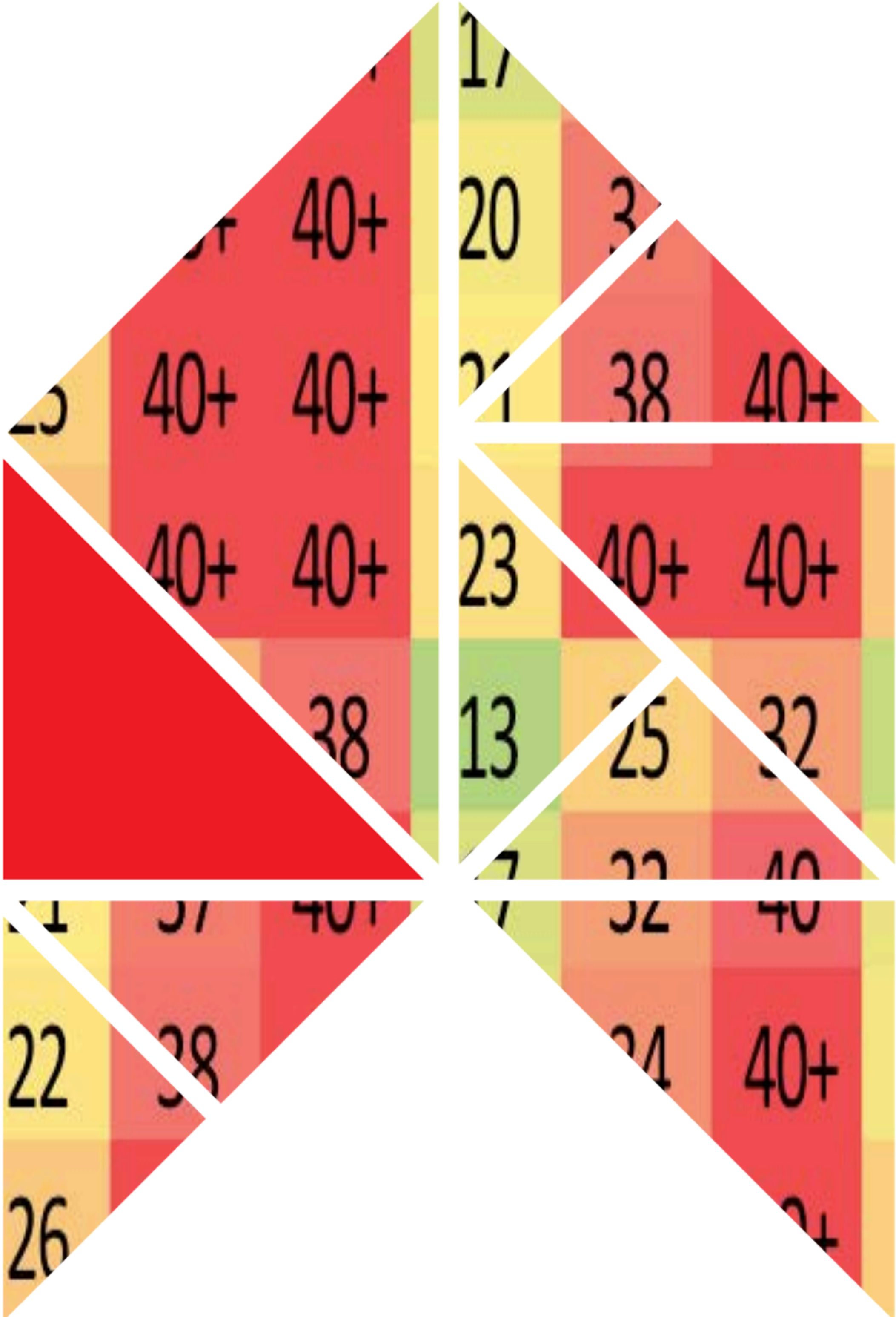
Study Report

SR346 [2016]

The value of sustainability – costs and benefits of sustainability and resilience features in houses

Ian Page



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Preface

This is the second of two reports prepared during research into how building owners can put a value on sustainability and resilience features in housing. The earlier report reviewed the literature on valuing sustainability and canvased builders' views on what their customers want. Generally, there is little appreciation of the benefits of above-code sustainability measures and many builders expressed an interest in receiving reliable information.

This report describes the development of information for builders to use with their clients when discussing sustainability type features. This information covers insulation, water efficiency, solar water heating (SWH) and solar power generation or photovoltaics (PV), efficient lighting, designing for extreme natural events, user-friendly design and lifecycle costs of cladding materials.

Note: This report is intended for builders and designers. Technically knowledgeable owners may also find the report of interest.

Acknowledgements

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The value of sustainability – costs and benefits of sustainability and resilience features in houses

BRANZ Study Report SR346

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Reference
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Abstract
This report provides an evidence base to help builders, designers and specifiers to make better-informed decisions around investing in sustainability features. It calculates costs and benefits for a range of sustainability features and resilience options in different scenarios. Features considered include greater than the minimum required levels of insulation; water conservation measures and rainwater tanks; lighting options; solar water heating; heat pump water heating; photovoltaic generation; resilience to flood, winds and earthquakes; lifetime design and material lifecycle cost.

Keywords
Housing; sustainability; resilience; thermal insulation; water efficiency; rainwater tanks; lighting; solar water heating; heat pump water heating; photovoltaic generation; wind; flood; earthquake, costs, benefits

Contents

Figures

Tables

Executive summary

This report covers the costs and benefits for a range of sustainability features and resilience options in houses under different scenarios. It is part of a larger study project into valuing sustainability and resilience features in New Zealand housing.

The analysis in this report indicates that:

- The minimum insulation R-values as set out in the schedule method of NZS 4218:2004 *Energy efficiency – Small building envelope* (as modified by H1/AS1) are near their financial optimum for most households. In cooler climates such as Wellington and the lower South Island, slightly more ceiling insulation and under-slab insulation is cost effective for the average occupancy. If households are heating to high levels in winter then even more insulation, including additional roof insulation, becomes cost effective.
- Flow restrictors on taps and showers save significant volumes of water. They also reduce electricity use for water heating and hence save on household energy bills, with further savings in locations where water metering is mandatory.
- Domestic rainwater tanks can supplement supply in reticulated areas, providing a significant share of water demand. In areas with metering their payback time is typically 9–15 years, which makes them marginally cost effective at the upper payback years. In some areas with lower costs of water and/or low rainfall the tanks are not cost effective at all.
- Solar water heating and photovoltaic generation are becoming more cost competitive as the equipment cost declines. However, unless the household circumstances are exceptional (i.e. high hot water or electricity use during the day), the solar appliances will have quite long payback periods, typically 10 years minimum.
- For heat pump hot water systems, the payback period is quite long, typically over 16 years.
- Where flooding occurs at 10-year or less intervals, raising a house that sits on an area subject to flooding is often the best financial option. For longer return periods, replacement of linings and insulation after flooding is generally more cost effective. Use of resilient materials for replacement has similar lifetime costs to like-for-like replacements and their quick re-instatement has socio-economic benefits.
- Incorporation of user-friendly or lifetime design features is not very expensive, typically about $3,000 extra for a new house design. This provides amenity to current and future users, particularly those with young children, or those who are infirmed or disabled.
- Future maintenance obligations for housing can be much reduced by selection of appropriate materials. Low initial cost usually dominates life cycle studies, however lower-maintenance, resilient materials do not cost much more than initially-cheap materials over a house lifetime, and the house better retains its 'as-new' appearance.
- Owners of older houses should consider strengthening roof connectors against the risk of wind damage. The simplest measure is to replace lead-head roof fixings with screw fixings in wind-prone areas. If there is evidence of roof assembly movement in storms then owners need to get expert advice. This advice may be on retrofitting rafter or truss connectors to the top plate and installing additional fixings of purlins to the trusses or rafters. Modern houses should be adequate in all situations.

- There may be a financial case for above-minimum bracing to reduce damage to new houses during frequent but non-life-threatening earthquakes. New houses with lightweight claddings generally have scope for increased bracing using additional sheet bracing materials such as bracing-grade plasterboard or plywood. If damage in a 20-year return earthquake can be reduced by about $3000 then increased bracing appears to be cost effective. However, further study on a range of these scenarios needs to be done to determine the net benefits.

1. Introduction

The research findings in this study report are part of a larger BRANZ project measuring the value of sustainability features in housing. Features such as extra insulation levels, water conservation and solar power add to a home's performance, but it is uncertain how much these improvements are valued by homeowners and what the benefit:cost ratios are.

The overall project aims to provide an evidence base to help builders, designers and specifiers to make better-informed decisions around investing in sustainability features.

Research conducted in year one of the project identified a need to provide builders with independent data on the costs and benefits of various sustainability measures (Study Report SR333 *Valuing sustainability and resilience features in housing*)[1]. A survey of real estate agents and valuers also identified a similar interest. Builders wanted quite basic information on whether insulation levels above the minimum require to comply with the New Zealand Building Code were cost effective for various households. That analysis and more is provided in this report, which covers data on the costs, benefits and payback periods for:

- improved thermal insulation and glazing
- increased water conservation and rainwater use
- lighting
- solar water heating
- heat pump water heating
- solar power
- resilience (to floods, wind, earthquakes)
- lifetime design
- material lifecycle cost.

Another part of the research project, focusing on solar power in housing, is described in Study Report SR353, *The value of sustainability: An investigation into barriers and enablers for solar power in New Zealand*[2].

[1] Jaques, R., Norman, D., & Page, I. (2015). *Valuing sustainability and resilience features in housing*. Study Report SR333. Wellington, New Zealand: BRANZ.
[2] Stoecklein, A., & Jaques, R. (2016). *The value of sustainability: An investigation into barriers and enablers for solar power in New Zealand*. Study Report SR353. Design Navigator Ltd for BRANZ Ltd, Judgeford, New Zealand.

2. Sustainability results

This section looks at efficiency measures in new housing covering:

- envelope thermal insulation
- water conservation and rainwater use
- lighting
- solar water heating
- heat pump water heating
- solar power (photovoltaic) generation.

Where possible, cost data is provided and the net benefits are discussed.

2.1 Insulation and glazing

2.1.1 Current requirements and insulation levels

The New Zealand Building Code clause H1 *Energy efficiency* sets out the general performance requirements of a building in terms of energy efficiency. It references and modifies the standard NZS 4218:2004 *Energy efficiency – Small building envelope*, which explains methods for demonstrating compliance with the Building Code. The simplest means is the schedule method, where there are 3 climate zones and minimum levels of thermal resistance (R-values) required for walls and ceiling that vary by zone (Table 1).

(NZS 4218:2009 *Thermal insulation – Housing and small buildings* has not been referenced by Building Code clause H1 at the time this study report is published. While it gives higher levels of minimum performance, 4218:2009 must be used as support for consent as an alternative solution for compliance with H1.)

Table 1. Component insulation requirements of the schedule method in NZS 4218:2004 Energy efficiency – Small building envelope (as modified by H1/AS1).

Climate zone	Roof R-value	Wall R-value	Glazing (vertical) R-value	Floor R-value
1	2.9	1.9	0.26	1.3
2	2.9	1.9	0.26	1.3
3	3.3	2.0	0.26	1.3

BRANZ surveys of insulation use in new housing indicate that a significant percentage of new houses have greater than the minimum required R-levels of insulation. Climate zones 1 and 2 require a wall R-value of 1.9 or more, and R 2.0 or more in zone 3. These thresholds are commonly achieved with insulation R-values of R 2.2 in zone 1 and 2, and R 2.6 in zone 3. BRANZ regularly surveys materials used in new buildings and the results for insulation are show in Table 2. The schedule method requirements are exceeded in 41% of zone 1 and 2 houses, and 26% of houses in zone 3.

For ceiling insulation in zone 1 and 2, R 3.2 insulation will achieve a component value of about R 2.9, and 31% of new houses exceeded this amount. In zone 3, R 3.6

insulation is commonly needed to exceed the required ceiling assembly R-value and 16% of houses exceeded that.

So between 16–41% of new houses already exceed the schedule method requirements, varying with the region and house component.

Table 2. BRANZ new dwellings survey 2015 – insulation levels

Insulation R values					
Walls			Ceilings		
	Zone 1 & 2	Zone 3		Zone 1 & 2	Zone 3
<R2.2	4%	4%	<R3.2	13%	5%
R2.2	55%	9%	R3.2	56%	15%
R2.3 to R2.5	12%	14%	R3.3 to R3.5	5%	1%
R2.6	19%	46%	R3.6	19%	62%
>R2.6	10%	26%	>R3.6	7%	16%
	100%	100%		100%	100%
From the BRANZ New Dwellings Survey 2015, 1195 houses.					

2.1.2 Is it cost effective to have more than the minimum insulation required?

The answer depends on a number of factors including:

- house type and location
- energy and insulation prices
- level and duration of indoor heating
- period of analysis
- discount rates.

The results of computer modelling using additional insulation are shown in Figures 1 and 2. A medium-sized home is used (148 m^2 excluding the unheated double garage) in three areas: Auckland, Wellington and Christchurch. A medium level of heating is assumed, with morning and evening heating to 20 °C.

The assumptions on energy costs and the financial factors are given in the charts following. Energy costs include the heat pump cost spread over kWh consumption. Heat pump appliances are assumed as the base case, since they are the most common form of heating in new housing. The calculations are in discounted dollars, which means future costs of energy use are discounted and compared to the cost of insulation.

The first set of charts (Figure 1) with benefit:cost ratios, help identify which insulation changes have the best payoff. The benefit is the reduced energy cost compared to the schedule method (discounted over 25 years). The cost is the additional cost of the insulation compared to the schedule method cost. Ratios must be over 1.0, otherwise the enhancement is not cost effective. These results are used to develop the tables for builders and designers to use with their clients on what measures are likely to be cost effective (Section 5).

The charts show insulation R-values rather than the wall or roof component R-value. The former need to be larger than in Table 1 to achieve the required schedule construction R-values. Cost-effective enhancements, above schedule method minimum requirements, from Figure 1 and Figure 2 are:

- Auckland – no enhancements are cost effective
- Wellington – under-slab perimeter insulation
- Christchurch – under-slab perimeter and whole-slab insulation (barely).

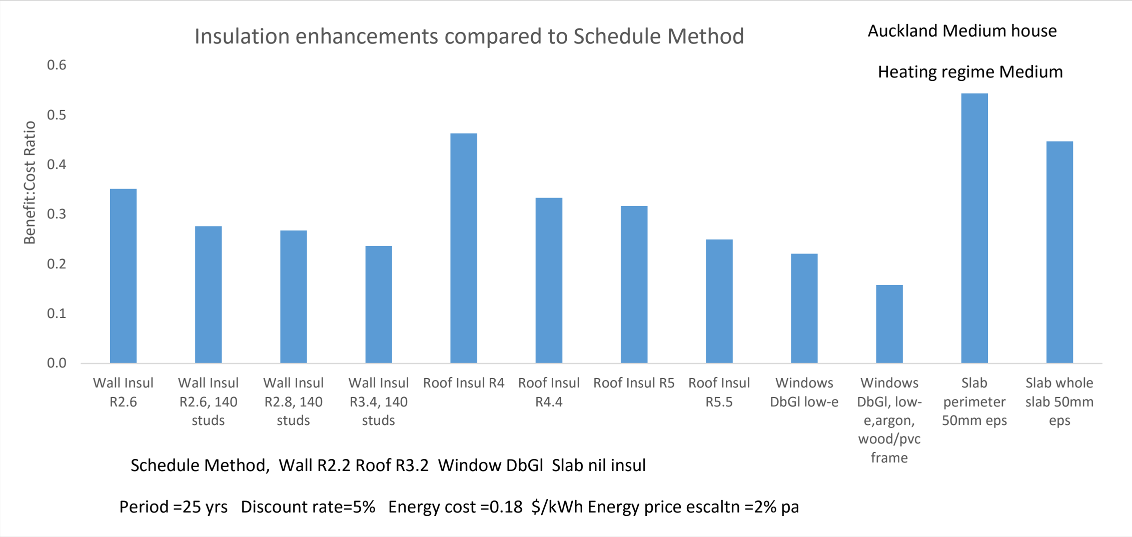
Figure 2 shows combinations of enhancements where enhanced insulation is added cumulatively. In these charts the insulation costs include the schedule method costs plus enhancements. The 3 lines in each panel are the cost of the insulation combination, energy cost (as before discounted over 25 years), and total cost.

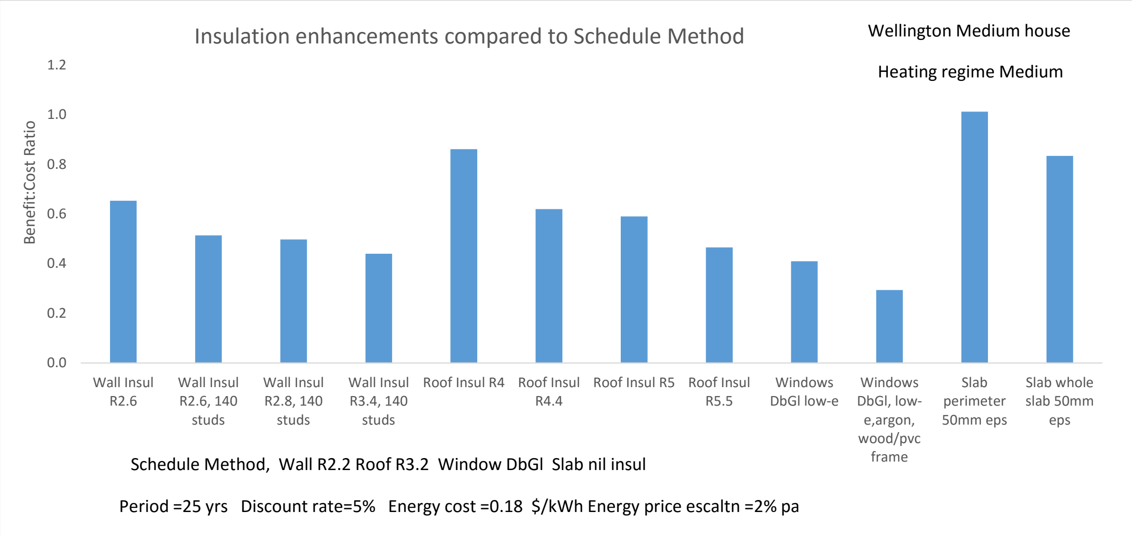
The aim is to identify the minimum total cost point on the charts. The most notable feature is the flatness of the total cost curves across most of their ranges, particularly in Wellington and Christchurch. This occurs because the additional cost of enhancements is almost wholly offset by the increased energy savings.

In Auckland, additional insulation after the first addition causes a visible rise in the total cost. In Wellington and Christchurch, the total cost is almost unchanged for the first 3 to 4 additions, compared to the schedule method level of insulation.

Because new owners are likely to want to minimise initial cost, their choice would be an insulation combination to the left. However, if government wished to control total energy demand they may choose an insulation combination toward the right of the cumulative combinations.

The results change when different parameters for heating levels, period of analysis and other financial factors are considered. These will have different results and may be more or less cost effective, as set out next and in Section 5: Analysis details and data sheets. For example, with a longer heating regime, additional insulation enhancements become cost effective in most regions. It could be argued the initial design should consider future owners who may wish to have higher comfort levels than those assumed in the medium scenario. In that case, while some above-code insulation measures are not cost effective for the initial owner, they could be for subsequent owners. Also, it is often a good selling point to have above-code insulation, for when the first owner comes to sell.





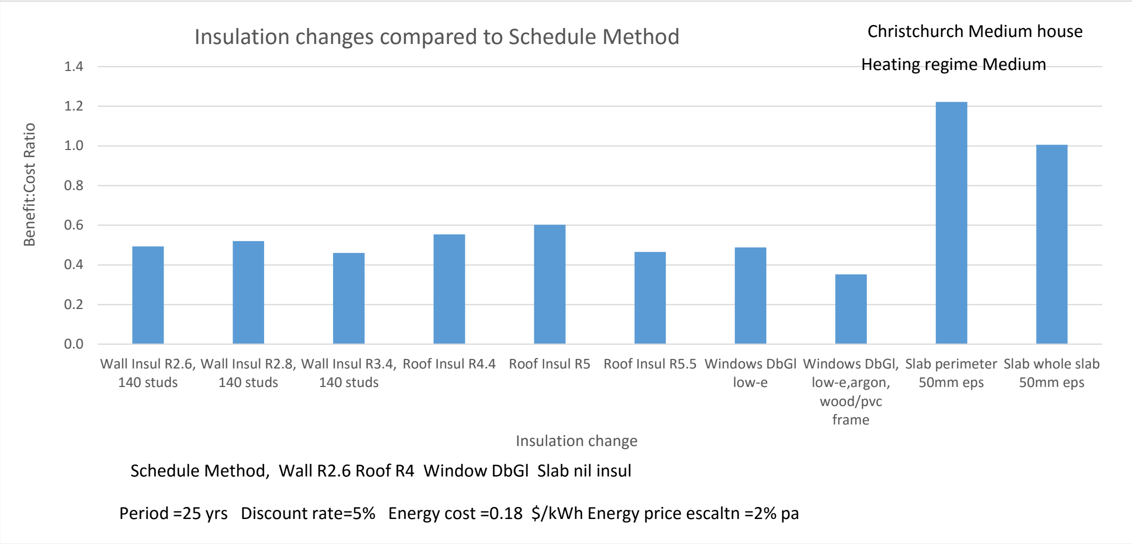


Figure 1. Medium-sized new house with above minimum-required insulation – benefit:cost ratios for various enhancements

Figure 2. Cumulative insulation enhancements – present values

2.1.3 Varying the parameters

The charts above are for a typical house using a typical heating regime described as medium heating. Under what circumstances can the benefits of greater than minimum required insulation show positive returns? Consider the medium-sized house in Wellington.

The parameter with the largest influence is the heating regime used by the household. As the default case we have assumed the medium heating regime of 20 °C for 2 hours in the morning and 6 hours in the evening. In a high heating regime (24-hour heating) other enhancements become cost effective (Figure 3).

Assuming 24-hour heating, extra wall and ceiling insulation become cost effective. That is, we now have roof insulation up to R 5.0, and walls with R 2.6 insulation are cost effective, and whole-slab insulation has a benefit:cost ratio near 2, (Figure 3). With all these enhancements the total cost saving is about 4%, compared to schedule method insulation (for a 25-year analysis period).

The savings become greater if there is more expensive heating in the absence of a heat pump. Electric radiant heating costs about 27c per kWh (the domestic price across most of New Zealand, and assuming 100% heating efficiency). With this change, additional ceiling insulation and insulation under the whole slab are cost effective in Wellington (Figure 4).

Of lesser effect are changes in the financial parameters such as energy price escalation and the analysis period. We have assumed 2% energy price escalation (above the general inflation rate), and a 25-year analysis period. If we double either of these then roof R 4.4 insulation or whole-slab insulation saves about 2% on the schedule method minimum insulation.

A fuller sensitivity analysis is in Section 5: Analysis details and data sheets, including consideration of other regions and other heating regimes.

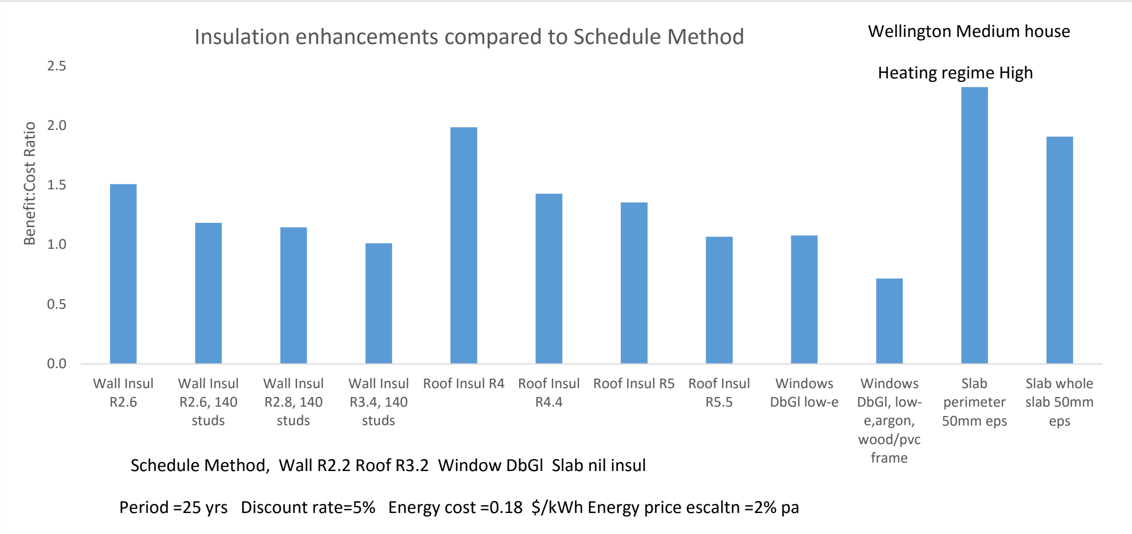


Figure 3. Benefit:cost ratios for various enhancements and high heating regime

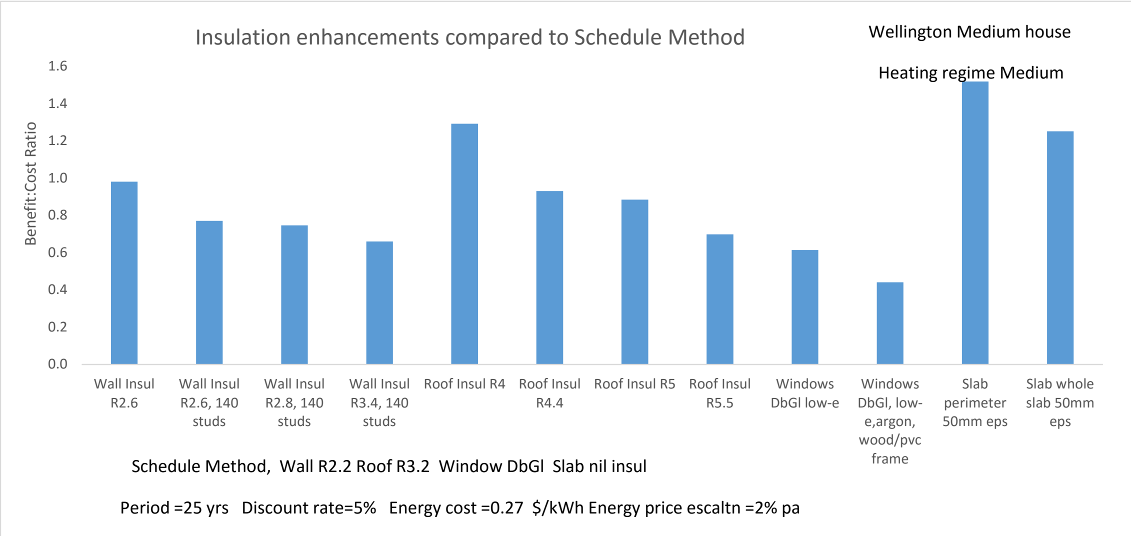


Figure 4. Benefit:cost ratios for various enhancements and higher energy price

2.2 Water efficiency

Table 3 shows potential savings from water-use efficiency looking at taps, showers and toilets only. The volumes saved are calculated on a per house basis and two types of cost have been included:

- a council charge for the water supply
- heating costs for hot water use, assuming electrical heating.

For the Auckland example in Table 3 the estimated annual saving ranges between $131 and $440, depending on the number of people in the house. The cost of installing water saving devices has not been considered since they are mostly low-cost items and dual-flush is usually the default option with nil extra cost for toilet cisterns.

In most regions households do not directly pay for water per unit used. However, the Table shows those cities where metering is compulsory or is available. The savings are significant considering that they come with little or no extra cost. The shower and taps require low cost flow restrictors and the toilet cistern needs to be specified as dual flush/ low volume.

Table 3. Water efficiency savings

Water efficiency - potential savings for new houses

Typical total water use = 180 Lpd

	Unit	Typical rate (1)	Star rate (2)		Typical (3) Lpd	Star rated Lpd	Persons	Household size 1	2	3	4
								Savings per house per day (litres)			
Shower	litre/min	8.0	6.0	WELS 3 Star Shower	53	40		13	26	40	53
Toilet	litre	8.0	4.0	WELS 4 Star Toilets	32	16		16	32	48	64
Taps	litre/min	12.0	7.0	WELS 5 Star Taps	25	15		11	21	32	42
					110	70		40	79	119	159
							Hot water energy savings kWh/year (5)	83	166	248	331

Water price c/litre including annual charge (assumes 270Lpd) (4)

Person per house	1	2	3	4	**$ Savings per year water and water heating**	1	2	3	4
Auckland	0.34	0.24	0.20	0.19	Auckland	131	234	337	440
Tauranga	0.21	0.19	0.19	0.19	Tauranga	113	222	331	440
Wellington	0.30	0.23	0.20	0.19	Wellington	127	231	336	440
Nelson	0.41	0.31	0.28	0.26	Nelson	143	256	370	483
Christchurch	0.26	0.16	0.12	0.11	Christchurch	120	211	302	393
Dunedin	0.29	0.21	0.19	0.18	Dunedin	124	228	331	435

(1) Typical for new housing. Source BRANZ Water end-use and efficiency project (2007) and BRANZ Auckland water use project (2008).
(2) BRANZ assumption for WELS ratings
(3) Assume 6.6 min per shower, one shower per person per day, 4 toilet flushes per person per day, taps are 14% total residential use .
Lpd = litres per person per day
(4) Price of water per litre is from schedule charges for the selected TAs. The price varies across houses sizes due to the fixed component of pricing. Wellington prices are estimated by BRANZ. Electricity rate= 27.5 c/kWh
(5) Allow 0.0348 kWh per litre heating from 16degC to 43degC, and allowing 10% for losses.

Domestic water used by appliance is based on work at BRANZ.[3]

2.2.1 Rainwater tanks

Rainwater tanks are used in many houses around New Zealand whether or not houses are connected to a reticulated system. In rural areas the homeowner has no choice and needs a tank system for supply. However, in cities and towns some owners and officials promote the merits of rainwater tank systems as a supplement to the reticulated supply. They are mandatory for new dwellings in Kapiti Coast District, a district with high per-person consumption and a significant cost to expand bulk supply. Rainwater is used for non-potable purposes such as toilet flushing, washing clothes and exterior taps for garden and other outdoor use.

The financial merit (or otherwise) of rainwater tanks is calculated using a unit price based on metering. Table 4 shows the water costs for selected councils. This includes the fixed annual cost spread over total consumption, plus the charge per litre used. Rainwater tanks are sized based on the number of people in the household, roof areas, and the likely rainfall in summer for the location. Payback is the number of years of water saving cost to cover the initial expenditure on the tanks, pump, electrician and plumbing.

[3] Heinrich, M. (2007). *Water end use and efficiency project (WEEP)*. Study Report SR159, BRANZ.

Table 4. Rainwater tanks financial calculations

Rainwater tanks cost effectiveness				**170 sqm house 3 persons**			
		180 Lpd	payback	**270 Lpd**	payback	**360 Lpd**	payback
		Council charge	years		years		years
Location		cents/litre		cents/litre		cents/litre	
Auckland		0.24	14	0.20	14	0.19	13
Tauranga		0.19	16	0.19	14	0.19	13
Wellington		0.23	15	0.20	14	0.19	13
Nelson		0.31	11	0.28	10	0.26	10
Christchurch		0.16	28	0.12	36	0.11	42
Dunedin		0.21	17	0.19	19	0.18	21
The payback period is the cost of the tank, pump and plumbing divided by the annual savings in water costs. Lpd = litres per person per day. Water cost savings allows for the annual charge plus the per litre charge.							

Cities that have metering commonly use 160–200 litres per person per day (Lpd). Unmetered cities use more, and up to 700 Lpd have been recorded in New Zealand.

It was decided to use a quite small range from 180–360 Lpd, as shown in the table. The payback years calculated are quite high and a simple payback of more than 15 years is generally uneconomic. In financial terms, 15 years represents a rate of return of about 5% on the initial cost which is the minimum we would expect. The calculations do not allow for any maintenance, or for power to run the pump which is likely to be a minor cost. A pump is usually necessary as gravity feed is incomplete with tanks on the ground.

In the table, Christchurch and Dunedin have long payback periods due to the low price of water and/or their lower rainfall than the other cities.

More detailed information is contained in Section 5: Analysis details and data sheets, including different-sized houses and households to that in Table 5. Generally the payback periods do not change significantly for bigger households, but for smaller households the payback period becomes longer.

2.3 Lighting

The amount of lighting installed in new housing is significantly greater in number than earlier decades according to BRANZ research. A new house survey is done by BRANZ every quarter and gets returns for 300 new dwellings.[4] Results are reported and published annually. Among the items surveyed is the number of ceiling lights. In Figure 5 the results for detached houses are expressed as average number by floor area where the averages are for groups of 10 lights, namely 0–10 lights, 11–20 lights, 21–30, etc. The 0–10 group has an average of about 8 lights and average floor area of 140 m2. The points lie on a straight line, indicating that on average the number of lights is directly proportional to floor area of the house, which is not unexpected.

The chart enables the number of lights for any house to be estimated knowing its floor area. The average floor area for a detached house in 2015 was 210 m^2 and the chart

[4] Curtis, M. (2015). *Physical characteristics of new dwellings*, Study Report SR330, BRANZ.

indicates an average of about 35 lights, a large number compared to a few years ago. In these circumstances it is important the lighting be as efficient as possible.

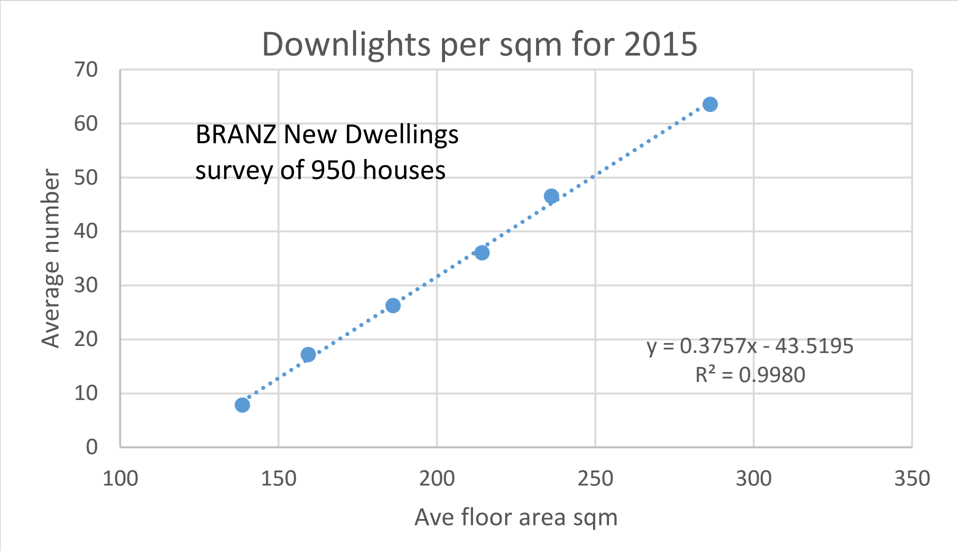


Figure 5. Lighting installed in new housing

New lighting technology in recent years has included halogens, compact fluorescent lights (CFLs) and light emitting diodes (LEDs).

Initially halogens were common replacements for incandescent bulbs in housing but now LEDs and CFLs are more common. The cost of the latter has dropped significantly in recent years. Table 5 indicates these are now more cost effective than the old-style incandescent bulbs, except for those used infrequently (less than 2 hours per week). With 3 hours' use per day the energy savings of a CFL compared to an incandescent light are sufficient to cover the extra bulb cost well within a single year.

The table assumes 3 hours per day use, but even quite low useage has a short payback period. As stated above, however, more than 2 hours per week is probably the minimum for preferring the more expensive bulbs. For little-used spare bedrooms, formal dining areas, second bathrooms and toilets, laundries and games rooms, incandescent bulbs are probably the better choice from a financial viewpoint.

Table 5. Payback periods for replacing incandescent light bulbs.

Replace incandescent light bulbs					
		Replace with		Straight or	
	Incandescent (1)	LED (2)	Covered CFL (3)	Twisted CFL (3)	
Illumination	<-------------------watts (for equal illumination)--------------------->				
415 lumens (40W)	40	7	12	12	
710 lumens (60W)	60	10	15	15	
920 lumens (75W)	75	14	18	18	
Life span years	1	10+	7	7	
Cost each bulb $					
40W equivalent	4.4	12	7	6	
60W	4.4	23	8	7	
75W	4.4	26	9	8	
Power savings $ per year (4)					
40W equivalent		9.8	8.3	8.3	
60W		14.8	13.3	13.3	
75W		18.0	16.9	16.9	
Payback period (years)					
40W equivalent		0.8	0.3	0.2	
60W		1.2	0.3	0.2	
75W		1.2	0.3	0.2	
Electricity price=	27	c per kWh			
(1) 1 year life only, 6 replacements @ $0.80 each discounted , to year 7, is $4.4 in present value.					
(2) Light emitting diodes (LED)s last a minimum of 20 years, but ignore any residual value					
after 7 years.					
(3) Compact fluroscent lights (CFL) last 7 years.					
(4) Savings compared to an incandscent bulb. Assume 3 hrs per day average use.					

2.4 Solar water heating

How much water does a household use? Those cities with metering average around 190 Lpd (Beacon 2008)[5], and heated water is about 64% of the total household use for those cities (Heinrich 2007).

A 2.4 m^2 solar roof panel system can supply a maximum of about 2,500 kWh per year for the whole North Island and the South Island down to Christchurch. In practice the useful energy supplied is less due to non-optimum orientation of the panels and time of demand not exactly matching peak solar gains. Also, if the system is sized to produce more than 70% of demand, there is a risk of over-heating in peak summer months. Effectively the maximum supply is reduced to 70% in northern zones and 60% in southern zones. This gives payback periods of about 10 years in the north and 12 years in the south (Table 6). More than 1 panel system of 2500kWh will be required in some cases to supply the hot water needs, and back-up electric heating will usually

[5] Wilson, D. (2010). *Water efficiency: Further benefits revealed*. Beacon Research Symposium June 2010. Beacon Pathway.

be required. Fuller details of the performance of actual installed solar water heaters are in a BRANZ study report.[6]

Table 6. Water use by function

Heated water use			
	litres per person per day (1)		
	Three Ldp scenarios		
Toilets	35	53	61
Washing mach.	40	60	70
Showers	50	75	88
Taps	25	38	44
Other (outside)	30	45	97
Total Lpd	180	270	360
Annual hot water demand kWh (2)	4380	6580	7670
Solar water panel installed $	5000	(3 sqm)	
Northern zone kWh/yr (3)	1750	assume 70% efficient	
Southern zone kWh/yr (3)	1500	assume 60% efficient	
	Payback period years		
Northern zone	10.4		
Southern zone	12.1		
(1) Based on Heinrich (2007) Study Report 159, BRANZ.			
(2) Washing mc, showers & taps heated to 45 degC, for 3 person household.			
(3) Northern zone for solar is North Island down to Christchurch.			
Southern zone for solar is south of Christchurch.			

2.5 Heat pump water heating

These systems cost $4500–$6000 for a 6–8 kW system. We assume delivered energy use is about 4,400 kWh per year (for the 3-person household, 180 Lpd household in Table 6), and the heat pump has an efficiency (COP) of about 1.5.[7] This gives a payback period of about 23 years when comparing the extra cost above a traditional cylinder, divided by the energy savings per year. Some heat pump systems have a COP of 2.0 and in these cases the payback period is about 16 years, which is almost financially justifiable.

[6] Pollard, A., and Zhao, J. (2008). *The performance of solar water heaters in New Zealand*. Study Report SR188, BRANZ.
[7] Pollard, A. (2010). *The energy performance of heat pump water heaters*. Study Report SR237, BRANZ.

2.6 Solar energy generation (photovoltaic)

The most common photovoltaic (PV) system purchased in New Zealand for domestic use is a 3kW system which costs around $10,000 installed. Assuming an average efficiency of about 55% during peak solar hours (6 hours per day), the annual output is about 3500 kWh in Auckland and about 15% less in the southern zone. Assuming this energy can be used within the household during the day (i.e. without the need for battery storage) the payback is about 11 years in the northern zone (to Christchurch) and about 13 years further south. In many households, continual use during the day at the level of generation will not be possible. In that case the payback period becomes longer.

While storage batteries are available their cost is still quite high and these systems have longer payback periods than above. Sales of electricity from domestic sources into the local grid are feasible but with current buy-back prices of about 7c/kWh the payback period may be uneconomic and will depend on the amount of energy exported.

A report[8] was commissioned by BRANZ on the barriers and enablers for solar power. This surveyed 301 people who had contacted a solar provider and included both purchasers and non-purchasers. Barriers include cost, low buy-back rates, and ongoing technology changes leaving 'stranded' assets. The enablers include power savings, a contribution to sustainability and renewable sources, and greater financial control over outgoings. The main deal-changer is a lower system price. Better advertising by government in their information resources would also help prospective installers.

There is obviously a market for solar PV and heat pump water heaters among environmentally-conscious consumers. A lower capital cost would appeal to a wider audience and uptake is expected to increase as technology improves and the initial cost declines.

[8] Stoecklein, A. & Jaques, R. (2016). *The value of sustainability: An investigation into barriers and enablers for solar power in New Zealand*. Study Report SR353. Design Navigator Ltd for BRANZ Ltd, Judgeford, New Zealand

3. Resilience results

This section looks at selected resilience measures in new housing, including:

- flooding mitigation
- wind damage to roofs
- earthquake damage reduction
- user-friendly design
- life costs for claddings

Where possible, cost data is provided and the net benefits are discussed.

3.1 Flooding resilience

Table 7 shows the costs for five flood damage mitigation options for two typical houses, one with a 120 m^2 floor area, and a larger house of 180 m^2. The options are applied before a flood event and the life cycle costs are calculated from installation. The costs are in present value (PV) and the options are:

- replace like-with-like
- replace damaged materials (linings, insulation, doors) with more resilient materials so future restoration is cheaper than like-with-like
- raise house above future flood levels
- install an earth bund around the land boundary
- install a flexible membrane within a concrete perimeter pit, for extension when there is a flood risk.

The costs assume quite small flood heights and do not include any damage to foundations, floor covers or appliances. A discount rate of 5% is assumed.

The modelling allows for different return periods. The table shows an example with an annual expected probability of 0.067, i.e. every 15 years there is flood damage. For this return period, the costs for three options – like-for-like replacement, replacing with resilient materials, and raising the house – are very similar.

Table 7. Lifetime costs for selected flood restoration options

Flood restoration options										
									Lifetime costs	
	Annual expected probability =	0.067	Repair or mitigation		Subsequent floods		Temporary		$ Present value	
	i.e. return period (years)=	15	cost for 1st flood		repair cost		accomodation			
Option			120sqm	180sqm hse	120sqm	180sqm	weeks	$	120sqm	180sqm
1	Replace like-with-like		12960	19440	12960	19440	10	4000	37600	52000
2	Replace with resilient materials		22330	33500	7104	10656	6	2400	36300	51800
3	Raise house		35000	50000	0	0	1	400	35500	50500
4	Bund one house		51960	58440	0	0	1	400	52400	58900
4	Flexible membrane		43960	66440	0	0	1	400	44400	66900
	Discount rate =	5%		Temporary accomodation $/wk= 400						
	Analysis period =	50 years	Costs for bund & membrane assume 0.3m freeboard & timber floor 0.5m above grd.							

With different flooding frequencies, the preferred option changes (see Figure 6, for a small house). With frequent floods (i.e. less than 10 years) the like-for-like replacements are the more expensive, while raising the house is the least expensive. At longer return periods, the like-for-like replacements are the least expensive in present dollar values. For medium periods, i.e. 15 or 20-year return periods, the first three options have very similar lifetime costs. The lifetime costs of raising the house, installing bunds or the flexible membrane are mainly unchanged with increased return periods because, apart from accommodation, all the costs are at year zero.

Figure 7 shows a larger house and it has similar results to the small house.

BRANZ is currently testing various other resilient measures for flood-prone houses, such as coating protection of framing and surfaces, but the testing and efficacy are not sufficiently advanced to be costed at this stage.

Usually, homeowners will have flood damage insurance and are not directly concerned with the financial aspects of potential mitigation. However, for areas subject to frequent flooding, insurance companies may cease offering insurance. Alternatively, they may require mitigation measures before offering insurance cover.

BRANZ has also done work in conjunction with NIWA on protecting houses using these and other measures,[9] including bunds protecting small groups of houses, and moving houses permanently to higher ground. That model allowed for variation in damage according to flood height, including total write-off. It is a quite complex model to be used where detailed catchment data is available, and was intended to be used for comparison with an area-wide catchment scheme.

The simple model in this report gives an indication of likely costs for small groups or single houses subject to fairly frequent flooding, and where relocation or area-wide stopbanks are unlikely to be affordable. It assumes similar amounts of damage and repair costs for flooding above floor level up to about 0.6 m in height. The lower halves of the linings are assumed to be replaced with new material, and resilient linings are cleaned and replaced after the wall cavities and insulation have been cleaned and dried. The flooring is assumed to not need replacing, but may need polyurethane recoating. Flooding higher than 0.6 m above floor level is likely to incur more damage than shown in the table.

Fuller details of the analysis, including material types and costs, are in Section 5: Analysis details and data sheets.

[9] Page (2012) *Evaluating costs/benefits for housing flood damage mitigation*. Climate change and urban impacts toolbox workshop July 2012. NIWA. Downloaded 21 March 2016 https://www.niwa.co.nz/sites/niwa.co.nz/files/session_11_-_stage_3_cbe_for_housing_adaptation_ip.pdf

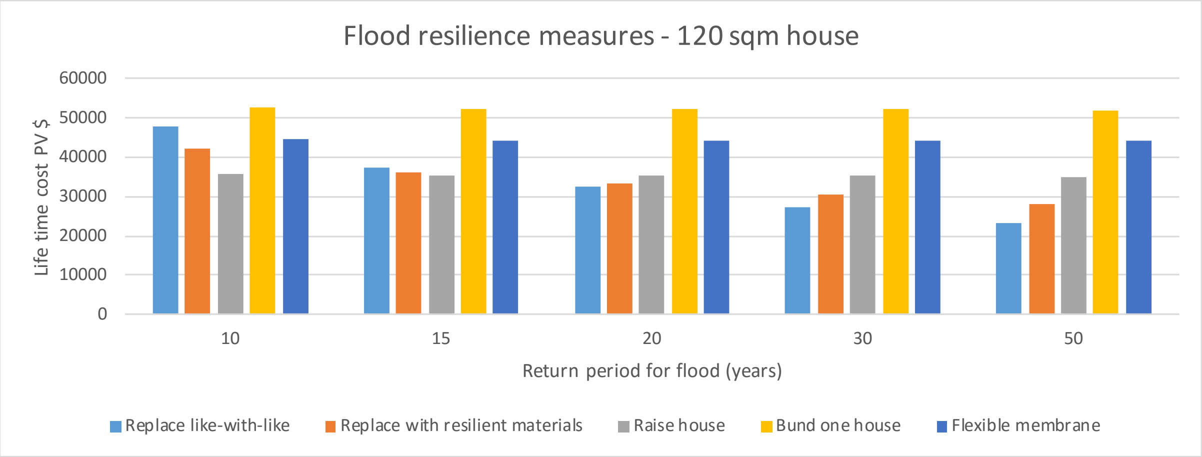


Figure 6. Flood restoration lifetime costs and the return period – 120 m² house.

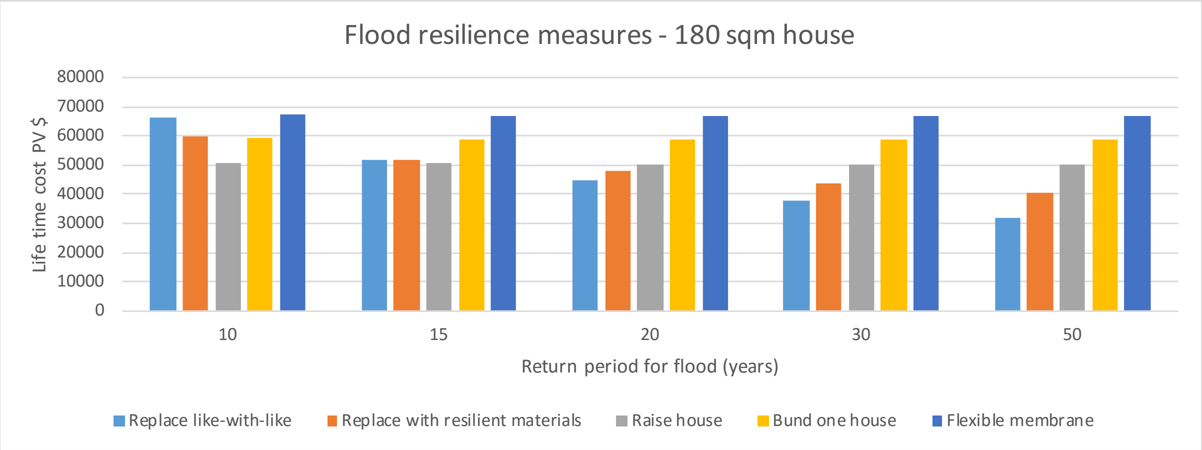


Figure 7. Flood restoration lifetime costs and the return period – 180 m² house.

3.2 Wind loading on roofs

As for flooding, an upgrade to deal with potential wind damage is mainly applicable to older existing houses where roof and windows fixings are below current new house requirements. Very occasionally, coastal parts of New Zealand are subject to localised windstorms or tornadoes, and roofs are damaged in these events. A BRANZ report[10] estimated roof-strengthening costs up to $2200 per house for houses built before 1999 and in High or Very High wind zones. This includes additional connections between truss and purlins, and in some cases fixing trusses to the top plate using an L bracket.

Roof claddings are usually fixed to purlins with lead-head nails in older houses. These nails corrode with time and lose the lead from the head, losing strength and weather resistance. These should be replaced. This is quite quickly and cheaply done using galvanised screw fixings with flexible washers and is recommended on all older houses.

A 2012 revision of the New Zealand Building Code Acceptable Solution E2/AS1 required extra fixings for window reveals to the building frame. This arose because of the introduction of an extra high wind zone and updated wind suction pressure calculations indicated a risk of suction in certain conditions.

Occurrence of these roof and window events is rare and data on damage is so sparse that it is difficult to do a cost:benefit analysis with any certainty. At this time, retrofit strengthening is not recommended as a matter of course on these houses (except roof cladding, which should be screw-fixed as set out in SR187). However, if a house is in a very high or greater wind zone and is particularly exposed to storms, then it may be wise to consult a registered building surveyor with a view of installing additional purlin and top plate fixings.

As climate change proceeds storms are expected to become more frequent in New Zealand and, assuming damage occurs more frequently, the advantages of retrofit strengthening may become more apparent.

3.3 Earthquake resilience

In the Canterbury earthquakes, some house foundations, claddings and linings suffered extensive damage. The main change to housing design coming out of this experience was the requirement to use ductile mesh in all floor slabs of new houses. It was apparent the existing style of floors, particularly those that were unreinforced, did not perform structurally during the earthquake. The design of other components was not changed. But is there a case for going further and reducing material damage for other components, beyond that needed for health and safety?

For example, if houses were stiffer then some or most of the earthquake (and wind) damage to linings and claddings could be avoided or reduced. Modern houses have many openings in external walls and already these walls are designed as bracing components for a large percentage of their area. However, additional well distributed bracing could be cost effective in reducing subsequent repairs to linings.

[10] Beattie, G. (2008). *Retrofitting of houses to resist extreme wind events*. Study Report SR187, BRANZ.

Houses designed to NZS 3604:2011 *Timber-framed Buildings* performed well in the Christchurch earthquakes in that life safety was maintained. If designers considered adding evenly distributed bracing, say up to 50% more, then this would be expected to reduce lateral earthquake deflections and therefore damage.

It is often possible to achieve this by using bracing grade plasterboard, additional plasterboard, plywood sheet or fibre-cement sheet. Adding 50% more bracing in a sample new house in Wellington (a single storey of light cladding construction) has an additional cost of about $1,800 (Table 19, in Section 5: Analysis details and data sheets). If the earthquake occurred soon after construction then it is money well spent. However, on a probability basis (assuming a 500 year return period) there would need to be a saving of about $45,000 per house in repair costs to justify the extra expenditure. This appears unlikely for houses with lightweight cladding, based on results from the Christchurch earthquakes, where 65% of inspected post-1980s houses had no or minimal damage to the linings.[11] For lightweight claddings, 85% of post-1980s houses had no or minimal damage and weatherboard claddings had close to zero damage overall.

It is possible that additional bracing could be cost effective in small earthquakes with short return periods. This is analysed in Table 19, which shows that to justify 50% more bracing in a new house the design would need to save $3,100 in repair costs expected over a 25 return period earthquake. This appears to be a possible scenario, but further work is needed on the likely damage for a variety of new house designs, and their repair costs for various return period earthquakes.

3.4 User-friendly design for housing

In New Zealand the most common standard for user-friendly housing is the Lifetime Design Specification, which incorporates features that facilitate better amenity in access and movement within the house. Features include:

- wider doors and passageways
- sufficient turning space within at least one bathroom and bedroom for wheelchairs
- wall strengthening in toilets/ bathrooms to fix grab–bars in the future
- fittings such as handles and switches and sockets at suitable heights for ease of access
- gentle gradients for the formed front door access, shelter, and appropriate external lighting
- sufficient width at car parking/garage areas for a wheelchair.

These houses are suitable for people of all ages but are particularly useful for parents with young children, big-bodied people, and the aged and infirm. Generally they do not have an institutional appearance but instead have a spacious feel with wide doorways and clear spaces in bathrooms and the kitchen area.

The additional cost to provide lifetime design features in new housing is quite low. Table 8 shows the details for a typical house. Minor design changes can usually accommodate the lifetime design features in a new house. The outside items relate to facilitating easy access particularly for wheelchairs, through widening the carpark area and access to the front door, with adequate lighting and shelter. The largest costs

[11] Beattie, G., Shelton, R. & Thomas, G. (2015). *Structural performance of houses in the Canterbury earthquake series*. Study Report SR327, BRANZ.

potentially arise from widening passageways, at about $4500 for this particular example. However, if room is taken from rooms adjacent to the passageway with no change in overall footprint then this cost is avoided. Usually a more open plan design is feasible to eliminate passageways.

The total extra cost then becomes about $3000 or 1% of the house build cost and could be lower because many designs will already have many of these features. Further details are available in a BRANZ study report.[12]

[12] Page, I. & Curtis, M. (2011). *Lifetime housing – the value case*. Study Report SR263, BRANZ.

Table 8. Typical costs to add user-friendly (UF) features to new housing

Typical additional UF costs - single storey house concrete floor		
	Floor area 176sqm incl garage ($299,000)	
	Items	$
Outside	Sufficient width at carpark/ garage	360
	Path with gentle slope/ sufficient width	310
	Roof shelter over front entrance	680
	Sensor lamp	30
		1,380
Inside	Hallway sufficient width (widen house by 150mm)	4,510
	Wide Internal doors, minimum 860mm (7 of)	420
	Extra size shower, seat, grab rail, strengthen walls	1,200
		6,130
	Total additional cost (Option 1 - All Outside and inside measures)	7,510
	Total additional cost (Option 2 - All measures except no floor area addition)	3,000

3.5 Minimising lifecycle costs of materials

One characteristic of a resilient building is that the maintenance requirement is low, but this usually means more expenditure up-front in the choice of materials. There is a trade-off between the two costs and this can be calculated as the lifetime cost. Future maintenance costs are discounted back to present day dollar values and added to the initial cost. The total is then spread over the life of the material so that materials with different durabilities can be compared on a consistent basis.

This analysis is shown in Table 9 for house claddings. Some materials need repainting every 10 years, while other materials last 40 years before requiring repairs or maintenance such as re-pointing.

The low-maintenance claddings are concrete tiles and clay or concrete bricks which have durabilities over 60 years, with a half-life check for any repairs that may be required.

Unpainted sheet metal claddings are the cheapest for lifecycle costs. They have a quite short lifespan but their initial cost is very low so their annual cost is also low. The assumed durabilities in years are shown in the table, together with the maintenance regime for each cladding.

The costs do not allow for disruption caused by maintenance or replacement. For example, there may be temporary accommodation expenses when claddings are replaced. These costs will affect the short durability sheet steel options more than the long-life materials.

There is also the issue of appearance – decisions are not made solely on cost. Appearance is important to the owner. The more expensive longer-life products maintain their appearance better than the cheaper materials. The first owners are unlikely to still be in residence at cladding replacement, but they will be concerned about resale value. Hence the predominance of the more expensive materials, particularly for wall claddings, such as clay brick and timber weatherboard. The market share of these was 37% and 34% respectively in the 2014 BRANZ new house survey.

Table 9. Roof and wall cladding lifetime costs

Lifetime costs of new house claddings				
Roof claddings	Average life	Initial cost		Lifetime
Type	years	$/sqm		$/sq per year
Corrugatedsteel 0.40mm zincalum, unpainted, no maintenance	20-30	33	)	
Corrugated steel 0.55mm ,zincalum unpainted, no maintenance.	30-40	39	)	$2.5 to $3.5
Aluminum corrugated 0.70mm unpainted, no maintenance	60-80	44	)	per sqm per year
Concrete tiles, re-point @ 35 yrs, replace some tiles.	80-100	52	)	
Metal tiles ZRX acrylic, no maintenance	40-60	62	)	$3.6 to $4.5
Corrugated steel 0.40mm , ZRX, pre-coated, re-paint @ 10 yrs	40-60	47	)	per sqm per year
Corrugated steel 0.55mm, ZRX, pre-coated, re-paint @ 10 yrs	40-60	53	)	
Trapezoidal steel low-rib, ZRX, 0.55mm, pre-coated, re-paint @ 10yrs	40-60	68	)	$4.6 to $6.0
Trough steel 0.55mm , ZRX,pre-coated, re-paint @ 10 yrs	40-60	78	)	per sqm per year
Wall claddings				
Corrugatedsteel 0.40mm zincalum, unpainted, no maint	20-25	54	)	
Corrugated steel 0.55mm pre-coated, re-paint @ 10yrs	40-50	74	)	$3.0 to $7.9
Sheet plywood and batten, painted, re-paint @ 10 yrs.	40-60	91	)	per sqm per year
Fibre cement sheet 7.5mm+PVC jointing, painted, re-paint @ 10 yrs	40-60	84	)	
Fibre cement planks 180 mm, painted, re-paint @ 10yrs.	30-40	117	)	
EIFS 60mm polystrene, re-paint @ 10 yrs.	30-40	136	)	$8.0 to $10.9
Facing clay bricks, 70mm, re-point @ 40 yrs.	60-80	150	)	per sqm per year
Concrete bricks, re-point 35 yrs.	60-80	150	)	
PVC weatherboard, no painting	25-35	159	)	
Fibre cement weatherboard profile, 150mm, painted, re-paint @ 10 yrs.	30-40	154	)	per sqm per year
Radiata weatherboard, painted, re-paint @ 10 yrs.	40-60	177	)	$11.0 to $15.0
Cedar weatherboard, unpainted, chemical wash @ 15yrs	25-35	205	)	
Maintenance costs are brought back to present values using a discount rate of 6%. This is added to the initial cost and the total divided by the life of the cladding to give $/sqm per year.				
For wall claddings the forming of the drainage cavity is included in the initial costs.				
For roof claddings concrete and metal tile battens have been included in the initial cost.				
Costs are based on the Rawlinson NZ Construction Handbook 2013/14.				

4. Discussion

Insulation levels as per the schedule method are near optimum in the three regions examined in detail. In Wellington and Christchurch, a slight amount of above-minimum insulation (namely under-slab perimeter insulation) is economic, but not in the upper North Island, assuming a medium heating regime.

The analysis has assumed a constant electricity price across New Zealand because an examination of local tariffs indicates there is not a great variation. However, this could change with the current Electricity Commission review of bulk transmission costs and charges. Prices in the North Island could increase, and decrease in the lower south. We have not allowed for this possible change in our analysis, instead assuming, as in the base case, that prices increase everywhere at 2% per annum.

The assumed price of electric radiant heat is 27 c/kWh, but with heat pumps the effective cost is somewhat lower. Manufacturers often quote a performance coefficient (COP) of 3 or above for their heat pumps. This is often assumed to mean the cost of delivering heating energy is a third of the electricity price. However, quite often the COP is somewhat lower in operation and we have conservatively assumed a COP of 2.0. On top of this, the cost of the heat pump needs to be included in the financials calculations. This is done in Table 10, and the two factors together give a price of about 18c/kWh for delivered heat in most regions.

Any summer cooling using heat pumps in reverse operation has been ignored in the analysis. This use of heat pumps occurs in several parts of the country and generally the amount of cooling is very much less than heating energy use. Hence the cooling energy savings with more insulation is not considered to be significant in the overall analysis.

Payback periods for extra insulation are shown in Tables 11 to 14. These indicate quite long periods for most locations except for the high heating regime. Many first owners of new homes are not home during the weekday and hence above-code insulation cannot be justified financially for their circumstances. However, we need to consider future owners, who may wish to heat differently, i.e. to a higher regime. It can be argued the design should consider their needs. Also, above-code insulation could be a selling point for the initial owner when they decide to move, and effectively recover the initial extra cost in the sales price.

The flatness of the insulation curves (Figure 2), indicate their relative insensitivity to which additional insulation combination is chosen. New Zealand currently has sufficient electricity supplies, with additional demand being met by wind generation on an incremental basis at quite low cost. However, should demand increase rapidly due to population growth and exhaustion of the lower-cost hydro and wind power sites, then government may look to electricity conservation measures to reduce future price rises. One method for this is to restrict growth in domestic demand through greater insulation requirements.

Similar arguments apply for domestic water supply where marginal costs can rise quite quickly as the lower-cost supply sites are exhausted. Even though domestic water supplies in most areas are not metered, there is a cost to providing water that is paid for through local body rates. Where metering has been introduced it has generally resulted in significant falls in consumption and is valuable tool in situations where supply costs increase significantly with growth in demand.

Rainwater tanks in reticulated areas help to reduce demand. They are cost effective in several locations where the supply cost is over about 0.15c per litre and summer rainfall is sufficient to replenish tank supply.

Solar water heating and solar power generation have quite long payback periods for domestic use and are not cost effective in most situations. Generally households should look to make savings in other areas, such as the types of heating appliance, slab insulation for new houses, efficient lighting and water saving devices.

The resilience factors considered in this report are generally catered for by regulation. For example, new housing in designated flood risk areas will need to be built to meet specific minimum floor level requirements. Current design loadings allow for severe wind and earthquake actions so safety is adequately addressed in new housing. However, additional bracing may be cost effective in reducing repair costs in smaller earthquakes, and BRANZ is doing more work on this.

Lifetime design housing costs very little more than standard housing and is well worth doing in new housing. The BRANZ study quoted earlier shows that early consideration of user-friendly features as set out in the Lifetime Design specifications provides a significant increase in amenity with minimal cost.

For households likely to be resident for a long period then maintenance is a concern and this burden can be significantly reduced through additional initial expenditure on more durable materials.

5. Analysis details and data sheets

5.1 Energy pricing and insulation variations

The derivation of the energy cost using heat pumps is shown in Table 10. Retail electricity prices do not vary much across New Zealand. The cost of the heat pump is expressed as cents per kWh over a 15-year life. It is added to the retail price divided by the coefficient of performance (COP). Conservative values for COP have been used, with slightly lower values in the cooler parts of New Zealand. The net result is that the energy delivered cost is about 18 c per kWh for all locations, and this was used as the base case because heat pumps are more common in new housing than radiant heaters.

Table 10. Energy cost with heat pumps

Energy cost assuming heat pump appliance						highest	lowest
	Auckland	Wellington	Christch	Invercargil	Queenstn	Balclutha	Rangiora
c/kWh (1)	27.4	27.0	27.0	25.8	27.6	39.1	25.4
kwH per yr (2)	3000	6100	7000	11600	10800		
Heat pump $ (3)	2600	3200	3700	5000	5000		
HP c/kWh (4)	8.3	5.1	5.1	4.2	4.5		
COP (5)	2.8	2.5	2.4	2.0	2.0		
Total c/kWh (6)	18.1	15.9	16.3	17.1	18.3	use 18 c/kWh all NZ	
(1) Domestic electricity (after discounts, incl GST), @ Nov 2015, source MBIE							
(2) Energy use medium sized house, medium heat regime.							
(3) Heat pump sized for peak kW and includes installation							
(4) Heat pump cost expressed as cost per kWh assuming 15 year life							
(5) Coefficient of performance, lower in cooler regions. A conservative estimate.							
(6) Effective energy cost per kWH delivered.							

Tables 11–14 show payback periods for above-minimum insulation. Two energy prices are shown, namely 18 c/kWh (heat pump) and 27 c/kWh (radiant heaters). The higher energy price makes extra insulation more cost effective and reduces the payback period. Some results:

- More roof and wall insulation is generally only cost effective at high heating regimes. With radiant heaters, the payback period reduces, but again extra insulation is cost effective only for high-heat regimes.
- Slightly more roof insulation is, however, cost effective in the lower North Island for the medium-heating regime.
- Under-slab insulation is cost effective for the medium-heating regime in the lower North Island and for all heat regimes in the South Island.

In the North Island, reticulated natural gas is available in most urban areas. The charges in the main centres are approximately 8c/kWh variable, daily fixed charge about 3 c/ kWh, and the gas heater with flue 6 c/kWh, giving a total of about 17 c/kWh. The latter two fixed charges have been converted to a unit consumption charge. The total is similar to the heat pump unit cost.

Table 11. Payback periods in years for above-minimum insulation - Climate zones 1 and 2 - 18 c per kWh (i.e heat pump heating)

Payback periods- Climate Zones 1 and 2	Whangarei			Auckland			Hamilton			Tauranga			Napier			New Plymouth			Palmerston Nor			Masterton			Wellington		
Heating regimes	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low
Wall Insul R2.6	40+	40+	40+	19	34	40+	13	25	30	20	35	40+	17	31	39	19	33	40+	10	21	25	9	19	23	10	21	25
Wall Insul R2.6, 140 studs	40+	40+	40+	23	40+	40+	16	30	36	24	40+	40+	20	37	40+	23	40	40+	13	26	30	12	24	28	13	26	31
Wall Insul R2.8, 140 studs	40+	40+	40+	24	40+	40+	16	31	37	25	40+	40+	21	38	40+	23	40+	40+	13	26	31	12	24	29	13	26	31
Wall Insul R3.4, 140 studs	40+	40+	40+	26	40+	40+	18	34	40	27	40+	40+	23	40+	40+	26	40+	40+	15	29	34	13	27	31	15	29	34
Roof Insul R4	40+	40+	40+	15	28	36	10	20	25	16	29	38	13	25	32	15	27	35	8	17	20	7	15	18	8	17	20
Roof Insul R4.4	40+	40+	40+	20	36	40+	13	26	32	21	37	40+	17	32	40	19	35	40+	11	22	26	10	20	24	11	22	26
Roof Insul R5	40+	40+	40+	21	37	40+	14	27	33	22	38	40+	18	34	40+	20	36	40+	11	23	27	10	21	25	11	23	27
Roof Insul R5.5	40+	40+	40+	25	40+	40+	17	33	39	26	40+	40+	22	40	40+	25	40+	40+	14	28	33	13	26	30	14	28	33
Windows DbGl low-e	40+	40+	40+	25	40+	40+	17	36	40+	26	40+	40+	22	40+	40+	24	40+	40+	14	30	36	12	28	33	14	31	36
DbGl, low-e,argon, wood/pvc frame	40+	40+	40+	34	40+	40+	24	40+	40+	35	40+	40+	30	40+	40+	33	40+	40+	20	39	40+	18	36	40+	20	39	40+
Slab 1.2 m perimeter 50mm eps	40+	40+	40+	13	25	32	9	18	22	14	25	34	11	22	28	13	24	31	7	15	18	6	13	16	7	15	18
Slab whole slab 50mm eps	40+	40+	40+	16	29	37	10	21	25	17	30	39	14	26	33	15	28	36	8	17	21	7	16	19	8	17	21

Payback periods are for additional insulation to the Schedule Method, Wall R2.2 Roof R3.2 Window DbGl Slab nil insul

Heating regimes. High: 20 degC for 24 hours

Medium: 20 degC for 2 hours morning, 6 hours evening. Discount rate=5% Energy cost =18 c/kWh

Low: 18 degC for 2 hours morning, 6 hours evening.

The payback period (years) needs to be in the green shading to be cost effective, otherwise the period is too long for the average homeowner. A payback period of 15 years represents a 5% return but it counts savings after the 15-year period up to 25 years.

Table 12. Payback periods in years for above-Code insulation - Climate zone 3 - 18c per kWh

Payback periods- Climate Zone 3	Taupo			Nelson			Christchurch			Dunedin			Queenstown			Invercargill		
Heating regimes	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low
Wall Insul R2.6, 140 studs	13	27	31	13	27	32	13	27	31	12	24	28	9	19	23	9	18	21
Wall Insul R2.8, 140 studs	12	26	30	13	26	31	13	25	30	11	23	27	9	18	22	8	17	20
Wall Insul R3.4, 140 studs	14	28	33	14	29	34	14	28	33	12	25	29	10	20	24	9	19	22
Roof Insul R4.4	12	24	28	12	25	29	12	24	28	11	21	25	8	18	20	8	16	19
Roof Insul R5	11	23	27	11	23	27	11	23	27	10	20	24	8	16	19	7	15	18
Roof Insul R5.5	13	28	32	14	28	33	14	28	32	12	25	29	10	20	24	9	19	22
Windows DbGl low-e	11	26	30	12	27	32	12	27	31	10	24	28	8	19	23	7	18	21
DbGl, low-e,argon, wood/pvc frame	16	34	39	17	35	40	17	34	40	15	31	36	12	25	29	11	24	28
Slab 1.2 m perimeter 50mm eps	6	13	15	6	13	15	6	12	15	5	11	13	4	9	10	4	8	10
Slab whole slab 50mm eps	7	15	18	7	15	18	7	15	18	6	13	16	5	10	12	4	10	12

Payback periods are for additional insulation to the Schedule Method, Wall R2.6 Roof R4 Window DbGl Slab nil insul

Heating regimes. High: 20 degC for 24 hours

Medium: 20 degC for 2 hours morning, 6 hours evening.

Low: 18 degC for 2 hours morning, 6 hours evening.

Discount rate=5% Energy cost =18 c/kWh

Table 13. Payback periods in years for above-Code insulation - Climate zones 1 and 2 - 27 c per kWh (i.e. radiant or panel heaters)

Payback periods- Climate Zones 1 and 2	Whangarei			Auckland			Hamilton			Tauranga			Napier			New Plymouth			Palmerston Nor			Masterton			Wellington		
Heating regimes	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low
Wall Insul R2.6	40+	40+	40+	13	25	32	9	18	22	14	26	35	12	23	29	13	25	32	7	15	18	6	14	17	7	15	18
Wall Insul R2.6, 140 studs	40+	40+	40+	17	30	39	11	22	27	17	31	40+	15	28	35	16	30	38	9	19	22	8	17	20	9	19	22
Wall Insul R2.8, 140 studs	40+	40+	40+	17	31	40	11	23	27	18	32	40+	15	28	35	17	30	39	9	19	23	8	17	21	9	19	23
Wall Insul R3.4, 140 studs	40+	40+	40+	19	34	40+	12	25	30	20	35	40+	17	31	39	18	33	40+	10	21	25	9	19	23	10	21	25
Roof Insul R4	40+	40+	40+	11	20	26	7	14	18	11	21	28	9	18	23	10	20	26	6	12	14	5	11	13	6	12	14
Roof Insul R4.4	40+	40+	40+	14	26	34	9	19	23	15	27	36	12	24	30	14	26	33	7	16	19	7	14	17	7	16	19
Roof Insul R5	40+	40+	40+	15	27	35	10	20	24	16	28	37	13	25	31	14	27	35	8	17	20	7	15	18	8	16	20
Roof Insul R5.5	40+	40+	40+	18	33	40+	12	24	29	19	34	40+	16	30	37	18	32	40+	10	20	24	9	18	22	10	20	24
Windows DbGl low-e	39	40+	40+	18	36	40+	12	26	32	18	37	40+	16	33	38	17	35	40	10	22	26	9	20	24	10	22	26
DbGl, low-e,argon, wood/pvc frame	40+	40+	40+	25	40+	40+	17	34	40	26	40+	40+	22	40+	40+	24	40+	40+	14	29	34	13	27	31	14	29	34
Slab 1.2 m perimeter 50mm eps	40+	40+	40+	9	18	23	6	12	15	10	18	25	8	16	21	9	17	23	5	10	12	4	9	11	5	10	13
Slab whole slab 50mm eps	40+	40+	40+	11	21	27	7	15	18	12	22	29	9	19	24	11	20	27	6	12	15	5	11	13	6	12	15

Payback periods are for additional insulation to the Schedule Method, Wall R2.2 Roof R3.2 Window DbGl Slab nil insul

Heating regimes. High: 20 degC for 24 hours

Medium: 20 degC for 2 hours morning, 6 hours evening.

Low: 18 degC for 2 hours morning, 6 hours evening.

Discount rate=5% Energy cost =27 c/kWh

The payback period (years) needs to be in the green shading to be cost effective, otherwise the period is too long for the average homeowner. A payback period of 15 years represents a 5% return, but it counts savings after the 15-year period up to 25 years.

Table 14. Payback periods in years for above-minimum insulation - Climate zone 3 – 27c per kWh

Payback periods- Climate Zone 3	Taupo			Nelson			Christchurch			Dunedin			Queenstown			Invercargill		
Heating regimes	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low
Wall Insul R2.6, 140 studs	9	19	23	9	20	23	9	19	23	8	17	20	6	14	16	6	13	15
Wall Insul R2.8, 140 studs	9	19	22	9	19	22	9	18	22	8	16	19	6	13	15	6	12	14
Wall Insul R3.4, 140 studs	9	20	24	10	21	25	10	20	24	9	18	21	7	15	17	6	14	16
Roof Insul R4.4	8	18	21	8	18	21	8	17	21	7	15	18	6	12	15	5	12	14
Roof Insul R5	7	16	19	8	17	20	8	16	19	7	14	17	5	11	14	5	11	13
Roof Insul R5.5	9	20	24	10	21	24	10	20	24	9	18	21	7	14	17	6	13	16
Windows DbGl low-e	8	18	22	8	20	23	8	19	23	7	17	20	5	13	16	5	13	15
DbGl, low-e,argon, wood/pvc frame	11	25	29	12	26	30	12	25	29	10	22	26	8	18	21	8	17	20
Slab 1.2 m perimeter 50mm eps	4	9	10	4	9	11	4	9	10	3	7	9	3	6	7	3	6	7
Slab whole slab 50mm eps	5	10	12	5	11	13	5	10	12	4	9	11	3	7	9	3	7	8

Payback periods are for additional insulation to the Schedule Method, Wall R2.6 Roof R4 Window DbGl Slab nil insul

Heating regimes. High: 20 degC for 24 hours

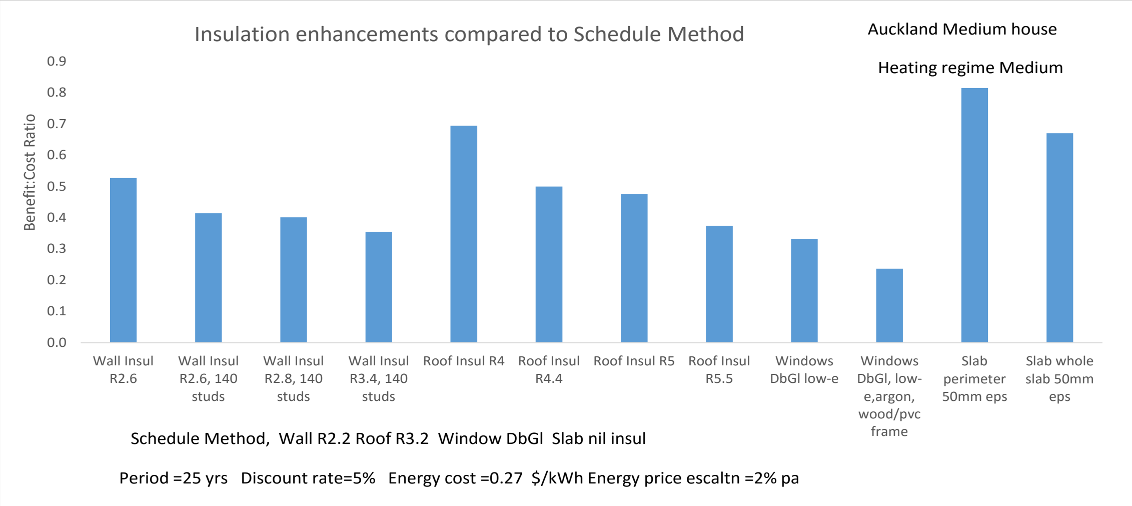
Medium: 20 degC for 2 hours morning, 6 hours evening. Discount rate=5% Energy cost =27 c/kWh

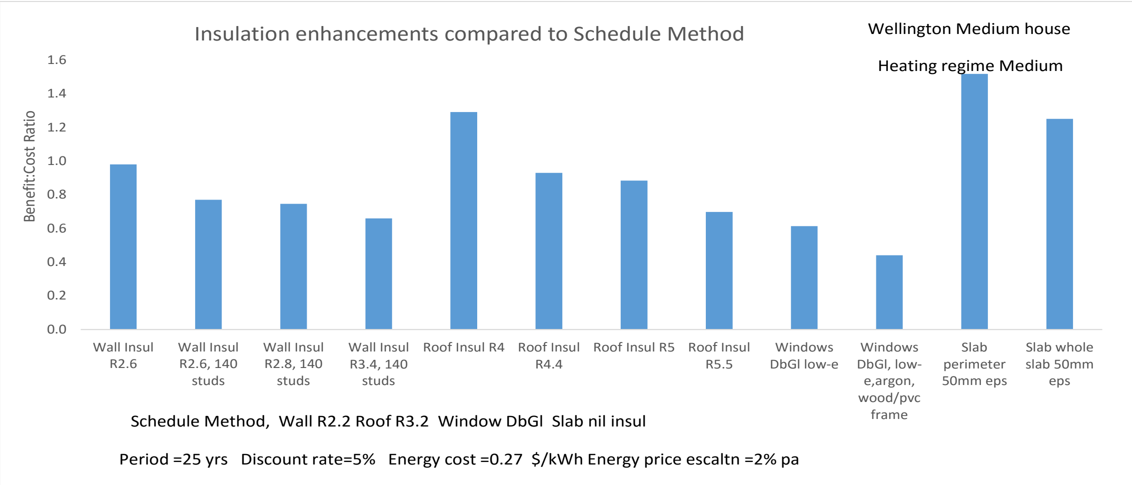
Low: 18 degC for 2 hours morning, 6 hours evening.

The payback period (years) needs to be in the green shading to be cost effective, otherwise the period is too long for the average homeowner.

5.2 Sensitivity analysis

A comparison of Figure 8 with Figure 1 shows benefit:cost ratios have improved with higher energy prices, but are still not over 1.0 in Auckland. However, in Wellington they are larger, encouraging additional roof insulation, and in Christchurch slab insulation becomes significantly more economic.





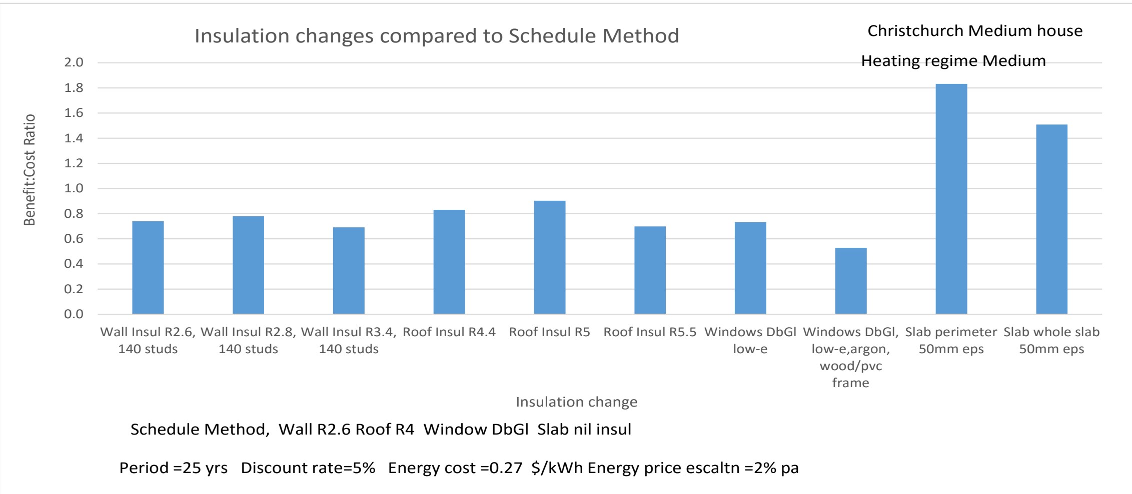
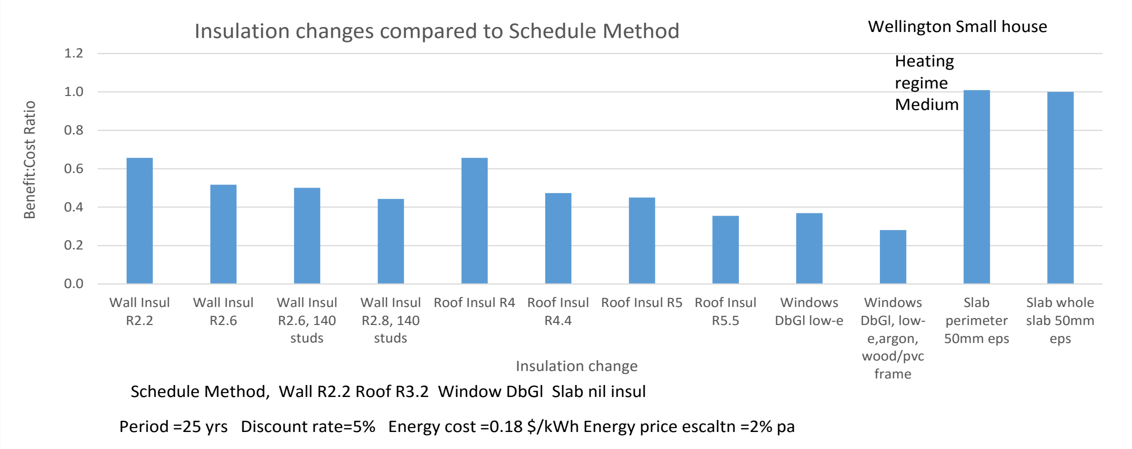
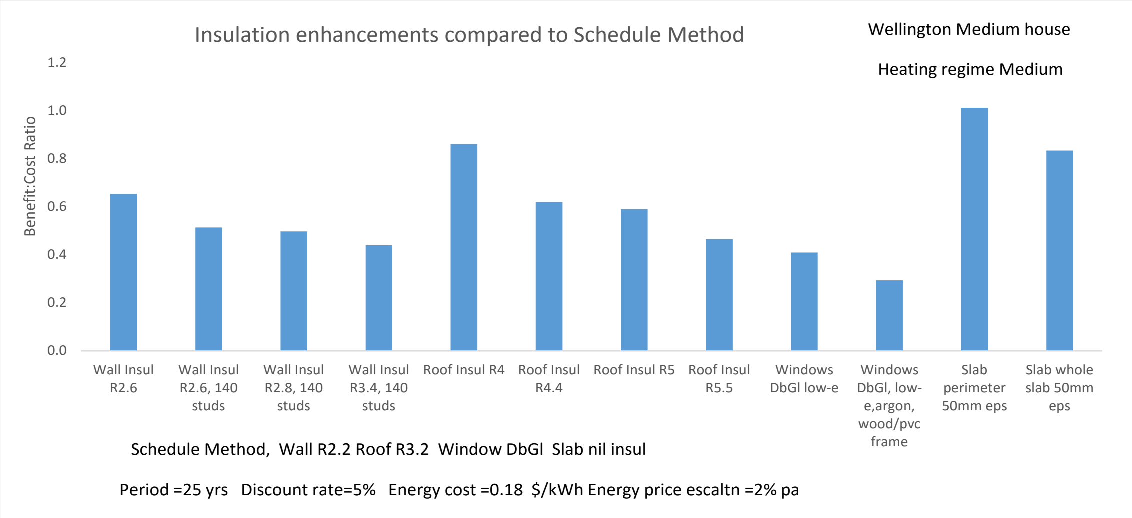


Figure 8. Benefit:cost ratios– high energy price (27c per kWh)

In Figure 9 the benefit:cost ratios are tested for three different sized houses in Wellington. The main change is that more roof insulation becomes cost effective. The houses sizes are small – 105 m^2 single storey; medium - 184 m^2 single storey, and large – 255 m^2 two storey. Garages are included in the floor area. The floor plan for the medium-sized house is shown in Figure 10.





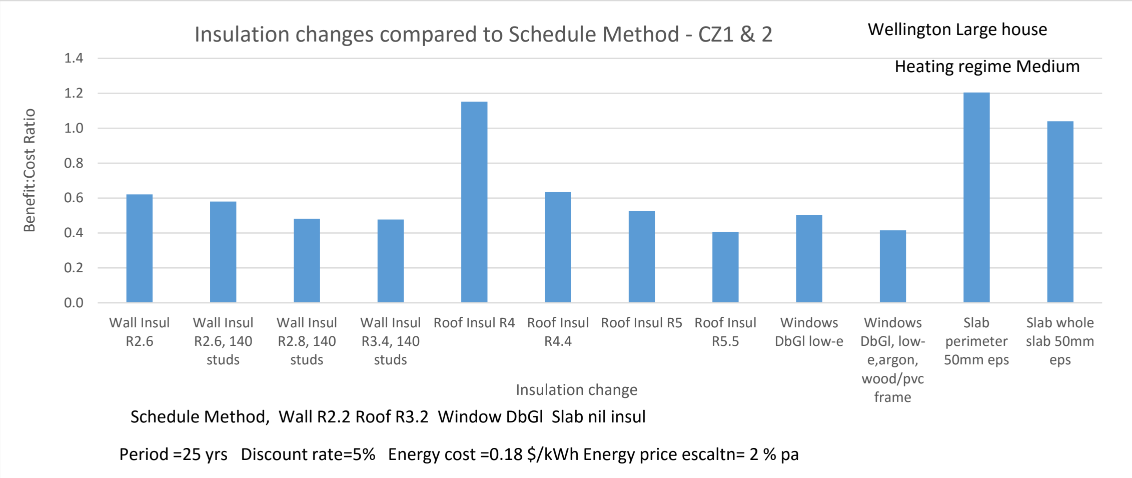


Figure 9. Benefit:cost ratios – different-sized houses

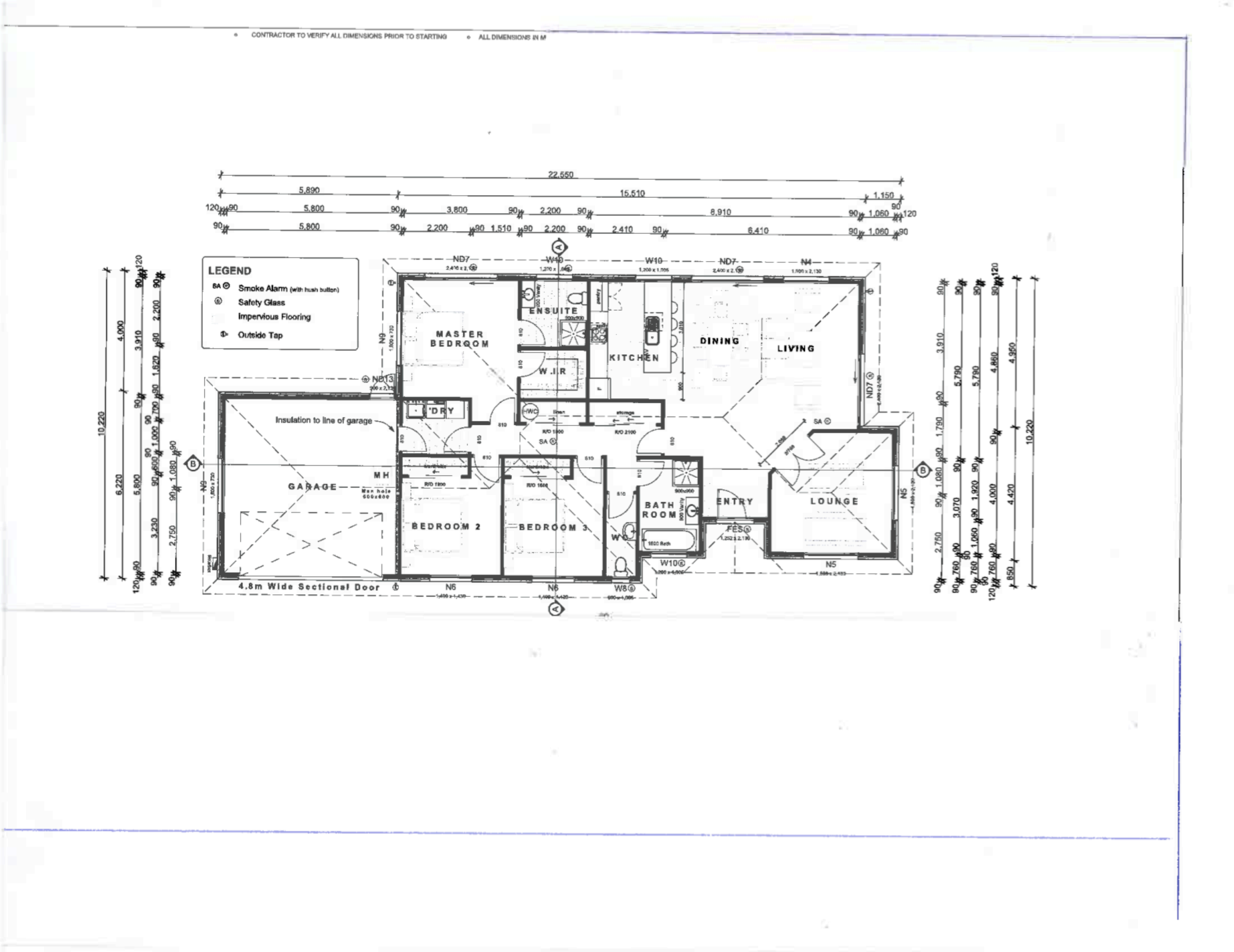


Figure 10. Floor plan for medium-sized house

In Figures 11–14, the financial parameters are changed including years of occupancy, energy cost, energy price escalation and the discount rate. It is a sensitivity analysis for more ceiling insulation in a medium-sized house with a medium heating regime

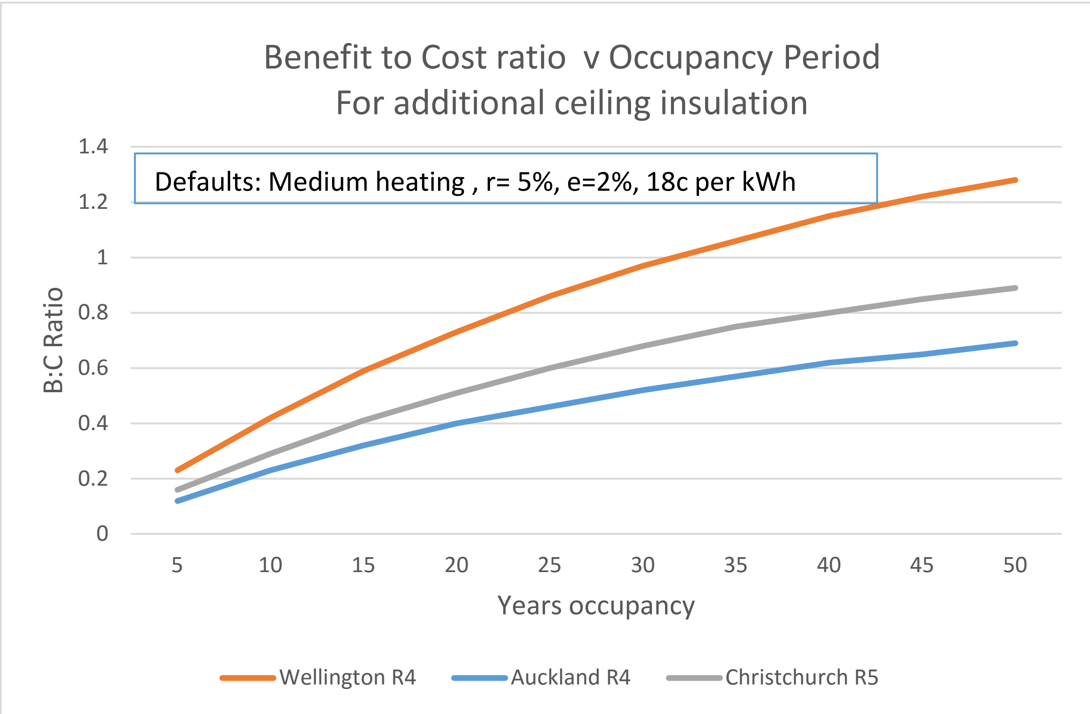


Figure 11. Benefit:cost ratio versus occupancy period

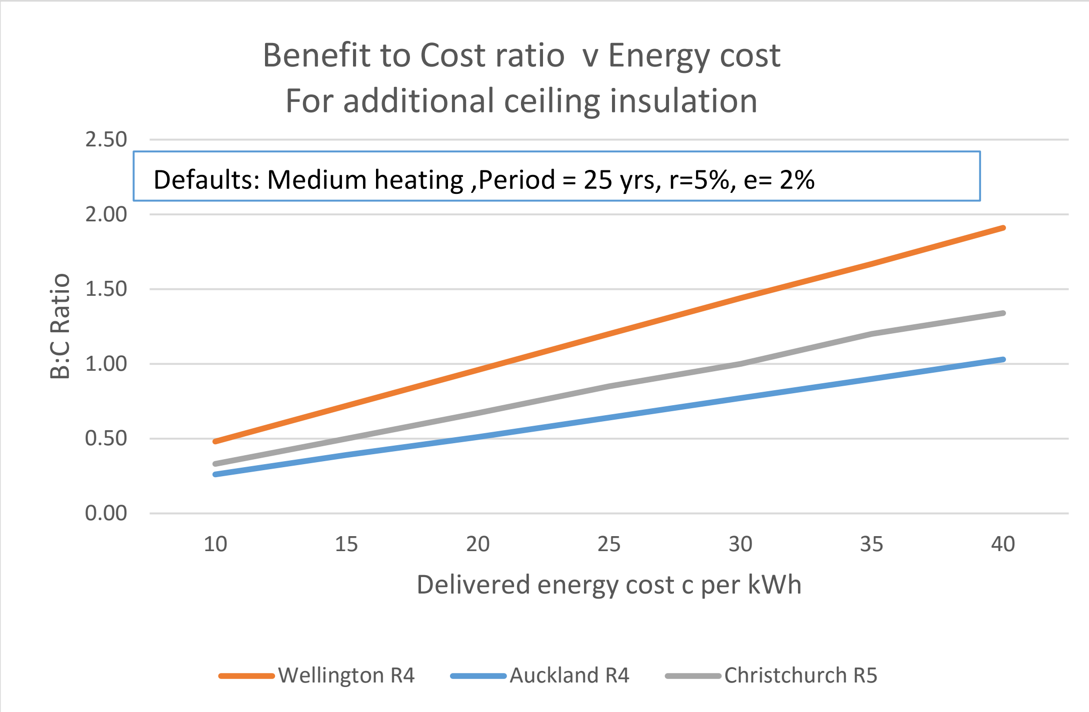


Figure 12. Benefit:cost ratio versus energy price

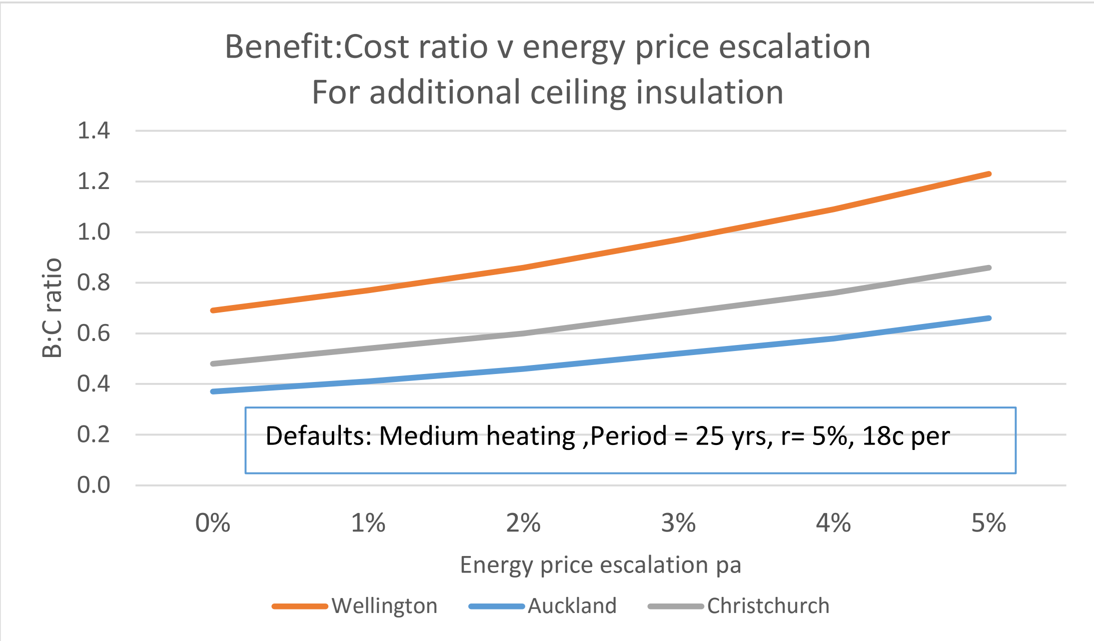


Figure 13. Benefit:cost ratio versus energy price escalation

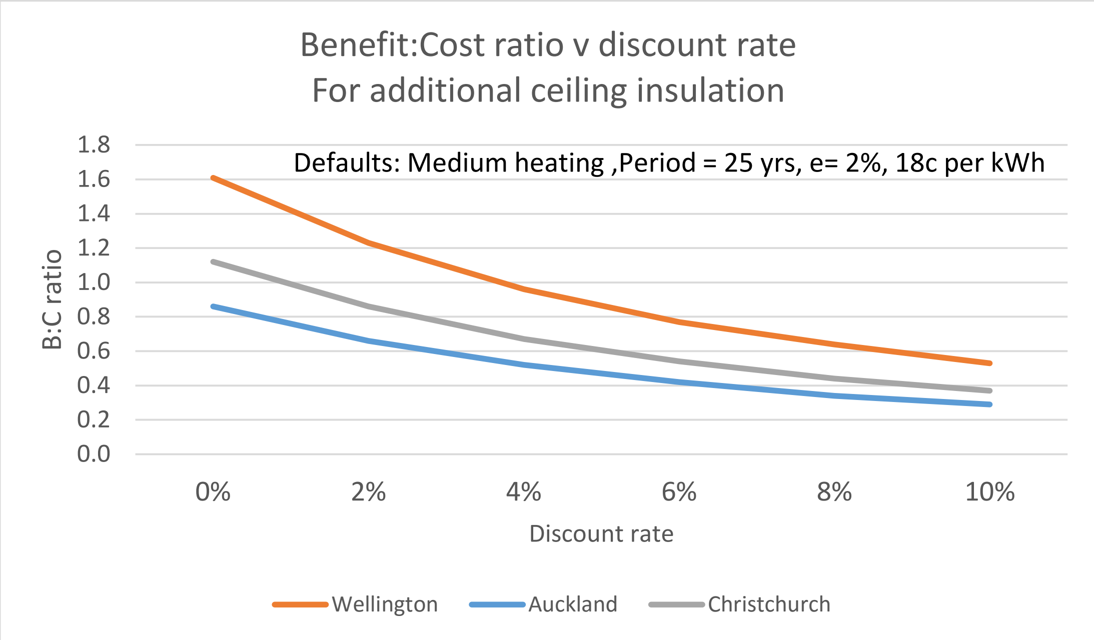


Figure 14. Benefit:cost ratio versus discount rate

The sensitivity analysis for the medium house, median heating regime is shown above in Figures 11–14. It shows that more ceiling insulation is justified in Wellington for over 30 years' occupancy (Figure 11). The minimum required structural durability of structures is 50 years, so from a national benefit viewpoint this insulation can be justified even if the first owner does not get the benefit of additional ceiling insulation. Also for national benefit, more ceiling insulation in Wellington is justified if the energy price is over 20 c/kWh (Figure 12), energy price escalation is over 3% pa (Figure 13) and if the discount rate is below 5% (Figure 14).

Tables 15–17 show the calculations for rainwater tank sizes and their costs. The calculations use the city summer and winter rainfalls, house sizes and number of occupants. The rainfall is assumed to occur on two occasions each month, which means the tank size can be smaller than if it was a single event. The maximum size was limited to 10,000 litres due to site restrictions on most redeveloped city housing sites. For example, the 180 Lpd case, Table 16, 200 m^2 house, the tank supplies between 44% and 87% of peak summer demand, depending on the location. The remaining summer water requirement is supplied from the city reticulation.

The three tables are for increasing water use per person per day (Lpd). At the high water use (360 Lpd) the payback comes down to about 10 years for some locations.

Table 18 has the calculation for flood repairs using like-for-like replacements and for installing more resilient materials. It indicates that spending an extra $40/m2 floor area enables resilient materials to be used for the linings, insulation, trim and doors. This investment reduces repair cost in future floods by $68/m^2.

Table 19 has the earthquake bracing calculations for a medium-sized house. Two types of cladding are used, lightweight and heavyweight, because the capacity for extra bracing varies between the two. The table indicates that for small earthquakes with a return period of 25 years, 50% more bracing above-minimum requirements is cost effective in houses with lightweight cladding if the damage otherwise incurred is more than $3,100. For a house with heavy cladding (wall and/or roof) it is difficult and quite expensive to install more bracing and its economics are not favourable. Further work is needed on the trade-off between bracing cost and reduced damage for minor but frequent earthquakes.

Table 15. Rainwater use details for 180 litres per person per day

Rainwater tanks - the financial case			Average use=180 Lpd, Moderate		
House size sqm	100	120	170	200	250
Persons #	1	2	3	4	4
Required tank size (litres) to supply toilet, washer and outdoor use					
Auckland	2,000	3,500	5,500	5,500	10,000
Tauranga	2,000	3,500	5,500	10,000	10,000
Wellington	2,000	3,500	5,500	10,000	10,000
Nelson	2,000	3,500	5,500	5,500	10,000
Christchurch	2,000	2,000	3,500	3,500	4,000
Dunedin	2,000	3,500	3,500	4,000	5,500
% of summer demand meet from rainwater tank					
Auckland	100%	91%	86%	76%	95%
Tauranga	100%	100%	98%	87%	100%
Wellington	100%	97%	91%	81%	100%
Nelson	100%	88%	83%	73%	92%
Christchurch	88%	53%	50%	44%	55%
Dunedin	100%	67%	63%	56%	70%
Cost tank + pump + plumbing + electrical $					
Auckland	2,550	2,750	3,050	3,050	4,250
Tauranga	2,550	2,750	3,050	4,250	4,250
Wellington	2,550	2,750	3,050	4,250	4,250
Nelson	2,550	2,750	3,050	3,050	4,250
Christchurch	2,550	2,550	2,750	2,750	2,850
Dunedin	2,550	2,750	2,750	2,850	3,050
Total annual water cost savings with a tank $					
Auckland	164	205	246	274	311
Tauranga	84	152	218	265	288
Wellington	143	196	243	275	313
Nelson	195	254	317	362	411
Christchurch	126	107	114	112	141
Dunedin	135	150	187	205	241
Simple payback period yrs					
Auckland	16	13	12	11	14
Tauranga	30	18	14	16	15
Wellington	18	14	13	15	14
Nelson	13	11	10	8	10
Christchurch	20	24	24	24	20
Dunedin	19	18	15	14	13
Cost of water cents/litre (for 3 person household and given Lpd)					
Auckland	0.43	0.29	0.24	0.21	0.21
Tauranga	0.22	0.20	0.19	0.19	0.19
Wellington	0.38	0.26	0.23	0.21	0.21
Nelson	0.52	0.36	0.31	0.29	0.29
Christchurch	0.36	0.21	0.16	0.13	0.13
Dunedin	0.36	0.25	0.21	0.20	0.20
Assume average water useage Lpd is =		180	of which about 58% can be supplied by		
rainwater for use in toilets, washer and outdoors. Tank size allows for the expected summer					
rainfall in each region.					

Table 16. Rainwater use details for 270 litres per person per day

Rainwater tanks - the financial case				Average use=270 Lpd, High	
House size sqm	100	120	170	200	250
Persons #	1	2	3	4	4
	Required tank size (litres) to supply toilet, washer and outdoor use				
Auckland	3,500	3,500	5,500	5,500	10,000
Tauranga	3,500	4,000	5,500	10,000	10,000
Wellington	3,500	3,500	5,500	10,000	10,000
Nelson	3,500	3,500	5,500	5,500	10,000
Christchurch	2,000	2,000	3,500	3,500	4,000
Dunedin	2,000	3,500	3,500	4,000	5,500
	% of summer demand meet from rainwater tank				
Auckland	100%	61%	58%	51%	64%
Tauranga	100%	69%	66%	58%	72%
Wellington	100%	64%	61%	54%	67%
Nelson	98%	59%	55%	49%	61%
Christchurch	59%	35%	33%	29%	37%
Dunedin	74%	45%	42%	37%	46%
	Cost tank + pump + plumbing + electrical $				
Auckland	2,750	2,750	3,050	3,050	4,250
Tauranga	2,750	2,850	3,050	4,250	4,250
Wellington	2,750	2,750	3,050	4,250	4,250
Nelson	2,750	2,750	3,050	3,050	4,250
Christchurch	2,550	2,550	2,750	2,750	2,850
Dunedin	2,550	2,750	2,750	2,850	3,050
	Total annual water cost savings with a tank $				
Auckland	190	204	256	296	329
Tauranga	118	179	254	314	352
Wellington	171	200	259	304	340
Nelson	231	264	343	399	450
Christchurch	109	81	89	91	113
Dunedin	136	134	169	186	233
	Simple payback period yrs				
Auckland	14	13	12	10	13
Tauranga	23	16	12	14	12
Wellington	16	14	12	14	13
Nelson	12	10	9	8	9
Christchurch	23	32	31	30	25
Dunedin	19	21	16	15	13
Cost of water cents/litre (for 3 person household and given Lpd)					
Auckland	0.34	0.24	0.20	0.19	0.19
Tauranga	0.21	0.19	0.19	0.19	0.19
Wellington	0.30	0.23	0.20	0.19	0.19
Nelson	0.41	0.31	0.28	0.26	0.26
Christchurch	0.26	0.16	0.12	0.11	0.11
Dunedin	0.29	0.21	0.19	0.18	0.18
Assume average water useage Lpd is =		270	of which about 58% can be supplied by		
rainwater for use in toilets, washer and outdoors. Tank size allows for the expected summer					
rainfall in each region.					

Table 17. Rainwater use details for 360 litres per person per day

Rainwater tanks - the financial case			Average use=360 Lpd, Very high		
House size sqm	100	120	170	200	250
Persons #	1	2	3	4	4
Required tank size (litres) to supply toilet, washer and outdoor use					
Auckland	3,500	3,500	5,500	5,500	10,000
Tauranga	3,500	4,000	5,500	10,000	10,000
Wellington	3,500	3,500	5,500	10,000	10,000
Nelson	3,500	3,500	5,500	5,500	10,000
Christchurch	2,000	2,000	3,500	3,500	4,000
Dunedin	2,000	3,500	3,500	4,000	5,500
% of summer demand meet from rainwater tank					
Auckland	64%	39%	36%	32%	40%
Tauranga	73%	44%	42%	37%	46%
Wellington	68%	41%	38%	34%	42%
Nelson	62%	37%	35%	31%	39%
Christchurch	37%	22%	21%	19%	23%
Dunedin	47%	28%	27%	24%	29%
Cost tank + pump + plumbing + electrical $					
Auckland	2,750	2,750	3,050	3,050	4,250
Tauranga	2,750	2,850	3,050	4,250	4,250
Wellington	2,750	2,750	3,050	4,250	4,250
Nelson	2,750	2,750	3,050	3,050	4,250
Christchurch	2,550	2,550	2,750	2,750	2,850
Dunedin	2,550	2,750	2,750	2,850	3,050
Total annual water cost savings with a tank $					
Auckland	179	205	265	313	344
Tauranga	136	195	280	326	387
Wellington	170	205	272	323	360
Nelson	222	263	339	380	474
Christchurch	89	67	77	80	100
Dunedin	130	123	158	177	221
Simple payback period yrs					
Auckland	15	13	12	10	12
Tauranga	20	15	11	13	11
Wellington	16	13	11	13	12
Nelson	12	10	9	8	9
Christchurch	29	38	36	34	29
Dunedin	20	22	17	16	14
Cost of water cents/litre (for 3 person household and given Lpd)					
Auckland	0.29	0.21	0.19	0.18	0.18
Tauranga	0.20	0.19	0.19	0.19	0.19
Wellington	0.26	0.21	0.19	0.18	0.18
Nelson	0.36	0.29	0.26	0.25	0.25
Christchurch	0.21	0.13	0.11	0.09	0.09
Dunedin	0.25	0.20	0.18	0.17	0.17
Assume average water useage Lpd is =		360	of which about 58% can be supplied by		
rainwater for use in toilets, washer and outdoors. Tank size allows for the expected summer					
rainfall in each region.					

Table 18. Installing flood resilience – detailed model of costs and benefits

House flood repairs cost options											
						Option 1		Option 2			
			Transfer ratio			Replace as was.		Replace for resilience.			
Cost items	Cost		item/sqm of	Cost per sqm		Cost per sqm		Cost per sqm			
First flood	Unit	$/unit	floor area	of floor area		of floor area		of floor area			
		(1)	(2)	(1) X (2)							
Remove insulation & plasterboard to 1.2m.	sqm	4	0.5	2.0		2.0		2.0			
Remove 1.2m plasterboard int walls	sqm	2	1.00	2.0		2.0		2.0			
Clean/ dry house	ea	2000	0.01	20.0		20.0		20.0			
Install replacement fg insulation to 1.2m	sqm	12	0.5	6.0		6.0					
Install replacement eps insulation to 1.2m	sqm	25	0.5	12.5				12.5			
Install resilient plywood walls 1.2 m	sqm	70	1.50	105.0				105.0			
or Replace plasterboard	sqm	30	1.5	45.0		45.0					
Install resilient trim	m	6	1.10	6.6				6.6			
or install MDF trim	m	4	1.0	4.0		4.0					
Recoat floors	sqm	20	1.0	20.0		20.0		20.0			
Replace MDF doors more resilient (plastic/ ply)	ea	180	0.1	18.0				18.0		Option 2 spends	
or Replace MDF doors with same	ea	90	0.1	9.0		9.0				an extra	
					Total	108.0	$/sqm	186.1	$/sqm	78.1	$/sqm
Subsequent floods with resilience										to upgrade for resilience	
Remove ply & trim ext walls, remove insulation	sqm	4	0.5	2.0							
Remove ply/trim interior walls	sqm	2	1.00	2.0							
Clean/ dry house	ea	2000	0.01	20.0							
Insulation no replacement	sqm										
Re-install existing plywood, repaint	sqm	12	1.50	18.0							
Re-install existing trim, recoat	m	2	1.10	2.2		Without resilience				Hence	
Recoat floors	sqm	15	1	15.0		(i.e. replace with like)		With resilience		Option 2 saves	
				59.2		108.0	$/sqm	59.2	$/sqm	48.8	$/sqm
								for every flood event after the first.			

Financial factors			**Flood factors**					
r=	5%	real discount rate	AEP=	0.067	i.e.	15	years return	AEP=annual expected probability
n=	50	years	Expected savings/yr=	3.25	$/sqm	=Opt2 savings x AEP		
USPWF=	18.26		PV savings=	59.4	$/sqm	=Expected savings/yr x USPWF (uniform series present worth)		
	=discounted summing factor			NG. Does not cover extra initial cost of		78.1	$/sqm	
			need AEP=	0.088	i.e.	11	yrs return period for breakeven	

Assumptions

Linings are replaced to 1.2m ht. They are removed for drying wall cavity and replacing the insulation. Plywood linings are reused after flooding.

Timber trim is reused after flooding, but original MDF is removed and replaced.

All cabling is above 1.2m height.

No fixed carpet, if particle board floor assume it is able to survive 1-2 days immersion without damage, but requires recoating.

Transfer ratio External wall =	0.5	sqm wall area/sqm floor area	
Transfer ratio Internal wall =	1.00	sqm wall area/sqm floor area	i.e.both sides of walls
Trim transfer ratio=	1.10	m/sqm floor area	
Internal doors	0.102	number/sqm floor area	

Table 19. How much bracing can be fitted into a typical new house?

Wellington - Medium sized new house																			
House		Required		Available	Bracing percentage required					Total	50% extra	Bracing percentage required					Total		Damage repair
area		BUs (5)		wall	Std	Stg	Ply +	Actual		cost	bracing	Std	Stg	Ply+	Actual		cost 150%	Cost	cost in
sqm		**Light wall**		length (1)	PB	PB	sht	BUs		bracings	Total BUs	PB	PB	sht	BUs		bracings	incr	25 years
		/roof		m				(2)		$ (3)					(4)		$ (3)	$	(6)
187	N-S eq	2057		36.2	100%	0%	0%	2172	OK	2433	3086	54%	46%	0%	3088	OK	3312	879	
	E-W eq	2057	governs	36.1	100%	0%	0%	2166	OK	2426	3086	53%	47%	0%	3099	OK	3322	896	
		Heavy wall																1775	3147
		/roof														(4)			
187	N-S eq	4301		36.2	0%	87%	13%	4304	OK	4796	6452	0%	0%	100%	5249	NG	7819	3023	
	E-W eq	4301	governs	36.1	0%	85%	15%	4314	OK	4852	6452	0%	0%	100%	5235	NG	7798	2946	(7)
(1) Allows for openings deducted from available leng						(3) Lining/bracing cost $/sqm												5969	10584
(2) Bracing capacity Standard Plasterboard =				60	BU/m		28				BU = bracing units, 20 BUs is 1 kN								
Strengthened plasterboard (Stg PB) =				115	BU/m		50												
Plywood + strengthened PB =				145	BU/m		90												
(4) Insufficient walls for 50% above NZS 3604 bracing capacity for this house with heavy cladding.																			
(5) EQ load, NZS 3604 11BU/sqm light, 23 BU/sqm heavy wall/ roof																			
(6) Damage avoided during 25 yr return period with					50%	increased bracing and benefit to cost ratio > 1.0.													
(7) Damage avoided during 25 yr return period with					22%	increased bracing and benefit to cost ratio > 1.0.										5% discount rate.			

This is a 187 m^2 single storey house in Wellington. Earthquake loads govern the bracing design as per NZS 3604. For lightweight construction, i.e. light roof and wall claddings, the standard plasterboard with a small amount of strengthened plasterboard provides the required bracing. To achieve a 50% increase in bracing capacity a significant amount of strengthened plasterboard is required, with a cost increase of about $1,775 per house.

The heavyweight claddings require most of the linings to be providing bracing (for the NZS 3604 loads). However, it is not possible to achieve a 50% increase above NZS 3604 in bracing capacity using plasterboard or sheet ply linings for the heavyweight house. The maximum amount of bracing capacity that can be achieved (using traditional methods) is 22% above the NZS 3604 requirement, and this costs an extra $5969. To achieve 50% over-capacity a specific design is required and would cost significantly more than $6000. The last column shows a 'serviceability' analysis assuming maximum bracing is installed using strengthened plasterboard or ply sheet. It indicates that if $3147 repair damage is avoided over 25 years in the light clad house from minor to moderate earthquakes, then the extra bracing of 50% is cost effective. For the heavy clad house, $10,600 of damage needs to be avoided.