	$ 5,462	$ -353	1.29	$ 1,571			-3286	9.9	42%	25%
		R2.7 (full ins.)	$ 12,750	$ -573	0.89	$ -1,340			-4423	3.9	42%	26%
	Glazing	R0.31 (thermall	$ 5,259	$ -702	2.66	$ 8,714			-6946	22.9	42%	27%
		R0.31 (low-E)	$ 5,635	$ -777	2.20	$ 8,433			-7539	16.1	41%	26%
		R0.39 (therm.br	$ 10,894	$ -1,556	2.52	$ 18,690			-15286	19.7	43%	28%
		R0.62 (triple gla	$ 28,851	$ -2,913	1.67	$ 23,310			-25800	6.9	38%	27%

Apartment

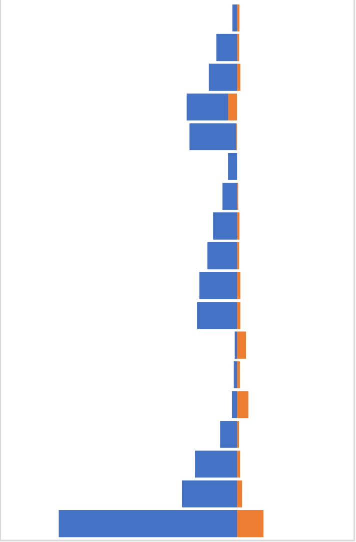
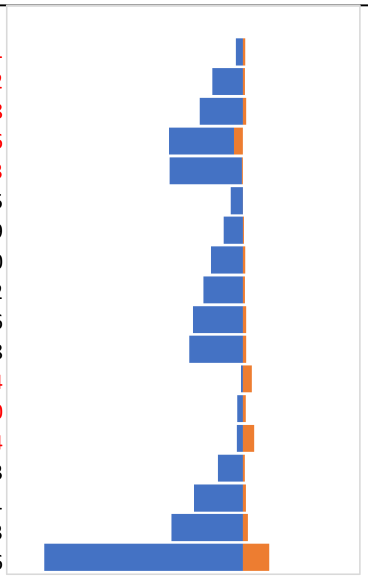
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort	
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room	M. Bed
Zone 5 - Christchurch	Base	Code min	-	-	-	-					59%	54%
		R2.0 (Z3 min)	-	-	-	-					59%	54%
	Wall	R2.5 (140mm)	$ 50,542	$ -576	0.23	$ -39,084			-7687	NA	59%	55%
		R2.9	$ 54,053	$ -882	0.32	$ -36,494			-11087	27.2	60%	55%
		R4.0 (staggered	$ 128,410	$ -1,420	0.22	$ -100,139			-24375	NA	60%	56%
		R4.6	$ 159,846	$ -1,605	0.20	$ -127,903			-22739	NA	60%	56%
	Roof	R3.3 (Z3 min)	-	-	-	-					59%	54%
		R3.9	$ 455	$ -75	3.26	$ 1,030			-903	13.8	59%	54%
		R4.3	$ 372	$ -203	10.84	$ 3,662			-2454	13.8	59%	54%
		R5.3	$ 3,225	$ -280	1.73	$ 2,354			-3149	7.2	59%	54%
		R6.3	$ 4,345	$ -387	1.77	$ 3,353			-4101	5.3	59%	54%
		R7.3	$ 5,465	$ -418	1.52	$ 2,863			-3890	3.5	59%	54%
	Floor	R2.0	$ 1,082	$ 357	NA	NA			4844	25.1	59%	53%
		R2.0	$ 1,082	$ 357	NA	NA			4844	25.1	59%	53%
		R2.7	$ 1,268	$ 647	NA	NA			8683	35.9	59%	53%
	Glazing	R0.31 (thermall	$ 37,613	$ -2,203	1.17	$ 6,237			-26474	12.7	61%	57%
		R0.31 (low-E)	$ 40,300	$ -4,345	1.72	$ 36,243			-53141	15.9	60%	57%
		R0.39 (therm.br	$ 77,913	$ -6,199	1.40	$ 35,527			-75058	13.9	65%	59%
		R0.62 (triple gla	$ 206,336	$ -19,287	1.55	$ 135,963			-220644	8.1	69%	63%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					55%	48%
		R2.0 (Z3 min)	-	-	-	-					55%	48%
	Wall	R2.5 (140mm)	$ 51,657	$ -977	0.38	$ -32,216			-10282	NA	55%	49%
		R2.9	$ 55,168	$ -1,516	0.55	$ -24,991			-15263	37.0	55%	49%
		R4.0 (staggered	$ 110,769	$ -2,429	0.44	$ -62,416			-30977	NA	56%	50%
		R4.6	$ 142,205	$ -2,744	0.38	$ -87,590			-30189	NA	56%	50%
	Roof	R3.3 (Z3 min)	-	-	-	-					55%	48%
		R3.9	$ 455	$ -117	5.14	$ 1,882			-1144	17.2	55%	48%
		R4.3	$ 372	$ -325	17.41	$ 6,107			-3177	17.6	55%	48%
		R5.3	$ 3,225	$ -452	2.79	$ 5,764			-4164	9.2	55%	48%
		R6.3	$ 4,345	$ -624	2.86	$ 8,083			-5515	6.8	55%	48%
		R7.3	$ 5,465	$ -676	2.46	$ 8,001			-5430	4.5	55%	48%
	Floor	R2.0	$ 1,263	$ 468	NA	NA			5031	26.1	54%	47%
		R2.0	$ 1,263	$ 468	NA	NA			5031	26.1	54%	47%
		R2.7	$ 1,263	$ 854	NA	NA			9070	37.5	54%	47%
	Glazing	R0.31 (thermall	$ 37,613	$ -3,804	2.01	$ 38,121			-37098	17.3	56%	52%
		R0.31 (low-E)	$ 40,300	$ -6,585	2.61	$ 80,837			-64583	19.1	56%	51%
		R0.39 (therm.br	$ 77,913	$ -10,018	2.27	$ 111,565			-97837	17.8	59%	55%
		R0.62 (triple gla	$ 206,336	$ -28,744	2.31	$ 324,215			-266393	9.6	63%	59%

net_carbon_static3 - Sheet: per_sqm - Page 1

Single Storey

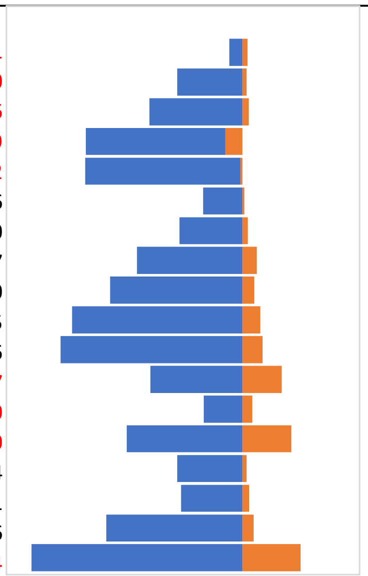
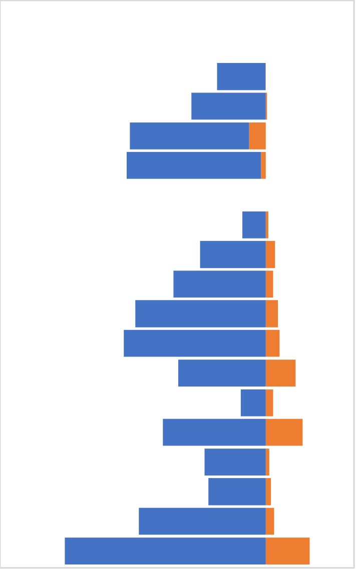
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 1 - Auckland	Base	Code min	-	-	-	-					73%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.37	$ -2			0	1.3	73%
		R2.5 (140mm)	$ 30	$ -0.3	0.194	$ -24			-3	7.5	74%
		R2.9	$ 31	$ -0.4	0.26	$ -23			-4	6.9	75%
		R4.0 (staggered	$ 57	$ -0.6	0.211	$ -45			-10	NA	75%
		R4.6	$ 70	$ -0.7	0.19	$ -57			-9	NA	76%
	Roof	R3.3 (Z3 min)	$ 2	$ -0.2	3.013	$ 3			-3	13.6	74%
		R3.6	$ 1	$ -0.4	5.828	$ 6			-4	8.0	75%
		R4.3	$ 10	$ -0.6	1.292	$ 3			-7	5.0	76%
		R4.9	$ 16	$ -0.8	1.016	$ 0			-9	7.7	76%
		R5.9	$ 18	$ -1.0	1.107	$ 2			-11	6.4	77%
		R6.6	$ 19	$ -1.1	1.138	$ 3			-12	6.2	78%
	Floor	R1.9 (underslab	$ 25	$ -0.2	0.166	$ -21			2	0.6	74%
		R2.0 (edge)	$ 17	$ -0.1	0.139	$ -15			0	1.4	74%
		R2.7 (full ins.)	$ 42	$ -0.3	0.14	$ -36			2	0.7	75%
	Glazing	R0.31 (thermall	$ 8	$ -0.3	0.76	$ -2			-3	8.0	75%
		R0.31 (low-E)	$ 9	$ -0.5	1	$ -0			-6	9.0	74%
		R0.39 (therm.bı	$ 17	$ -0.8	0.885	$ -2			-9	8.5	76%
		R0.62 (triple gla	$ 44	$ -2.1	0.804	$ -10			-20	4.1	75%
Zone 2 - Napier	Base	Code min	-	-	-	-					65%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.641	$ -1			-1	2.1	65%
		R2.5 (140mm)	$ 29	$ -0.5	0.33	$ -20			-5	11.6	66%
		R2.9	$ 31	$ -0.7	0.448	$ -17			-7	10.8	66%
		R4.0 (staggered	$ 54	$ -1.0	0.375	$ -34			-14	NA	67%
		R4.6	$ 69	$ -1.1	0.325	$ -47			-13	NA	68%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.4	5.048	$ 6			-4	19.2	66%
		R3.6	$ 1	$ -0.6	9.876	$ 10			-6	11.3	66%
		R4.3	$ 12	$ -1.0	1.632	$ 8			-10	7.1	67%
		R4.9	$ 15	$ -1.2	1.628	$ 9			-13	10.8	68%
		R5.9	$ 17	$ -1.6	1.814	$ 14			-16	9.0	69%
		R6.6	$ 18	$ -1.7	1.892	$ 16			-17	8.7	69%
	Floor	R1.9 (underslab	$ 27	$ -0.3	0.207	$ -21			1	0.7	65%
		R2.0 (edge)	$ 17	$ -0.2	0.2	$ -14			-1	1.8	66%
		R2.7 (full ins.)	$ 44	$ -0.4	0.184	$ -36			1	0.9	65%
	Glazing	R0.31 (thermall	$ 8	$ -0.5	1.258	$ 2			-5	12.3	66%
		R0.31 (low-E)	$ 9	$ -0.7	1.302	$ 3			-7	10.8	66%
		R0.39 (therm.bı	$ 17	$ -1.2	1.311	$ 6			-13	11.6	67%
		R0.62 (triple gla	$ 44	$ -2.7	1	$ 0			-24	4.7	65%

Two Storey

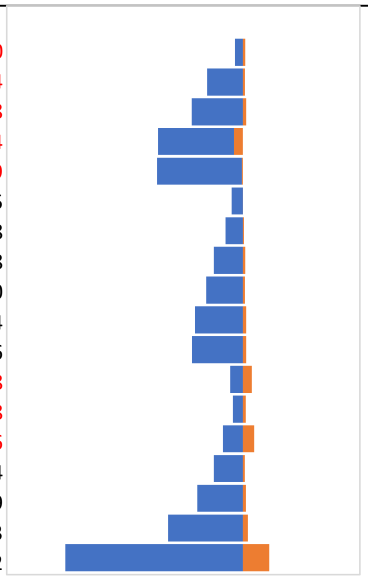
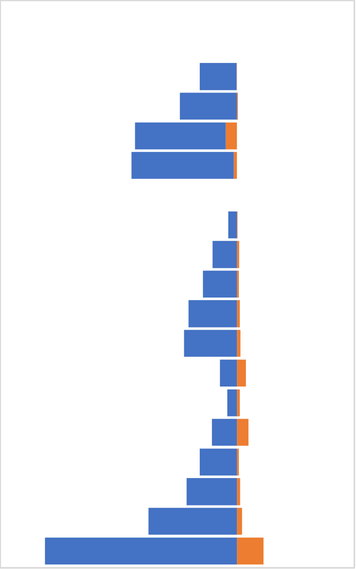
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 1 - Auckland	Base	Code min	-	-	-	-					68%
	Wall	R2.0 (Z3 min)	$ 4	$ -0.1	0.503	$ -2			-1	1.8	69%
		R2.5 (140mm)	$ 38	$ -0.5	0.243	$ -28			-5	9.3	70%
		R2.9	$ 39	$ -0.6	0.325	$ -27			-7	8.6	71%
		R4.0 (staggered	$ 73	$ -0.9	0.258	$ -54			-14	NA	73%
		R4.6	$ 89	$ -1.0	0.234	$ -68			-14	NA	73%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.2	5.468	$ 3			-2	24.6	68%
		R3.6	$ 1	$ -0.3	10.54	$ 6			-4	14.6	68%
		R4.3	$ 5	$ -0.5	2.336	$ 6			-6	9.1	69%
		R4.9	$ 7	$ -0.7	1.803	$ 6			-8	13.7	69%
		R5.9	$ 9	$ -0.8	1.963	$ 8			-10	11.3	69%
		R6.6	$ 9	$ -0.9	2.014	$ 9			-10	10.9	69%
	Floor	R1.9 (underslab	$ 14	$ -0.1	0.073	$ -13			2	0.3	69%
		R2.0 (edge)	$ 12	$ -0.1	0.125	$ -11			0	1.2	69%
		R2.7 (full ins.)	$ 26	$ -0.1	0.09	$ -24			2	0.5	69%
	Glazing	R0.31 (thermall	$ 9	$ -0.4	0.805	$ -2			-4	8.5	70%
		R0.31 (low-E)	$ 10	$ -1.0	1.533	$ 7			-11	13.8	69%
		R0.39 (therm.bı	$ 19	$ -1.2	1.145	$ 3			-14	11.0	71%
		R0.62 (triple gla	$ 51	$ -4.0	1.316	$ 19			-44	6.7	68%
Zone 2 - Napier	Base	Code min	-	-	-	-					62%
	Wall	R2.0 (Z3 min)	$ 4	$ -0.2	0.859	$ -1			-1	2.8	62%
		R2.5 (140mm)	$ 37	$ -0.7	0.401	$ -22			-8	14.0	63%
		R2.9	$ 39	$ -1.1	0.542	$ -18			-12	13.1	63%
		R4.0 (staggered	$ 68	$ -1.6	0.467	$ -36			-21	NA	65%
		R4.6	$ 88	$ -1.8	0.402	$ -53			-21	NA	65%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.3	8.752	$ 5			-3	33.3	62%
		R3.6	$ 1	$ -0.5	17.08	$ 9			-5	19.6	62%
		R4.3	$ 6	$ -0.8	2.771	$ 10			-8	12.1	62%
		R4.9	$ 7	$ -1.0	2.761	$ 12			-11	18.3	62%
		R5.9	$ 8	$ -1.2	3.034	$ 16			-13	15.1	63%
		R6.6	$ 8	$ -1.3	3.182	$ 18			-14	14.6	63%
	Floor	R1.9 (underslab	$ 15	$ -0.0	0.054	$ -14			2	0.2	61%
		R2.0 (edge)	$ 12	$ -0.1	0.219	$ -10			-1	1.9	62%
		R2.7 (full ins.)	$ 27	$ -0.1	0.109	$ -24			2	0.5	62%
	Glazing	R0.31 (thermall	$ 9	$ -0.6	1.317	$ 3			-7	12.9	63%
		R0.31 (low-E)	$ 10	$ -1.2	1.926	$ 11			-13	16.0	62%
		R0.39 (therm.bı	$ 19	$ -1.7	1.613	$ 13			-19	14.3	63%
		R0.62 (triple gla	$ 51	$ -4.9	1.592	$ 36			-50	7.5	61%

net_carbon_static3 - Sheet: per_sqm - Page 2

Single Storey

			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 3 - Wellington	Base	Code min	-	-	-	-					55%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.768	$ -1			-1	2.6	55%
		R2.5 (140mm)	$ 32	$ -0.6	0.378	$ -20			-7	15.1	56%
		R2.9	$ 33	$ -0.9	0.514	$ -16			-10	14.1	56%
		R4.0 (staggered	$ 55	$ -1.3	0.468	$ -29			-18	NA	57%
		R4.6	$ 70	$ -1.4	0.407	$ -42			-18	NA	58%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.4	5.027	$ 6			-4	20.0	56%
		R3.6	$ 1	$ -0.6	9.843	$ 10			-7	11.8	56%
		R4.3	$ 12	$ -1.0	1.609	$ 7			-10	7.4	57%
		R4.9	$ 15	$ -1.2	1.666	$ 10			-14	11.3	58%
		R5.9	$ 17	$ -1.6	1.857	$ 15			-17	9.5	58%
		R6.6	$ 17	$ -1.7	1.937	$ 16			-18	9.2	59%
	Floor	R1.9 (underslab	$ 24	$ -0.9	0.702	$ -7			-6	2.3	57%
		R2.0 (edge)	$ 17	$ -0.4	0.428	$ -10			-3	4.0	56%
		R2.7 (full ins.)	$ 41	$ -1.1	0.521	$ -20			-8	2.4	57%
	Glazing	R0.31 (thermall	$ 8	$ -0.6	1.505	$ 4			-7	15.4	56%
		R0.31 (low-E)	$ 9	$ -0.6	1.06	$ 1			-6	9.2	55%
		R0.39 (therm.bı	$ 17	$ -1.3	1.344	$ 6			-14	12.5	57%
		R0.62 (triple gla	$ 44	$ -2.0	0.739	$ -14			-17	3.6	53%
Zone 4 - Turangi	Base	Code min	-	-	-	-					50%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	50%
		R2.5 (140mm)	$ 29	$ -0.6	0.436	$ -16			-7	NA	50%
		R2.9	$ 30	$ -1.0	0.64	$ -11			-11	61.5	51%
		R4.0 (staggered	$ 50	$ -1.6	0.626	$ -19			-21	NA	51%
		R4.6	$ 66	$ -1.8	0.526	$ -31			-21	NA	52%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	50%
		R3.6	$ (0)	$ -0.3	NA	$ 6			-3	9.3	51%
		R4.3	$ 12	$ -0.9	1.45	$ 5			-9	7.2	51%
		R4.9	$ 13	$ -1.2	1.844	$ 11			-13	12.7	52%
		R5.9	$ 15	$ -1.7	2.193	$ 18			-18	10.9	52%
		R6.6	$ 15	$ -1.9	2.412	$ 22			-19	10.6	52%
	Floor	R1.9 (underslab	$ 27	$ -1.1	0.861	$ -4			-9	3.0	51%
		R2.0 (edge)	$ 17	$ -0.3	0.384	$ -10			-3	3.4	50%
		R2.7 (full ins.)	$ 43	$ -1.3	0.616	$ -17			-10	2.8	52%
	Glazing	R0.31 (thermall	$ 8	$ -0.8	1.99	$ 8			-9	19.1	51%
		R0.31 (low-E)	$ 9	$ -0.8	1.4	$ 4			-8	11.5	50%
		R0.39 (therm.bı	$ 17	$ -1.7	1.77	$ 14			-18	15.5	51%
		R0.62 (triple gla	$ 44	$ -2.6	0.993	$ -0			-24	4.6	46%

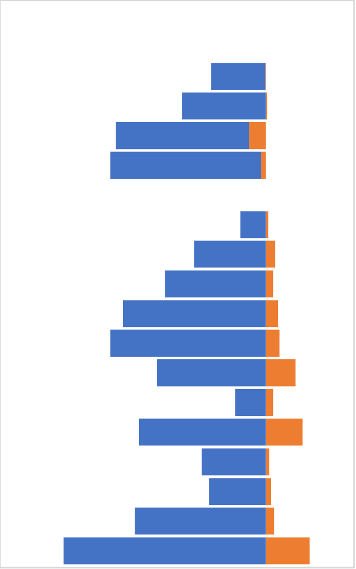
Two Storey

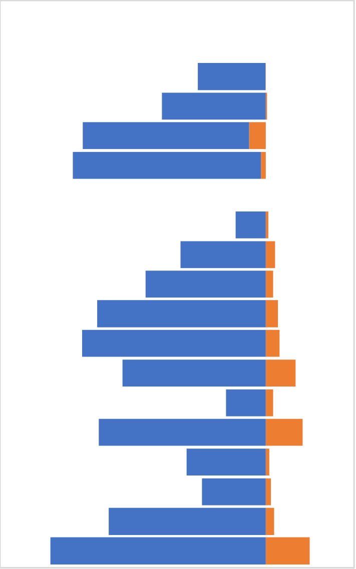
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 3 - Wellington	Base	Code min	-	-	-	-					53%
	Wall	R2.0 (Z3 min)	$ 4	$ -0.2	0.901	$ -0			-2	3.1	53%
		R2.5 (140mm)	$ 40	$ -0.8	0.412	$ -24			-10	16.4	54%
		R2.9	$ 42	$ -1.2	0.566	$ -18			-14	15.5	55%
		R4.0 (staggered	$ 69	$ -1.8	0.512	$ -34			-24	NA	56%
		R4.6	$ 89	$ -2.0	0.445	$ -49			-25	NA	56%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.3	7.72	$ 5			-3	30.7	53%
		R3.6	$ 1	$ -0.4	14.81	$ 8			-5	17.8	53%
		R4.3	$ 6	$ -0.7	2.422	$ 8			-8	11.2	53%
		R4.9	$ 7	$ -0.9	2.505	$ 10			-10	17.0	54%
		R5.9	$ 8	$ -1.1	2.811	$ 14			-13	14.4	54%
		R6.6	$ 8	$ -1.2	2.931	$ 16			-14	13.9	54%
	Floor	R1.9 (underslab	$ 14	$ -0.3	0.425	$ -8			-1	1.4	55%
		R2.0 (edge)	$ 12	$ -0.2	0.378	$ -8			-2	3.4	54%
		R2.7 (full ins.)	$ 25	$ -0.5	0.366	$ -16			-2	1.7	56%
	Glazing	R0.31 (thermall	$ 9	$ -0.7	1.47	$ 4			-8	15.0	54%
		R0.31 (low-E)	$ 10	$ -1.1	1.725	$ 9			-12	15.0	53%
		R0.39 (therm.bı	$ 19	$ -1.7	1.612	$ 13			-20	15.0	54%
		R0.62 (triple gla	$ 51	$ -4.2	1.36	$ 22			-43	6.7	48%
Zone 4 - Turangi	Base	Code min	-	-	-	-					48%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	49%
		R2.5 (140mm)	$ 36	$ -0.9	0.498	$ -18			-11	NA	49%
		R2.9	$ 38	$ -1.4	0.735	$ -10			-16	70.6	50%
		R4.0 (staggered	$ 63	$ -2.3	0.715	$ -18			-29	NA	51%
		R4.6	$ 84	$ -2.5	0.601	$ -34			-30	NA	51%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	48%
		R3.6	$ (0)	$ -0.2	NA	$ 4			-2	14.0	49%
		R4.3	$ 6	$ -0.6	2.193	$ 7			-6	10.8	49%
		R4.9	$ 6	$ -0.8	2.771	$ 11			-9	19.0	49%
		R5.9	$ 7	$ -1.2	3.323	$ 17			-13	16.5	49%
		R6.6	$ 7	$ -1.3	3.654	$ 19			-14	16.0	49%
	Floor	R1.9 (underslab	$ 15	$ -0.4	0.575	$ -6			-2	2.0	50%
		R2.0 (edge)	$ 12	$ -0.2	0.396	$ -7			-2	3.3	49%
		R2.7 (full ins.)	$ 27	$ -0.6	0.46	$ -14			-4	2.2	50%
	Glazing	R0.31 (thermall	$ 9	$ -0.9	1.984	$ 9			-10	19.1	49%
		R0.31 (low-E)	$ 10	$ -1.2	2.012	$ 12			-14	16.5	48%
		R0.39 (therm.bı	$ 19	$ -2.2	2.031	$ 22			-24	17.8	50%
		R0.62 (triple gla	$ 51	$ -4.8	1.556	$ 34			-47	7.2	44%

net_carbon_static3 - Sheet: per_sqm - Page 3

Single Storey

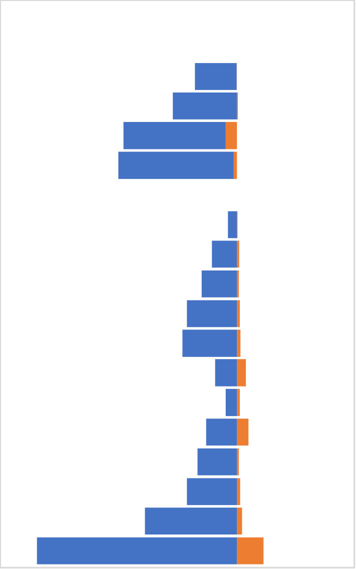
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 5 - Christchurch	Base	Code min	-	-	-	-					44%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	45%
		R2.5 (140mm)	$ 22	$ -0.6	0.573	$ -9			-8	NA	45%
		R2.9	$ 23	$ -1.0	0.826	$ -4			-12	69.1	45%
		R4.0 (staggered	$ 56	$ -1.5	0.555	$ -25			-23	NA	46%
		R4.6	$ 69	$ -1.7	0.502	$ -34			-24	NA	46%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	45%
		R3.6	$ (0)	$ -0.3	NA	$ 6			-4	10.1	45%
		R4.3	$ 9	$ -0.8	1.886	$ 8			-9	7.8	46%
		R4.9	$ 14	$ -1.2	1.631	$ 9			-14	13.8	46%
		R5.9	$ 17	$ -1.7	1.938	$ 16			-20	11.9	46%
		R6.6	$ 18	$ -1.8	2.047	$ 18			-22	11.6	46%
	Floor	R1.9 (underslab	$ 30	$ -1.3	0.833	$ -5			-12	3.7	46%
		R2.0 (edge)	$ 17	$ -0.4	0.428	$ -9			-4	4.2	45%
		R2.7 (full ins.)	$ 47	$ -1.5	0.627	$ -17			-14	3.5	46%
	Glazing	R0.31 (thermall	$ 8	$ -0.7	1.854	$ 7			-9	20.1	45%
		R0.31 (low-E)	$ 9	$ -0.7	1.224	$ 2			-8	11.3	44%
		R0.39 (therm.bı	$ 17	$ -1.5	1.621	$ 12			-19	16.0	45%
		R0.62 (triple gla	$ 44	$ -2.3	0.885	$ -6			-24	4.6	41%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					39%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	39%
		R2.5 (140mm)	$ 22	$ -1.0	0.882	$ -3			-10	NA	39%
		R2.9	$ 24	$ -1.5	1.268	$ 6			-16	85.8	39%
		R4.0 (staggered	$ 48	$ -2.4	1.01	$ 0			-28	NA	40%
		R4.6	$ 62	$ -2.7	0.889	$ -7			-29	NA	40%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	39%
		R3.6	$ (0)	$ -0.4	NA	$ 9			-4	12.0	39%
		R4.3	$ 9	$ -1.3	2.831	$ 16			-12	9.3	40%
		R4.9	$ 12	$ -1.8	2.83	$ 23			-17	16.5	40%
		R5.9	$ 15	$ -2.5	3.26	$ 34			-24	14.1	40%
		R6.6	$ 16	$ -2.7	3.426	$ 38			-26	13.7	40%
	Floor	R1.9 (underslab	$ 29	$ -2.1	1.461	$ 13			-17	4.9	40%
		R2.0 (edge)	$ 17	$ -0.6	0.701	$ -5			-5	5.5	39%
		R2.7 (full ins.)	$ 45	$ -2.4	1.076	$ 3			-20	4.5	40%
	Glazing	R0.31 (thermall	$ 8	$ -1.2	2.885	$ 15			-12	24.8	39%
		R0.31 (low-E)	$ 9	$ -0.9	1.745	$ 8			-9	12.8	38%
		R0.39 (therm.bı	$ 17	$ -2.3	2.448	$ 27			-23	19.2	39%
		R0.62 (triple gla	$ 44	$ -3.2	1.189	$ 10			-26	4.9	34%

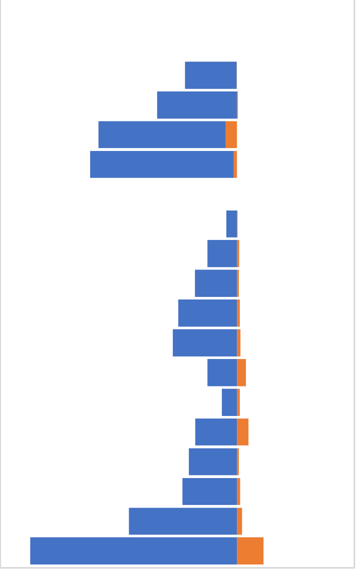




Two Storey

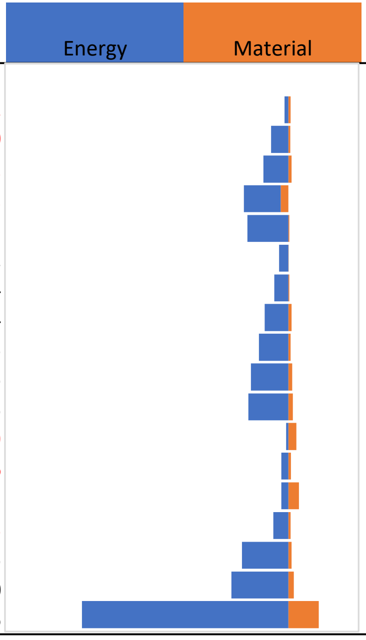
			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 5 - Christchurch	Base	Code min	-	-	-	-					43%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	43%
		R2.5 (140mm)	$ 28	$ -0.9	0.661	$ -9			-12	NA	44%
		R2.9	$ 30	$ -1.4	0.949	$ -2			-18	79.4	45%
		R4.0 (staggered	$ 70	$ -2.3	0.638	$ -25			-33	NA	46%
		R4.6	$ 88	$ -2.5	0.577	$ -37			-34	NA	46%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	43%
		R3.6	$ (0)	$ -0.2	NA	$ 4			-2	14.4	43%
		R4.3	$ 4	$ -0.6	2.689	$ 7			-7	11.2	43%
		R4.9	$ 7	$ -0.8	2.334	$ 9			-10	19.8	44%
		R5.9	$ 8	$ -1.1	2.771	$ 14			-14	17.0	44%
		R6.6	$ 8	$ -1.2	2.921	$ 16			-15	16.5	44%
	Floor	R1.9 (underslab	$ 17	$ -0.5	0.565	$ -7			-4	2.5	44%
		R2.0 (edge)	$ 12	$ -0.3	0.419	$ -7			-2	3.9	44%
		R2.7 (full ins.)	$ 29	$ -0.7	0.475	$ -15			-6	2.7	45%
	Glazing	R0.31 (thermall	$ 9	$ -0.9	1.867	$ 8			-11	20.3	44%
		R0.31 (low-E)	$ 10	$ -1.1	1.767	$ 9			-13	16.3	43%
		R0.39 (therm.bı	$ 19	$ -2.0	1.863	$ 19			-25	18.4	44%
		R0.62 (triple gla	$ 51	$ -4.4	1.438	$ 27			-50	7.5	39%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					37%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	37%
		R2.5 (140mm)	$ 28	$ -1.4	1.006	$ 0			-15	NA	38%
		R2.9	$ 30	$ -2.2	1.461	$ 14			-23	98.9	38%
		R4.0 (staggered	$ 61	$ -3.5	1.158	$ 10			-40	NA	39%
		R4.6	$ 78	$ -4.0	1.018	$ 1			-42	NA	40%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	37%
		R3.6	$ (0)	$ -0.3	NA	$ 6			-3	17.3	37%
		R4.3	$ 4	$ -0.8	4.006	$ 12			-8	13.2	37%
		R4.9	$ 6	$ -1.2	4.011	$ 17			-11	23.3	38%
		R5.9	$ 7	$ -1.6	4.624	$ 25			-16	19.9	38%
		R6.6	$ 7	$ -1.8	4.871	$ 28			-17	19.4	38%
	Floor	R1.9 (underslab	$ 16	$ -0.8	1.005	$ 0			-6	3.4	39%
		R2.0 (edge)	$ 12	$ -0.4	0.696	$ -4			-4	5.2	38%
		R2.7 (full ins.)	$ 28	$ -1.2	0.829	$ -5			-9	3.6	39%
	Glazing	R0.31 (thermall	$ 9	$ -1.3	2.884	$ 17			-13	24.8	38%
		R0.31 (low-E)	$ 10	$ -1.5	2.441	$ 18			-15	17.9	37%
		R0.39 (therm.bı	$ 19	$ -3.0	2.766	$ 38			-30	21.7	38%
		R0.62 (triple gla	$ 51	$ -5.7	1.876	$ 53			-52	7.8	32%

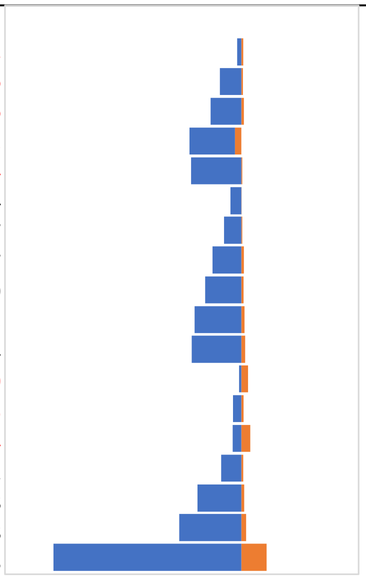




net_carbon_static3 - Sheet: per_sqm - Page 4

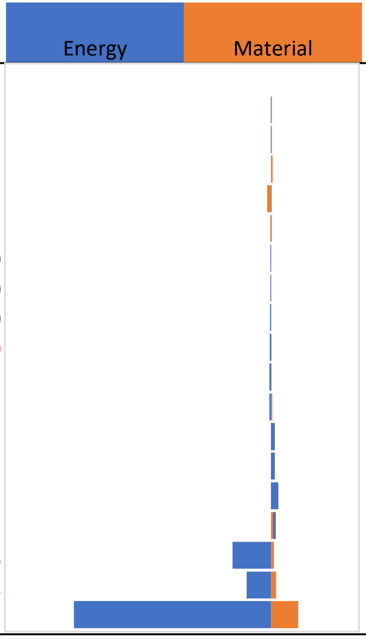
Medium Density

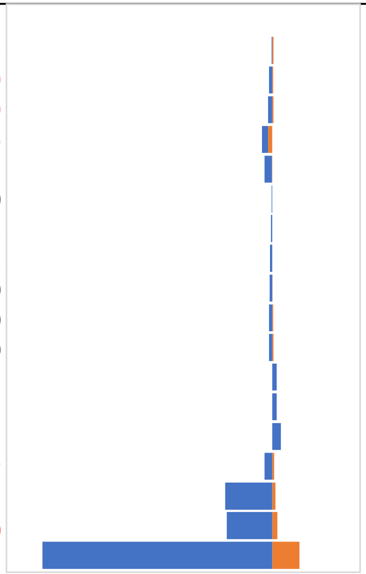




			Economics				Carbon (kg CO2 eq / 50yr)				Comfort
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 1 - Auckland	Base	Code min	-	-	-	-					75%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.444	$ -1			0	1.6	75%
		R2.5 (140mm)	$ 26	$ -0.3	0.216	$ -20			-3	8.4	76%
		R2.9	$ 29	$ -0.4	0.276	$ -21			-4	7.5	77%
		R4.0 (staggered	$ 54	$ -0.6	0.221	$ -42			-9	NA	78%
		R4.6	$ 66	$ -0.7	0.199	$ -53			-8	36.0	79%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.1	4.564	$ 2			-2	20.5	75%
		R3.6	$ 1	$ -0.2	8.637	$ 4			-3	11.9	75%
		R4.3	$ 4	$ -0.4	1.916	$ 4			-4	7.5	75%
		R4.9	$ 6	$ -0.5	1.496	$ 3			-5	11.3	75%
		R5.9	$ 7	$ -0.6	1.64	$ 5			-7	9.5	75%
		R6.6	$ 8	$ -0.6	1.681	$ 5			-7	9.1	75%
	Floor	R1.9 (underslab	$ 9	$ -0.0	0.068	$ -9			1	0.2	74%
		R2.0 (edge)	$ 8	$ -0.1	0.275	$ -6			-1	2.7	75%
		R2.7 (full ins.)	$ 17	$ -0.1	0.129	$ -15			1	0.7	75%
	Glazing	R0.31 (thermall	$ 8	$ -0.2	0.639	$ -3			-3	6.8	76%
		R0.31 (low-E)	$ 8	$ -0.7	1.464	$ 5			-9	13.2	76%
		R0.39 (therm.bı	$ 16	$ -0.9	1.028	$ 0			-10	9.9	78%
		R0.62 (triple gla	$ 42	$ -3.3	1.323	$ 16			-36	6.7	76%
Zone 2 - Napier	Base	Code min	-	-	-	-					65%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.67	$ -1			-1	2.2	66%
		R2.5 (140mm)	$ 25	$ -0.5	0.356	$ -16			-5	12.6	67%
		R2.9	$ 29	$ -0.6	0.448	$ -16			-7	11.3	67%
		R4.0 (staggered	$ 51	$ -0.9	0.372	$ -32			-13	NA	68%
		R4.6	$ 65	$ -1.1	0.321	$ -44			-12	53.0	69%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.2	7.86	$ 4			-3	29.9	66%
		R3.6	$ 0	$ -0.4	15.34	$ 7			-4	17.6	66%
		R4.3	$ 5	$ -0.6	2.523	$ 7			-6	11.0	66%
		R4.9	$ 6	$ -0.8	2.541	$ 9			-8	16.8	66%
		R5.9	$ 7	$ -1.0	2.844	$ 13			-11	14.1	66%
		R6.6	$ 7	$ -1.0	2.945	$ 14			-11	13.5	66%
	Floor	R1.9 (underslab	$ 10	$ -0.0	0.096	$ -9			1	0.3	65%
		R2.0 (edge)	$ 8	$ -0.2	0.425	$ -5			-1	3.8	66%
		R2.7 (full ins.)	$ 18	$ -0.2	0.197	$ -14			0	1.0	65%
	Glazing	R0.31 (thermall	$ 8	$ -0.4	1.121	$ 1			-5	10.9	67%
		R0.31 (low-E)	$ 8	$ -0.9	1.815	$ 8			-10	15.1	66%
		R0.39 (therm.bı	$ 16	$ -1.3	1.464	$ 8			-14	13.0	68%
		R0.62 (triple gla	$ 42	$ -3.9	1.569	$ 28			-40	7.4	65%

Apartment

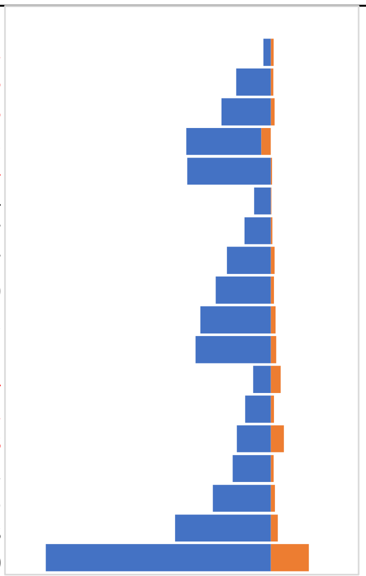
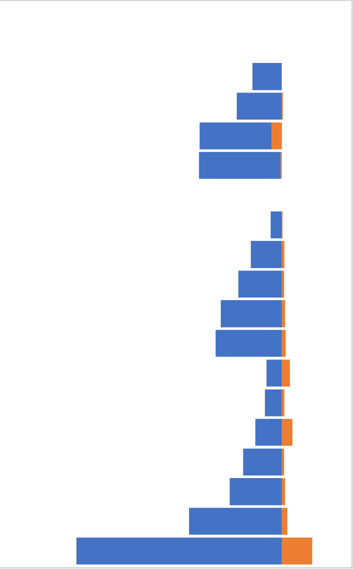




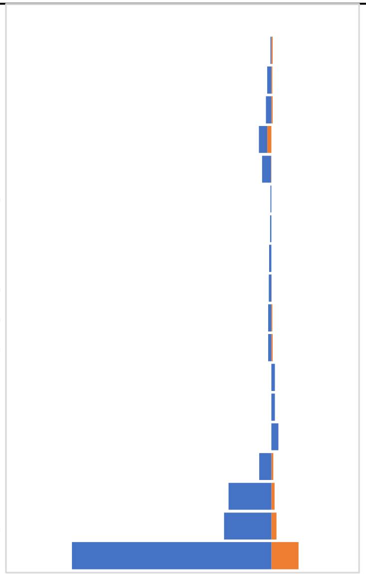
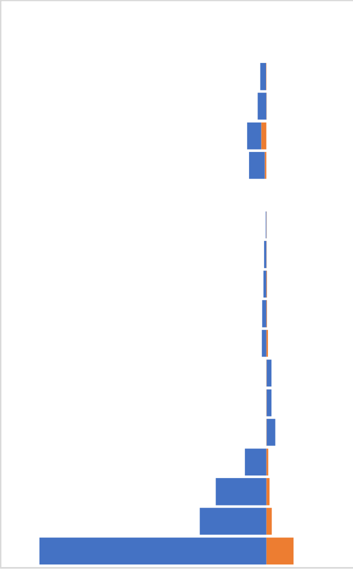
			Economics				Carbon (kg CO2 eq / 50yr)				Comfor
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living r
Zone 1 - Auckland	Base	Code min	-	-	-	-					79%
	Wall	R2.0 (Z3 min)	$ 2	$ -0.0	0.003	$ -2			0	0.0	79%
		R2.5 (140mm)	$ 22	$ -0.0	4E-04	$ -22			0	0.0	80%
		R2.9	$ 23	$ 0.0	NA	#VALUE!			1	0.0	80%
		R4.0 (staggered	$ 42	$ 0.0	NA	#VALUE!			-1	NA	80%
		R4.6	$ 52	$ 0.0	NA	#VALUE!			0	NA	79%
	Roof	R3.3 (Z3 min)	$ 0	$ -0.0	3.389	$ 0			0	6.8	79%
		R3.6	$ 0	$ -0.0	1.546	$ 0			0	5.1	79%
		R4.3	$ 0	$ -0.0	2.775	$ 0			0	4.3	79%
		R4.9	$ 1	$ -0.0	0.632	$ -0			0	2.3	79%
		R5.9	$ 1	$ -0.0	0.573	$ -1			0	1.6	79%
		R6.6	$ 2	$ -0.0	0.479	$ -1			0	1.0	79%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			1	23.1	79%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			1	23.1	79%
		R2.7 (full ins.)	$ 0	$ 0.2	NA	#VALUE!			3	34.3	79%
	Glazing	R0.31 (thermall	$ 12	$ 0.1	NA	#VALUE!			2	1.4	79%
		R0.31 (low-E)	$ 13	$ -1.1	1.359	$ 6			-13	12.2	81%
		R0.39 (therm.bı	$ 25	$ -0.7	0.491	$ -14			-7	4.7	80%
		R0.62 (triple gla	$ 66	$ -5.6	1.413	$ 33			-62	7.2	90%
Zone 2 - Napier	Base	Code min	-	-	-	-					71%
	Wall	R2.0 (Z3 min)	$ 2	$ -0.0	0.13	$ -2			0	0.4	72%
		R2.5 (140mm)	$ 22	$ -0.1	0.086	$ -20			-1	3.0	72%
		R2.9	$ 23	$ -0.1	0.113	$ -20			-1	2.7	73%
		R4.0 (staggered	$ 40	$ -0.2	0.098	$ -36			-4	NA	73%
		R4.6	$ 51	$ -0.2	0.084	$ -47			-3	NA	74%
	Roof	R3.3 (Z3 min)	$ 0	$ -0.0	9.375	$ 0			0	10.5	71%
		R3.6	$ 0	$ -0.0	4.219	$ 1			0	10.6	71%
		R4.3	$ 0	$ -0.1	8.072	$ 1			-1	9.2	71%
		R4.9	$ 1	$ -0.1	1.263	$ 0			-1	5.0	71%
		R5.9	$ 2	$ -0.1	1.229	$ 0			-1	3.6	71%
		R6.6	$ 2	$ -0.1	1.067	$ 0			-1	2.4	71%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			2	28.4	71%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			2	28.4	71%
		R2.7 (full ins.)	$ 0	$ 0.3	NA	#VALUE!			3	41.1	71%
	Glazing	R0.31 (thermall	$ 12	$ -0.2	0.39	$ -7			-2	3.8	74%
		R0.31 (low-E)	$ 13	$ -1.5	1.807	$ 13			-16	15.0	74%
		R0.39 (therm.bı	$ 25	$ -1.4	0.992	$ -0			-15	8.8	78%
		R0.62 (triple gla	$ 66	$ -7.1	1.788	$ 63			-74	8.4	88%

net_carbon_static3 - Sheet: per_sqm - Page 5

Medium Density

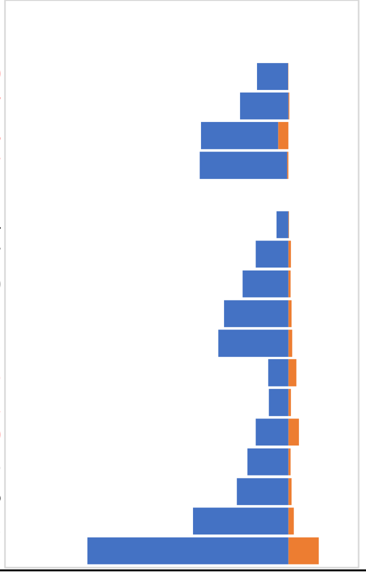
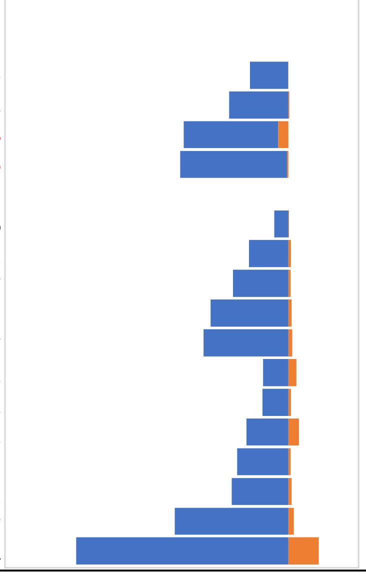
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 3 - Wellington	Base	Code min	-	-	-	-					59%
	Wall	R2.0 (Z3 min)	$ 3	$ -0.1	0.704	$ -1			-1	2.4	59%
		R2.5 (140mm)	$ 27	$ -0.5	0.332	$ -18			-5	13.4	60%
		R2.9	$ 31	$ -0.7	0.423	$ -18			-7	12.1	61%
		R4.0 (staggered	$ 52	$ -1.0	0.383	$ -32			-14	NA	62%
		R4.6	$ 67	$ -1.1	0.333	$ -44			-13	58.7	63%
	Roof	R3.3 (Z3 min)	$ 1	$ -0.2	7.637	$ 4			-3	30.4	59%
		R3.6	$ 0	$ -0.4	14.84	$ 7			-4	17.8	59%
		R4.3	$ 5	$ -0.6	2.413	$ 7			-7	11.1	59%
		R4.9	$ 6	$ -0.7	2.497	$ 9			-8	17.0	60%
		R5.9	$ 7	$ -0.9	2.774	$ 12			-11	14.2	60%
		R6.6	$ 7	$ -1.0	2.893	$ 13			-11	13.7	60%
	Floor	R1.9 (underslab	$ 9	$ -0.2	0.524	$ -4			-1	1.8	59%
		R2.0 (edge)	$ 8	$ -0.3	0.845	$ -1			-4	7.8	60%
		R2.7 (full ins.)	$ 17	$ -0.5	0.534	$ -8			-3	2.6	60%
	Glazing	R0.31 (thermall	$ 8	$ -0.5	1.33	$ 2			-6	13.6	61%
		R0.31 (low-E)	$ 8	$ -0.8	1.517	$ 5			-9	13.2	59%
		R0.39 (therm.bı	$ 16	$ -1.3	1.433	$ 8			-14	13.3	61%
		R0.62 (triple gla	$ 42	$ -3.0	1.197	$ 10			-31	5.9	55%
Zone 4 - Turangi	Base	Code min	-	-	-	-					51%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	52%
		R2.5 (140mm)	$ 25	$ -0.5	0.406	$ -15			-6	NA	53%
		R2.9	$ 28	$ -0.8	0.557	$ -13			-9	49.3	53%
		R4.0 (staggered	$ 47	$ -1.3	0.535	$ -22			-17	NA	54%
		R4.6	$ 63	$ -1.4	0.453	$ -35			-17	NA	55%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	52%
		R3.6	$ (0)	$ -0.2	NA	$ 4			-2	14.8	52%
		R4.3	$ 5	$ -0.5	2.314	$ 6			-6	11.4	52%
		R4.9	$ 5	$ -0.8	2.943	$ 10			-8	20.2	52%
		R5.9	$ 6	$ -1.1	3.484	$ 15			-12	17.3	52%
		R6.6	$ 6	$ -1.2	3.827	$ 17			-13	16.8	52%
	Floor	R1.9 (underslab	$ 10	$ -0.3	0.546	$ -4			-1	1.9	52%
		R2.0 (edge)	$ 8	$ -0.3	0.744	$ -2			-3	6.5	52%
		R2.7 (full ins.)	$ 18	$ -0.5	0.527	$ -8			-3	2.5	52%
	Glazing	R0.31 (thermall	$ 8	$ -0.7	1.8	$ 6			-7	17.3	53%
		R0.31 (low-E)	$ 8	$ -0.9	1.821	$ 8			-10	14.9	51%
		R0.39 (therm.bı	$ 16	$ -1.6	1.846	$ 15			-18	16.2	53%
		R0.62 (triple gla	$ 42	$ -3.6	1.449	$ 22			-36	6.7	49%

Apartment

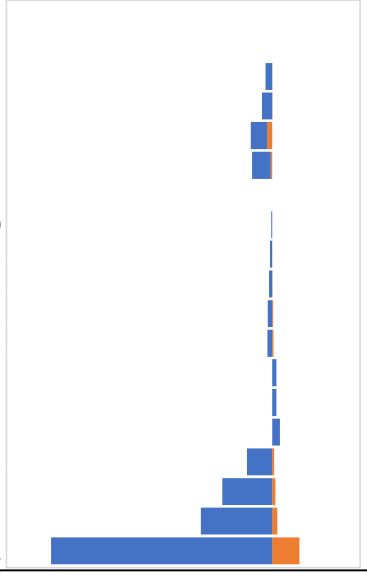
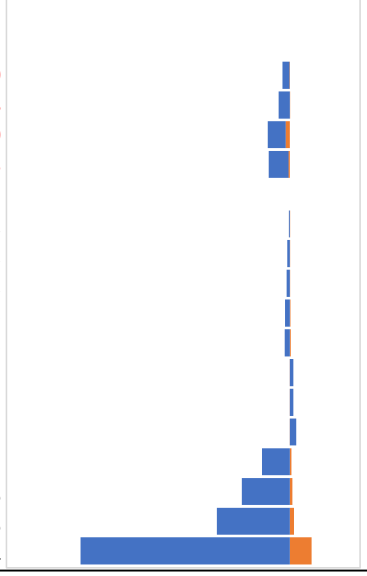
			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfor**
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living r
Zone 3 - Wellington	Base	Code min	-	-	-	-					69%
	Wall	R2.0 (Z3 min)	$ 2	$ -0.0	0.227	$ -2			0	0.8	69%
		R2.5 (140mm)	$ 24	$ -0.1	0.101	$ -21			-1	4.0	70%
		R2.9	$ 25	$ -0.2	0.135	$ -21			-1	3.7	71%
		R4.0 (staggered	$ 41	$ -0.2	0.121	$ -36			-4	NA	72%
		R4.6	$ 52	$ -0.3	0.102	$ -47			-3	NA	72%
	Roof	R3.3 (Z3 min)	$ 0	$ -0.0	11.62	$ 0			0	13.6	69%
		R3.6	$ 0	$ -0.0	3.838	$ 1			0	10.1	69%
		R4.3	$ 0	$ -0.1	7.446	$ 1			-1	8.9	69%
		R4.9	$ 1	$ -0.1	1.151	$ 0			-1	4.9	69%
		R5.9	$ 2	$ -0.1	1.109	$ 0			-1	3.4	69%
		R6.6	$ 2	$ -0.1	0.963	$ -0			-1	2.2	69%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			1	21.9	69%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			1	21.9	69%
		R2.7 (full ins.)	$ 0	$ 0.2	NA	#VALUE!			3	32.6	69%
	Glazing	R0.31 (thermall	$ 12	$ -0.4	0.594	$ -5			-4	6.1	73%
		R0.31 (low-E)	$ 13	$ -1.3	1.569	$ 9			-14	13.6	73%
		R0.39 (therm.bı	$ 25	$ -1.4	0.994	$ -0			-15	9.2	79%
		R0.62 (triple gla	$ 66	$ -5.9	1.486	$ 39			-63	7.3	90%
Zone 4 - Turangi	Base	Code min	-	-	-	-					62%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	62%
		R2.5 (140mm)	$ 21	$ -0.2	0.168	$ -18			-2	NA	63%
		R2.9	$ 22	$ -0.3	0.247	$ -17			-3	23.8	63%
		R4.0 (staggered	$ 37	$ -0.4	0.239	$ -28			-7	NA	64%
		R4.6	$ 49	$ -0.5	0.201	$ -39			-6	NA	65%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	62%
		R3.6	$ 0	$ -0.0	2.712	$ 0			0	11.1	62%
		R4.3	$ 0	$ -0.1	10.51	$ 1			-1	13.2	62%
		R4.9	$ 1	$ -0.1	1.424	$ 1			-1	6.9	62%
		R5.9	$ 2	$ -0.1	1.558	$ 1			-1	5.1	62%
		R6.6	$ 2	$ -0.1	1.397	$ 1			-1	3.3	62%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			2	29.0	62%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			2	29.0	62%
		R2.7 (full ins.)	$ 0	$ 0.3	NA	#VALUE!			3	42.2	62%
	Glazing	R0.31 (thermall	$ 12	$ -0.7	1.12	$ 1			-7	10.8	66%
		R0.31 (low-E)	$ 13	$ -1.6	1.976	$ 16			-17	16.2	65%
		R0.39 (therm.bı	$ 25	$ -2.1	1.484	$ 14			-22	13.0	70%
		R0.62 (triple gla	$ 66	$ -7.1	1.79	$ 63			-73	8.3	77%

net_carbon_static3 - Sheet: per_sqm - Page 6

Medium Density

			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfort**
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living room
Zone 5 - Christchurch	Base	Code min	-	-	-	-					48%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	48%
		R2.5 (140mm)	$ 19	$ -0.5	0.508	$ -9			-6	NA	48%
		R2.9	$ 22	$ -0.8	0.679	$ -7			-10	52.9	49%
		R4.0 (staggered	$ 52	$ -1.2	0.465	$ -28			-18	NA	50%
		R4.6	$ 65	$ -1.4	0.421	$ -37			-18	NA	50%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	48%
		R3.6	$ (0)	$ -0.2	NA	$ 4			-2	15.7	48%
		R4.3	$ 3	$ -0.5	2.904	$ 7			-6	12.0	48%
		R4.9	$ 6	$ -0.7	2.506	$ 9			-9	21.3	48%
		R5.9	$ 7	$ -1.0	2.961	$ 13			-12	18.2	48%
		R6.6	$ 7	$ -1.1	3.129	$ 15			-14	17.7	48%
	Floor	R1.9 (underslab	$ 11	$ -0.3	0.558	$ -5			-2	2.5	48%
		R2.0 (edge)	$ 8	$ -0.3	0.768	$ -2			-3	7.4	48%
		R2.7 (full ins.)	$ 19	$ -0.5	0.537	$ -9			-4	3.1	48%
	Glazing	R0.31 (thermall	$ 8	$ -0.6	1.689	$ 5			-8	18.3	49%
		R0.31 (low-E)	$ 8	$ -0.8	1.592	$ 6			-10	14.7	48%
		R0.39 (therm.b	$ 16	$ -1.5	1.684	$ 12			-18	16.6	49%
		R0.62 (triple gla	$ 42	$ -3.1	1.255	$ 13			-35	6.6	45%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					41%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	42%
		R2.5 (140mm)	$ 19	$ -0.7	0.767	$ -5			-8	NA	42%
		R2.9	$ 23	$ -1.2	1.032	$ 1			-12	64.8	43%
		R4.0 (staggered	$ 45	$ -1.9	0.82	$ -8			-21	NA	44%
		R4.6	$ 58	$ -2.1	0.724	$ -16			-22	NA	44%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	42%
		R3.6	$ (0)	$ -0.3	NA	$ 6			-3	18.8	42%
		R4.3	$ 3	$ -0.8	4.419	$ 12			-7	14.5	42%
		R4.9	$ 5	$ -1.1	4.405	$ 17			-11	25.6	42%
		R5.9	$ 6	$ -1.5	5.103	$ 25			-15	22.0	42%
		R6.6	$ 6	$ -1.7	5.369	$ 27			-17	21.4	42%
	Floor	R1.9 (underslab	$ 11	$ -0.5	0.938	$ -1			-4	3.1	42%
		R2.0 (edge)	$ 8	$ -0.5	1.288	$ 2			-5	9.9	42%
		R2.7 (full ins.)	$ 18	$ -0.8	0.895	$ -2			-6	3.9	42%
	Glazing	R0.31 (thermall	$ 8	$ -1.0	2.657	$ 13			-10	22.9	42%
		R0.31 (low-E)	$ 8	$ -1.1	2.2	$ 12			-11	16.1	41%
		R0.39 (therm.b	$ 16	$ -2.2	2.521	$ 27			-22	19.7	43%
		R0.62 (triple gla	$ 42	$ -4.2	1.672	$ 34			-37	6.9	38%

Apartment

			Economics				**Carbon (kg CO2 eq / 50yr)**				**Comfor**
	Element	R-value	Extra Cost	Annual Savings	BCR	NPV	Energy	Material	Net	Ratio	Living rc
Zone 5 - Christchurch	Base	Code min	-	-	-	-					59%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	59%
		R2.5 (140mm)	$ 16	$ -0.2	0.227	$ -13			-2	NA	59%
		R2.9	$ 17	$ -0.3	0.325	$ -12			-4	27.2	60%
		R4.0 (staggered	$ 41	$ -0.5	0.22	$ -32			-8	NA	60%
		R4.6	$ 51	$ -0.5	0.2	$ -41			-7	NA	60%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	59%
		R3.6	$ 0	$ -0.0	3.265	$ 0			0	13.8	59%
		R4.3	$ 0	$ -0.1	10.84	$ 1			-1	13.8	59%
		R4.9	$ 1	$ -0.1	1.73	$ 1			-1	7.2	59%
		R5.9	$ 1	$ -0.1	1.772	$ 1			-1	5.3	59%
		R6.6	$ 2	$ -0.1	1.524	$ 1			-1	3.5	59%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			2	25.1	59%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			2	25.1	59%
		R2.7 (full ins.)	$ 0	$ 0.2	NA	#VALUE!			3	35.9	59%
	Glazing	R0.31 (thermall	$ 12	$ -0.7	1.166	$ 2			-8	12.7	61%
		R0.31 (low-E)	$ 13	$ -1.4	1.721	$ 12			-17	15.9	60%
		R0.39 (therm.b	$ 25	$ -2.0	1.404	$ 11			-24	13.9	65%
		R0.62 (triple gla	$ 66	$ -6.2	1.548	$ 44			-71	8.1	69%
Zone 6 - Queenstown	Base	Code min	-	-	-	-					55%
	Wall	R2.0 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	55%
		R2.5 (140mm)	$ 17	$ -0.3	0.376	$ -10			-3	NA	55%
		R2.9	$ 18	$ -0.5	0.547	$ -8			-5	37.0	55%
		R4.0 (staggered	$ 35	$ -0.8	0.437	$ -20			-10	NA	56%
		R4.6	$ 46	$ -0.9	0.384	$ -28			-10	NA	56%
	Roof	R3.3 (Z3 min)	#VALUE!	#VALUE!	-	#VALUE!			0	0.0	55%
		R3.6	$ 0	$ -0.0	5.138	$ 1			0	17.2	55%
		R4.3	$ 0	$ -0.1	17.41	$ 2			-1	17.6	55%
		R4.9	$ 1	$ -0.1	2.787	$ 2			-1	9.2	55%
		R5.9	$ 1	$ -0.2	2.86	$ 3			-2	6.8	55%
		R6.6	$ 2	$ -0.2	2.464	$ 3			-2	4.5	55%
	Floor	R1.9 (underslab	$ 0	$ 0.1	NA	#VALUE!			2	26.1	54%
		R2.0 (edge)	$ 0	$ 0.1	NA	#VALUE!			2	26.1	54%
		R2.7 (full ins.)	$ 0	$ 0.3	NA	#VALUE!			3	37.5	54%
	Glazing	R0.31 (thermall	$ 12	$ -1.2	2.014	$ 12			-12	17.3	56%
		R0.31 (low-E)	$ 13	$ -2.1	2.609	$ 26			-21	19.1	56%
		R0.39 (therm.b	$ 25	$ -3.2	2.27	$ 36			-31	17.8	59%
		R0.62 (triple gla	$ 66	$ -9.2	2.307	$ 104			-85	9.6	63%

2021_extra_results_static_FINAL - Sheet: Single

model	climate	R	W	F	G	Total Energy (kWh/yr)	Total Energy (kWh/m2/yr)	Energy saving (kWh/yr)	Energy saving (kWh/m2/yr)	Extra cost ($)	As % of total	Annual savings ($)	Annual savings (%)	Living daytime comfort hours	Degree hours too cold	Degree hours too hot	Change in coldness (%)	Change in overheating (%)		Roof	Walls	Floor	Windows
Base	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	3420	21.9	0	0	0	0	0		73%	2010	231	0%	0%		0	0	0	0
	Zone 2 - Napier	R2.9	R1.9	R1.3	R0.26	4890	31.4	0	0	0	0	0		65%	4240	342	0%	0%		0	0	0	0
	Zone 3 - Wellington	R2.9	R1.9	R1.3	R0.26	5670	36.4	0	0	0	0	0		55%	7240	5	0%	0%		0	0	0	0
	Zone 4 - Turangi	R3.3	R2.0	R1.3	R0.26	7480	47.9	0	0	0	0	0		50%	9700	98	0%	0%		0	0	0	0
	Zone 5 - Christchurch	R3.3	R2.0	R1.3	R0.26	8730	56	0	0	0	0	0		45%	13200	362	0%	0%		0	0	0	0
	Zone 6 - Queenstown	R3.3	R2.0	R1.3	R0.26	11200	71.6	0	0	0	0	0		39%	18500	58	0%	0%		0	0	0	0
Low	Zone 1 - Auckland	R2.9	R1.9	R1.3	R0.26	3420	21.9	0	0	$ -	0.0%	$ -	0%	73%	2010	231	0%	0%	Cost breakdown	$ -	$ -	$ -	$ -
	Zone 2 - Napier	R3.3	R1.9	R1.3	R0.29	4290	27.5	-602	-4	$ 1,760	0.4%	-$ 159	-12%	67%	3990	290	-6%	-15%		$ 217	$ -	$ -	$ 1,550
	Zone 3 - Wellington	R3.3	R2.2	R1.5	R0.29	4490	28.8	-1190	-8	$ 8,400	1.9%	-$ 300	-21%	58%	6480	4	-10%	-20%		$ 217	$ 4,180	$ 2,450	$ 1,550
	Zone 4 - Turangi	R3.7	R2.2	R1.9	R0.33	5860	37.6	-1610	-10	$ 11,300	2.8%	-$ 432	-22%	54%	8650	107	-11%	9%		$ 1,200	$ 3,650	$ 3,990	$ 2,470
	Zone 5 - Christchurch	R3.7	R2.2	R1.9	R0.33	6920	44.4	-1810	-12	$ 10,700	2.3%	-$ 430	-21%	47%	12100	382	-8%	6%		$ 842	$ 2,820	$ 4,530	$ 2,470
	Zone 6 - Queenstown	R4.2	R2.4	R2.2	R0.39	8130	52.1	-3030	-20	$ 15,300	3.7%	-$ 909	-27%	42%	16200	56	-12%	-3%		$ 1,320	$ 2,900	$ 6,780	$ 4,330
Medium	Zone 1 - Auckland	R5.0	R2.4	R1.9	R0.39	2180	14	-1230	-8	$ 14,700	3.2%	-$ 301	-36%	83%	1040	186	-48%	-19%		$ 2,550	$ 4,020	$ 3,820	$ 4,330
	Zone 2 - Napier	R5.4	R2.6	R2.2	R0.42	2900	18.6	-1990	-13	$ 16,800	3.9%	-$ 525	-41%	74%	2430	307	-43%	-10%		$ 2,370	$ 3,800	$ 6,620	$ 4,020
	Zone 3 - Wellington	R6.0	R2.8	R2.5	R0.45	2850	18.3	-2820	-18	$ 18,700	4.3%	-$ 714	-50%	66%	4090	3	-44%	-40%		$ 2,600	$ 5,010	$ 6,160	$ 4,950
	Zone 4 - Turangi	R6.6	R3.2	R2.8	R0.49	3800	24.4	-3680	-24	$ 18,200	4.4%	-$ 986	-49%	60%	5850	91	-40%	-7%		$ 2,300	$ 4,420	$ 6,530	$ 4,950
	Zone 5 - Christchurch	R7.0	R3.5	R3.2	R0.55	3790	24.3	-4940	-32	$ 21,400	4.6%	-$ 1,170	-57%	57%	7600	429	-42%	19%		$ 2,860	$ 7,890	$ 4,770	$ 5,870
	Zone 6 - Queenstown	R7.4	R3.8	R3.6	R0.62	4680	30	-6480	-42	$ 24,200	5.8%	-$ 1,940	-58%	44%	14300	36	-23%	-38%		$ 2,530	$ 7,660	$ 6,020	$ 8,040
High	Zone 1 - Auckland	R6.6	R2.9	R2.5	R0.48	1840	11.8	-1570	-10	$ 18,900	4%	-$ 383	-46%	86%	701	176	-65%	-24%		$ 2,870	$ 4,680	$ 6,370	$ 4,950
	Zone 2 - Napier	R7.0	R3.2	R2.8	R0.52	2410	15.4	-2480	-16	$ 20,500	5%	-$ 656	-51%	78%	1680	326	-60%	-5%		$ 2,870	$ 5,100	$ 6,620	$ 5,870
	Zone 3 - Wellington	R7.4	R3.5	R3.2	R0.55	2030	13	-3640	-23	$ 25,100	6%	-$ 919	-64%	74%	2510	13	-65%	160%		$ 2,790	$ 9,010	$ 7,470	$ 5,870
	Zone 4 - Turangi	R7.8	R3.8	R3.6	R0.62	2670	17.1	-4810	-31	$ 28,700	7%	-$ 1,290	-64%	58%	6110	64	-37%	-35%		$ 3,710	$ 8,400	$ 8,510	$ 8,040
	Zone 5 - Christchurch	R8.4	R4.4	R4.2	R0.68	3130	20.1	-5600	-36	$ 48,200	10%	-$ 1,330	-64%	55%	9080	390	-31%	8%		$ 4,260	$ 10,400	$ 21,500	$ 12,100
	Zone 6 - Queenstown	R9.0	R5.0	R4.8	R0.76	3630	23.3	-7540	-48	$ 50,100	12%	-$ 2,260	-68%	50%	12500	73	-32%	26%		$ 4,310	$ 11,200	$ 22,600	$ 12,100

Assumes COP/EER = 2 for livingrooms

	low	high	
Zone 1 - Auckland	$ 425,580	$ 487,860	$ 456,720
Zone 2 - Napier	$ 394,440	$ 477,480	$ 435,960
Zone 3 - Wellington	$ 394,440	$ 477,480	$ 435,960
Zone 4 - Turangi	$ 378,870	$ 441,150	$ 410,010
Zone 5 - Christchurch	$ 415,200	$ 508,620	$ 461,910
Zone 6 - Queenstown	$ 384,060	$ 446,340	$ 415,200

Whole house estimates based off QVcostbuilders standard building costs per square meter estimates

2021_extra_results_static_FINAL - Sheet: HeatCool_disaggregated

model	climate	Set	R	W	F	G	Cooling (kWh/m2)	Heating (kWh/m2)	Total Cooling (kWh)	Total Heating (kWh)
4_M_SS	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	8.7	13	1354	2063
4_M_SS	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	8.0	23	1252	3639
4_M_SS	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	3.6	33	555	5116
4_M_SS	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	4.5	43	706	6770
4_M_SS	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	4.2	52	657	8072
4_M_SS	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	3.5	68	543	10619
4_M_SS	Zone 1 - Auckland	Low	R2.9	R1.9	R1.3	R0.26	8.7	13	1354	2063
4_M_SS	Zone 2 - Napier	Low	R3.3	R1.9	R1.3	R0.29	6.3	21	986	3303
4_M_SS	Zone 3 - Wellington	Low	R3.3	R2.2	R1.5	R0.29	3.0	26	475	4011
4_M_SS	Zone 4 - Turangi	Low	R3.7	R2.2	R1.9	R0.33	4.3	33	673	5192
4_M_SS	Zone 5 - Christchurch	Low	R3.7	R2.2	R1.9	R0.33	4.0	40	624	6295
4_M_SS	Zone 6 - Queenstown	Low	R4.2	R2.4	R2.2	R0.39	3.0	49	465	7664
4_M_SS	Zone 1 - Auckland	Medium	R5.0	R2.4	R1.9	R0.39	7.7	6	1194	991
4_M_SS	Zone 2 - Napier	Medium	R5.4	R2.6	R2.2	R0.42	6.8	12	1055	1849
4_M_SS	Zone 3 - Wellington	Medium	R6.0	R2.8	R2.5	R0.45	3.3	15	518	2328
4_M_SS	Zone 4 - Turangi	Medium	R6.6	R3.2	R2.8	R0.49	4.1	20	646	3153
4_M_SS	Zone 5 - Christchurch	Medium	R7.0	R3.5	R3.2	R0.55	4.9	19	769	3017
4_M_SS	Zone 6 - Queenstown	Medium	R7.4	R3.8	R3.6	R0.62	0.8	29	120	4559
4_M_SS	Zone 1 - Auckland	High	R6.6	R2.9	R2.5	R0.48	7.6	4	1190	655
4_M_SS	Zone 2 - Napier	High	R7.0	R3.2	R2.8	R0.52	7.4	8	1146	1263
4_M_SS	Zone 3 - Wellington	High	R7.4	R3.5	R3.2	R0.55	4.7	8	729	1304
4_M_SS	Zone 4 - Turangi	High	R7.8	R3.8	R3.6	R0.62	1.1	16	175	2490
4_M_SS	Zone 5 - Christchurch	High	R8.4	R4.4	R4.2	R0.68	2.0	18	314	2820
4_M_SS	Zone 6 - Queenstown	High	R9.0	R5.0	R4.8	R0.76	1.4	22	225	3401

Heating and cooling figures disaggregated with COP/EER of heatpump = 2 assumed in the living rooms

2021_extra_results_static_FINAL - Sheet: COP_EER=1

model	climate	Set	R	W	F	G	Cooling (kWh/m2)	Heating (kWh/m2)	Total Cooling (kWh)	Total Heating (kWh)
4_M_SS	Zone 1 - Auckland	Base	R2.9	R1.9	R1.3	R0.26	11.5	18	1789	2788
4_M_SS	Zone 2 - Napier	Base	R2.9	R1.9	R1.3	R0.26	10.8	31	1682	4841
4_M_SS	Zone 3 - Wellington	Base	R2.9	R1.9	R1.3	R0.26	4.4	43	685	6695
4_M_SS	Zone 4 - Turangi	Base	R3.3	R2.0	R1.3	R0.26	5.7	57	894	8833
4_M_SS	Zone 5 - Christchurch	Base	R3.3	R2.0	R1.3	R0.26	5.6	67	878	10467
4_M_SS	Zone 6 - Queenstown	Base	R3.3	R2.0	R1.3	R0.26	4.3	88	664	13702
4_M_SS	Zone 1 - Auckland	Low	R2.9	R1.9	R1.3	R0.26	11.5	18	1789	2788
4_M_SS	Zone 2 - Napier	Low	R3.3	R1.9	R1.3	R0.29	8.4	28	1307	4393
4_M_SS	Zone 3 - Wellington	Low	R3.3	R2.2	R1.5	R0.29	3.7	34	569	5258
4_M_SS	Zone 4 - Turangi	Low	R3.7	R2.2	R1.9	R0.33	5.4	43	844	6782
4_M_SS	Zone 5 - Christchurch	Low	R3.7	R2.2	R1.9	R0.33	5.3	52	831	8168
4_M_SS	Zone 6 - Queenstown	Low	R4.2	R2.4	R2.2	R0.39	3.6	64	556	9903
4_M_SS	Zone 1 - Auckland	Medium	R5.0	R2.4	R1.9	R0.39	9.9	9	1550	1367
4_M_SS	Zone 2 - Napier	Medium	R5.4	R2.6	R2.2	R0.42	9.0	16	1397	2494
4_M_SS	Zone 3 - Wellington	Medium	R6.0	R2.8	R2.5	R0.45	4.0	20	626	3085
4_M_SS	Zone 4 - Turangi	Medium	R6.6	R3.2	R2.8	R0.49	5.1	27	802	4159
4_M_SS	Zone 5 - Christchurch	Medium	R7.0	R3.5	R3.2	R0.55	6.5	25	1014	3932
4_M_SS	Zone 6 - Queenstown	Medium	R7.4	R3.8	R3.6	R0.62	0.9	38	136	5873
4_M_SS	Zone 1 - Auckland	High	R6.6	R2.9	R2.5	R0.48	9.9	6	1544	930
4_M_SS	Zone 2 - Napier	High	R7.0	R3.2	R2.8	R0.52	9.7	11	1520	1723
4_M_SS	Zone 3 - Wellington	High	R7.4	R3.5	R3.2	R0.55	5.9	11	914	1735
4_M_SS	Zone 4 - Turangi	High	R7.8	R3.8	R3.6	R0.62	1.3	21	208	3264
4_M_SS	Zone 5 - Christchurch	High	R8.4	R4.4	R4.2	R0.68	2.7	24	416	3704
4_M_SS	Zone 6 - Queenstown	High	R9.0	R5.0	R4.8	R0.76	1.7	28	262	4433

Raw energy figures with no COP or EER adjustment