STUDY REPORT

SR 235 (2010)

Housing Life Cycle and Sustainability – Part Two

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Preface

This is the second of a series of two reports prepared during research into the incorporation of sustainability into the existing housing stock.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for designs and owners.

Housing Life Cycle and Sustainability – Part Two

BRANZ Study Report SR 235

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Abstract

This report covers a variety of topics related to the housing stock and its renovation/upgrade through its life cycle. For life cycle cost reasons it is generally better to repair and extend the life of housing rather than demolish and re-build. But is the same true of sustainability impacts? A total energy use analysis is used as a proxy for environmental impacts, to compare renovation with re-build. Making alterations/additions to housing is an ideal opportunity to upgrade the thermal performance of existing houses, but this study finds these opportunities are being missed.

When owners retrofit with insulation they usually expect to be more comfortable, and this report looks at cost effective ways to improve comfort levels. The final topic is the role of house re-location and the reasons why houses are moved. Thermal envelope upgrades at time of re-location are analysed based on survey results.

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1. INTRODUCTION

This report is a continuation of earlier work on incorporating sustainability features into the existing housing stock during times of major renovation and maintenance. The previous report *Sustainability and Housing Life Cycle – Part One* (Page and Fung 2009) showed that most common types of retrofit, i.e. ceiling and floor insulation, draughtproofing, cylinder and pipe wraps, efficient lights and water efficiency measures (low flow shower heads, flow restrictors) are cost effective in all regions. Also, retrofit of wall insulation and double glazing is cost effective for some heating regimes. The main aspects considered in this Part Two report are:

- Embodied and operational energy comparison for renovation versus demolition and re-build
- Relocating housing – the reasons why it is done
- Improving indoor temperature comfort levels – the costs and benefits.

2. SUMMARY

The main findings were:

From a life cycle cost perspective it is better to extend the life of a house through major renovation and incorporation of sustainability features (i.e. insulation, water efficiency) than demolish it and re-build.

However, if total energy use (operational and embodied) is used as a proxy for environmental impact of housing, then it is better to demolish and rebuild immediately.

Redeveloping detached housing to multi-unit construction, rather than maintaining detached housing stock, is likely to be cheaper in terms of life cycle cost and better from a total energy use perspective.

When owners undertake major additions and alterations (A&A) to existing houses they do not appear to upgrade the insulation in the existing structure to any large extent. This is a wasted opportunity to improve the overall thermal performance of the house.

Relocation of houses occurs for a number of reasons and the main driver is cost i.e. relocated existing houses are cheaper than new housing on most sites. Approximately 2,000 houses were relocated in 2008, equivalent to about 9% of new houses built at that time.

Over 60% of relocated existing houses had ceiling insulation retrofitted at the new site and 46% had wall insulation retrofitted.

To achieve improved comfort levels (from 16°C to 20°C) in houses, it is cheaper in most parts of the country to install efficient heaters (e.g. heat pump, solid or gas fuel) and ceiling and floor insulation than to continue to use electric heating in an un-insulated house.

3. LITERATURE REVIEW

A number of countries have CO_2 emission reduction targets and energy efficiency in buildings is one measure to help achieve these. The UK Government in 2004 set a goal of 60% reduction in emissions from the 1990 level by 2050 (later raised to 80% in 2009). Boardman 2007 provides a plan for the housing sector to meet reductions of the size in the initial targets (60% reductions). The paper suggests two-thirds of the savings come from reduction in demand and one-third through use of low carbon technologies (heat pumps, district heating schemes, solar water and photovoltaics). As an estimated 87% of the stock will still exist by 2050 a large retrofit programme is needed. The proposal allows for a proposed four-fold increase in the rate of demolition of houses (those most difficult to upgrade). Other features of the proposal are the average size of new houses is reduced and through a variety of measures their net energy use is near zero. Also, for all houses, significant percentages will have solar water panels (60% of houses, mainly retrofits) and photovoltaics (30%), more loft insulation, an extensive programme of retrofitting walls (cavity and external insulation systems, triple glazing), and ventilation airflow management measures.

Several authors have noted how extremely challenging the Boardman proposals are. Lomas (2009) states the inability of the construction industry to deliver expected performance means the expected saving may not be achieved. Occupant behaviour before and after retrofit is not well understood so expected savings may not occur. Also getting homeowners to upgrade will encounter many obstacles. Herring (2009) notes the “re-bound” or take-back effect does not appear to have been considered in the Boardman estimates.

Lowe (2009) suggests a mix of economic, regulation, cultural and technology approaches are needed to meet the targets. He notes that getting the optimal mixes of these four approaches is difficult in aggressive free-market economies and that the Government needs to be more hands-on.

Thomsen and van der Flier (2009) examined the merits of replacement or renovation in terms of sustainability for Dutch housing. They reviewed various Dutch studies and state the findings are not conclusive as yet. Materials and waste impacts are lower with renovation/transformation compared to demolition and rebuild. However energy performance in new build is better than can be generally achieved by renovation.

Meijer et al (2009) reviewed the characteristics, policies and barriers for upgrading the housing stock in eight European countries. The barriers they found were lack of knowledge of decision makers, unconvincing cost-benefit relationships, inappropriate products directed for new build rather than retrofit, few best practice examples, small-scale unprofessional renovators, high costs and long paybacks for owners. They recommend decision makers, i.e. owners and renovators, should be educated on how to integrate improvements into the natural maintenance cycle.

Pellegrini-Masini et al (2010) examined the life cycle costs of achieving emissions targets in the UK (the revised 80% carbon reduction target by 2050). The interim target by 2030 for the housing stock is a 50% reduction in CO_2 emissions. The types of measures examined were:

- double brick wall cavity insulation or 90 mm mineral wool external render finish
- loft insulation from the current 100 mm to 250 mm thickness
- current double glazing replaced with triple glazing
- reduction in airflows from 0.75 ach to 0.23 ach
- CFL lighting, mechanical ventilator and heat exchanger, and
- efficient appliances (dishwasher, fridge, washing machine, home entertainment).

They found that retrofit of all these measures into all houses in the stock achieves the 50% savings target. The initial cost is about £17,000 and the payback period is about 60 years (which is only cost effective at about 1.5% discount rate). Based on household income distributions they state that repayments on this expenditure are “prohibitively expensive for most households.” A more limited set of interventions omits triple glazing and wall insulation, giving a total cost of about £3,300. Now the payback is about 12 years and this package delivers about a 30% emissions reduction by 2030. The authors conclude by saying: "Mass adoption of this intervention set can be viewed with scepticism because of, for instance, lack of information, capital costs, and competing motivations in consumption. It is questionable therefore whether (a) current methods of communicating information on the appropriate technologies and financial incentives available to householders and (b) the scale of the financial incentives themselves are commensurate with the emission savings aspirations of the government."

In New Zealand the Government is currently reviewing its energy efficiency and conservation strategy (NZEECS). The last version was produced in 2007 and it is not known when the next review will be complete. The current version has a target of 162,000 homes retrofitted with efficiency measures by 2025, saving about 2,700 kWh per year per house. These savings are readily achieved with floor retrofit and ceiling insulation, and these measures are cost effective in all regions, as shown in the Part One report. The new Heat Smart government programme raises the target with 189,000 retrofits expected by 2013, and with government subsidies it seems certain to achieve this target. However it will cover only about 20% of the eligible houses needing retrofit and additional funding beyond 2013 will be required. If all 900,000 eligible under-insulated houses are retrofitted then the annual savings would be about 8 PJ per year, which is about 13% of total household energy use. Other savings that are available (namely efficient lights, solar water panels, low flow shower heads etc) are not included. However it is apparent the savings target in New Zealand is very much lower than the 80% reduction implied by the UK Government carbon emissions targets.

Another UK paper (Plimmer et al 2008) looked at the issues involved in comparing refurbishment versus demolition and re-build. In general it was noted older houses have a longer life than new replacements and often their maintenance costs are lower. Refurbishment is usually more affordable than building from new, it generates less waste, and it contributes toward heritage conservation and retention of existing communities. Despite this the industry perceives a range of barriers including lack of skills and knowledge about retrofitting sustainable features, constraints on work methods in heritage areas and full VAT on refurbishment compared to zero VAT on new build. Little use is made of whole life costing when comparing rebuild with refurbishment, mainly due to lack of data and knowledge.

4. RENOVATION VERSUS DEMOLISH AND RE-BUILD

4.1 Detached housing

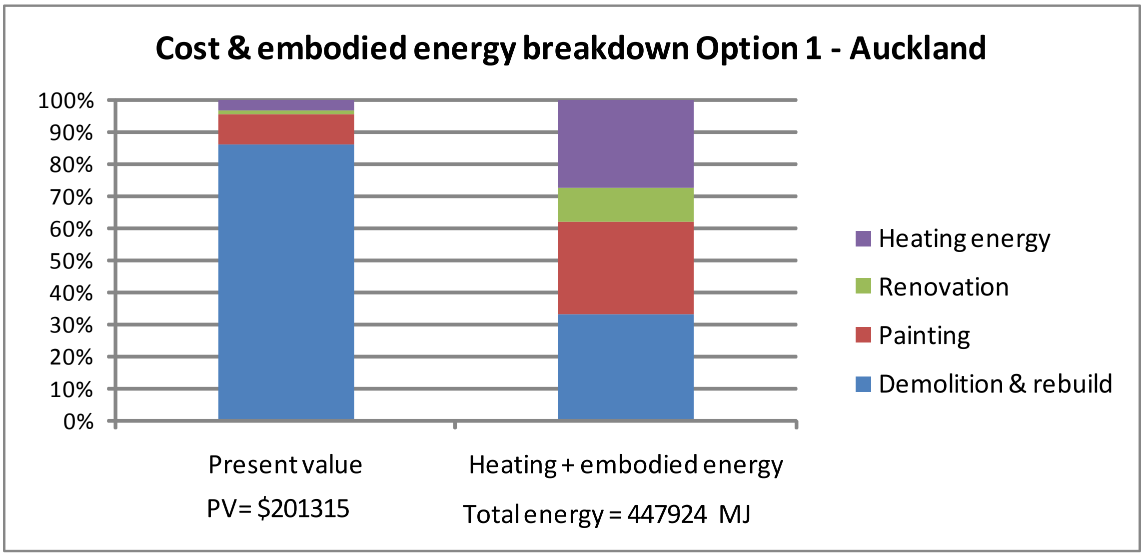
The earlier report (Page and Fung 2009) found that from a life cycle cost perspective it is better to extensively renovate an aging house (1950s to 1960s era) and extend its life, rather than a second option which is to demolish and re-build. The renovation allowed for replacement and upgrades including ceiling, wall and floor insulation, double glazing, re-roofing, replacing some weatherboard cladding, painting and electrical re-wiring. A third option considered was to do nothing to the house for 10 years, then demolish and replace. It was not as favourable, in life cycle cost terms as the immediate renovation option.

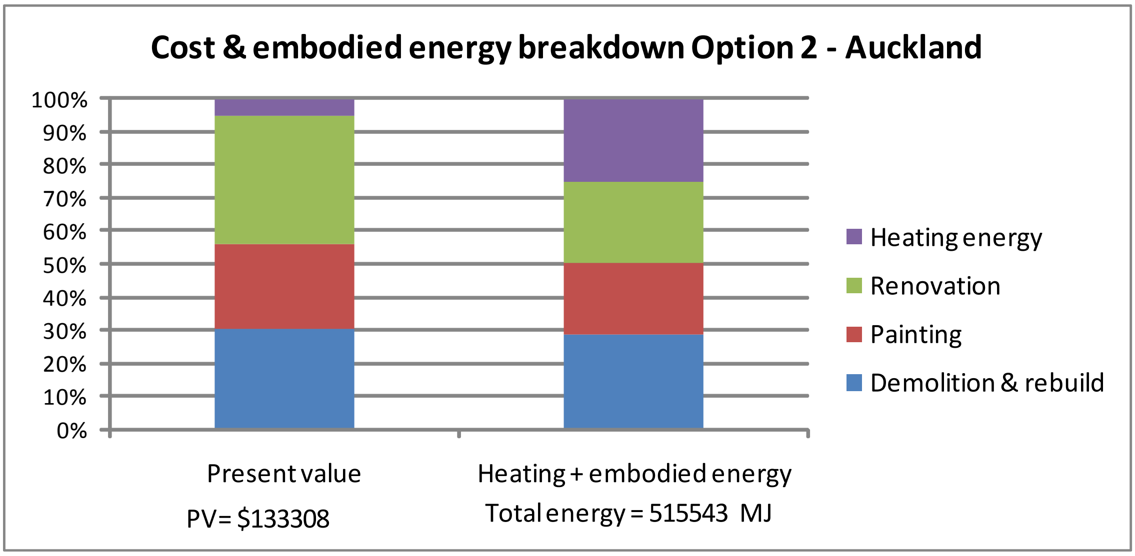
This section extends the analysis to look at the environmental impacts of the three choices. The options are:

- Option 1 – Demolish and rebuild, minor renovations at years 30 and 60 years, 90-year analysis period.
- Option 2 – Major renovations now for another 30 years' life, then demolish/rebuild, minor renovations at year 60, 90-year analysis period.
- Option 3 – Do nothing now. demolish and re-build in 10 years, minor renovation at years 40 and 70, 90 year analysis period.

The environmental impact is proxied by embodied and operational energy only. Other impacts such as material and construction impacts on ecology, waste and water are difficult to assess due to lack of New Zealand data and have been ignored.

In all options the rebuild is to an optimum orientation with passive solar features. The results are shown in Figure 1 to Figure 4 for Auckland, Wellington, Christchurch and Dunedin. The embodied energy of construction, renovation and maintenance has been added to the operational space heating energy over the life of the houses i.e. 90 years ahead. They are for a typical small house, 93 sqm floor area, assuming a timber floor initially and then re-built on a concrete slab.





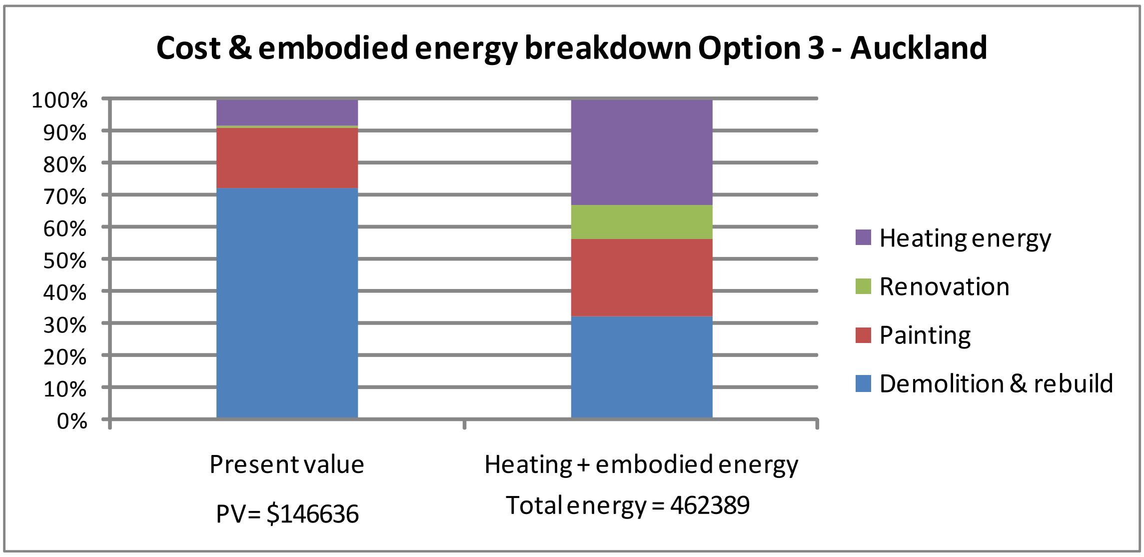
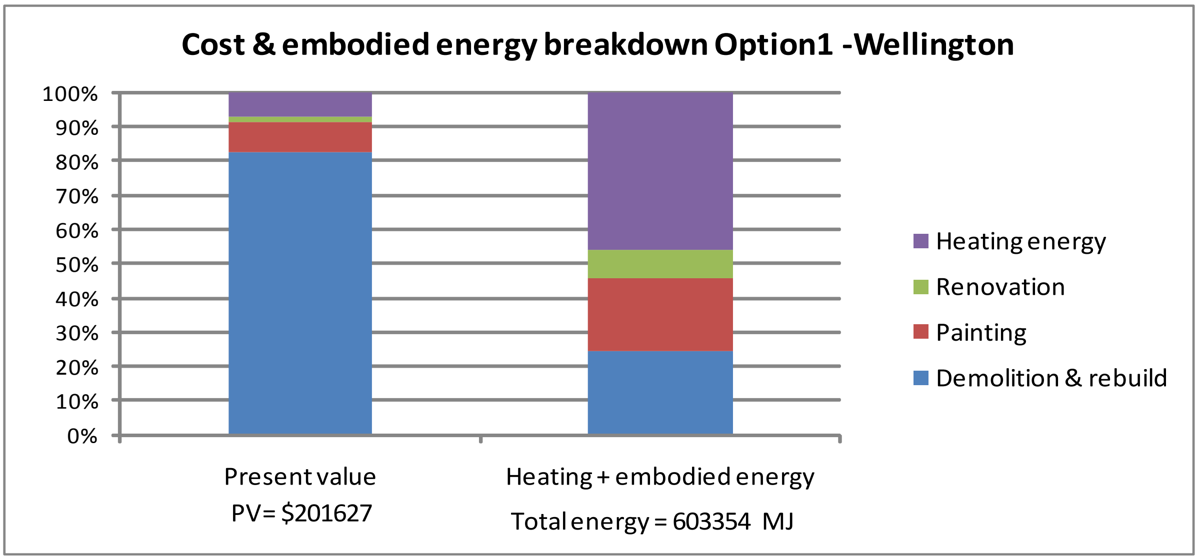
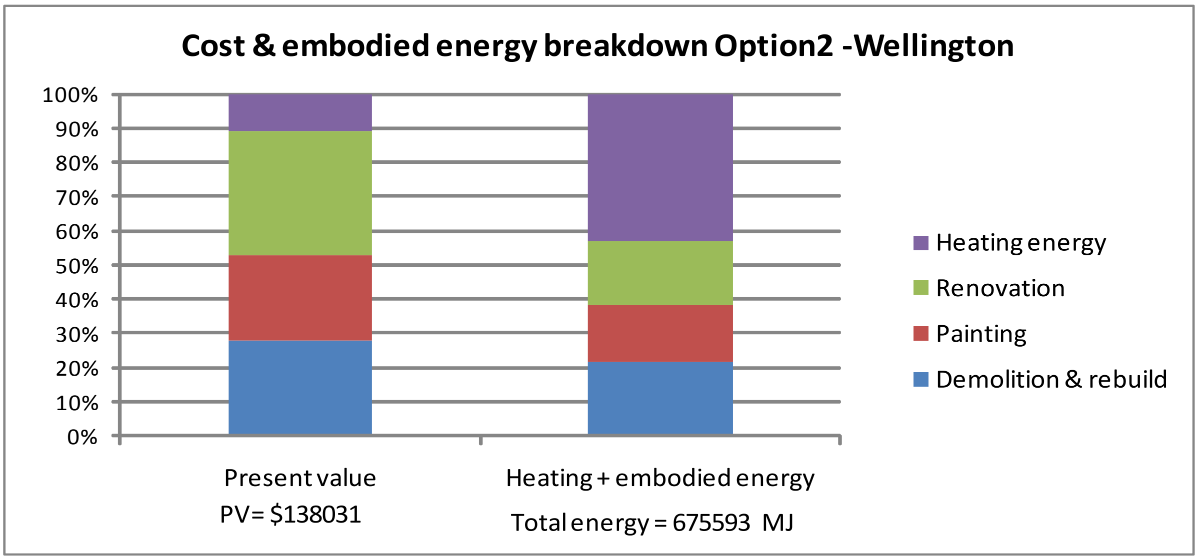


Figure 1. Main work components by cost and energy – Auckland





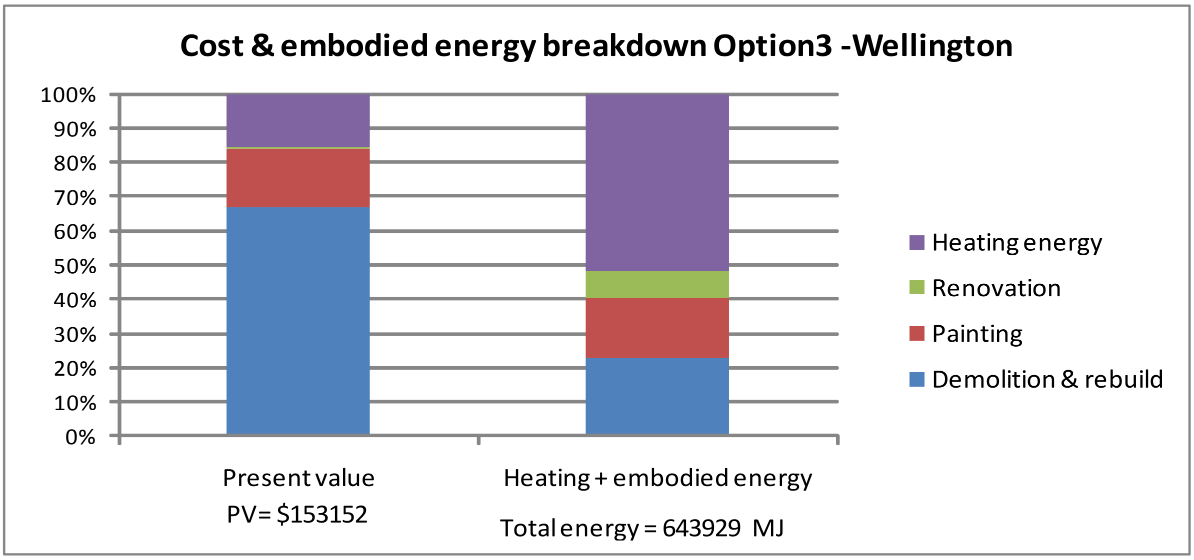


Figure 2. Main work components by cost and energy – Wellington

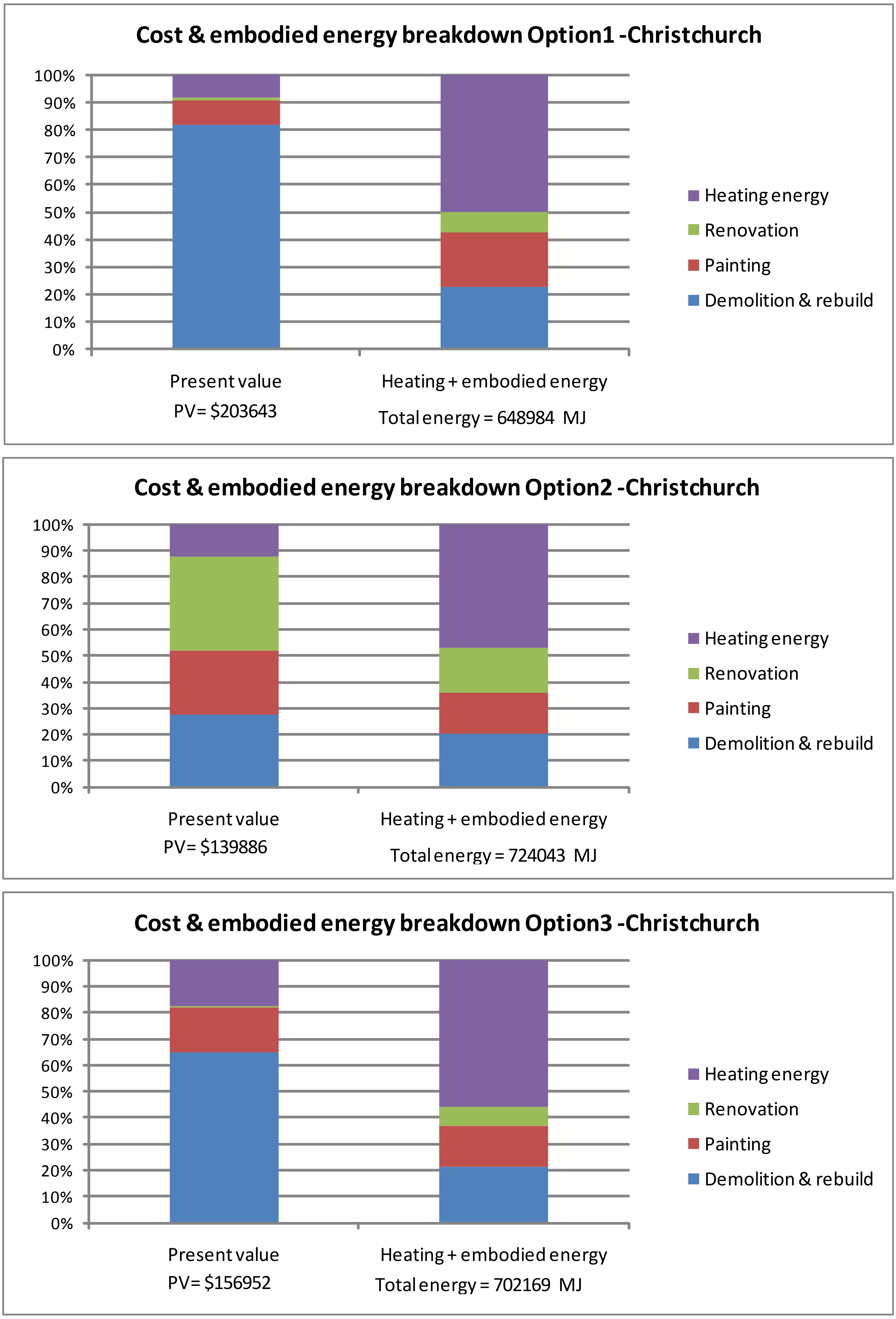
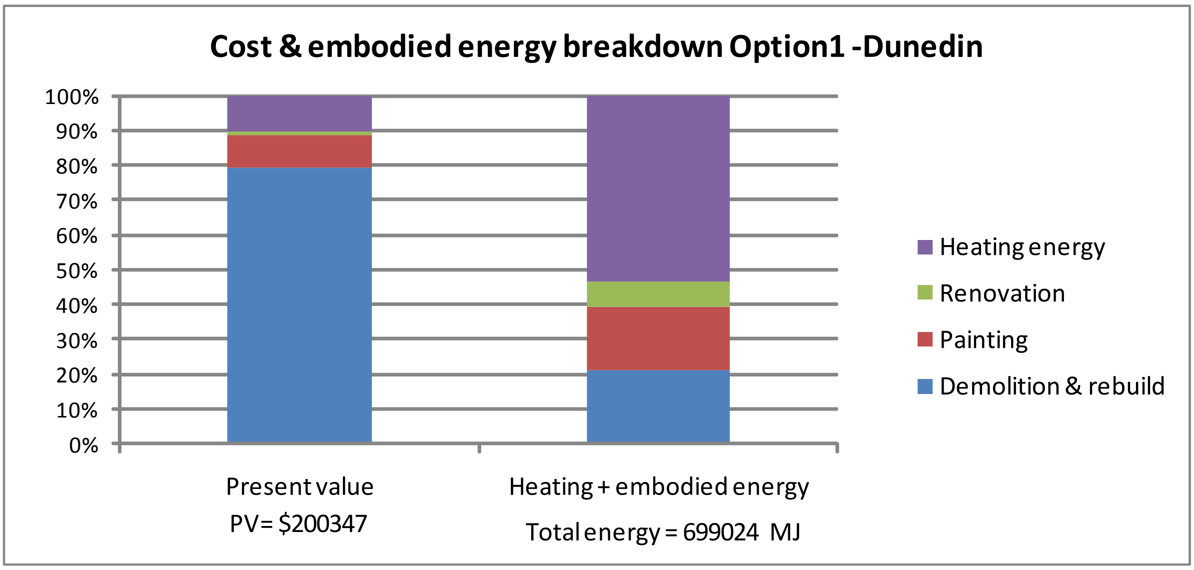
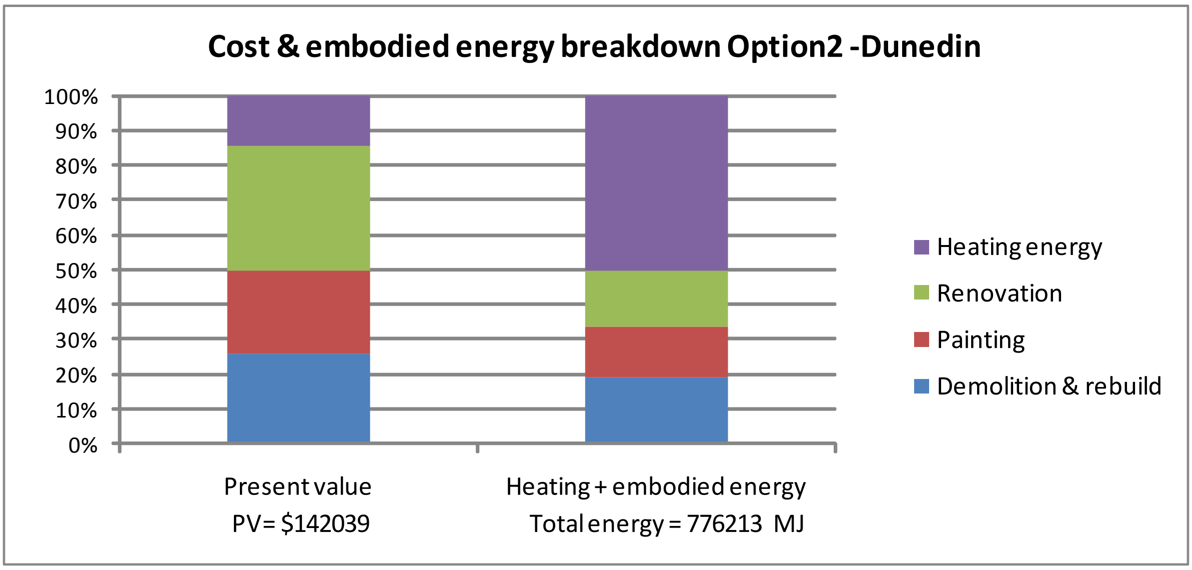


Figure 3. Main work components by cost and energy – Christchurch





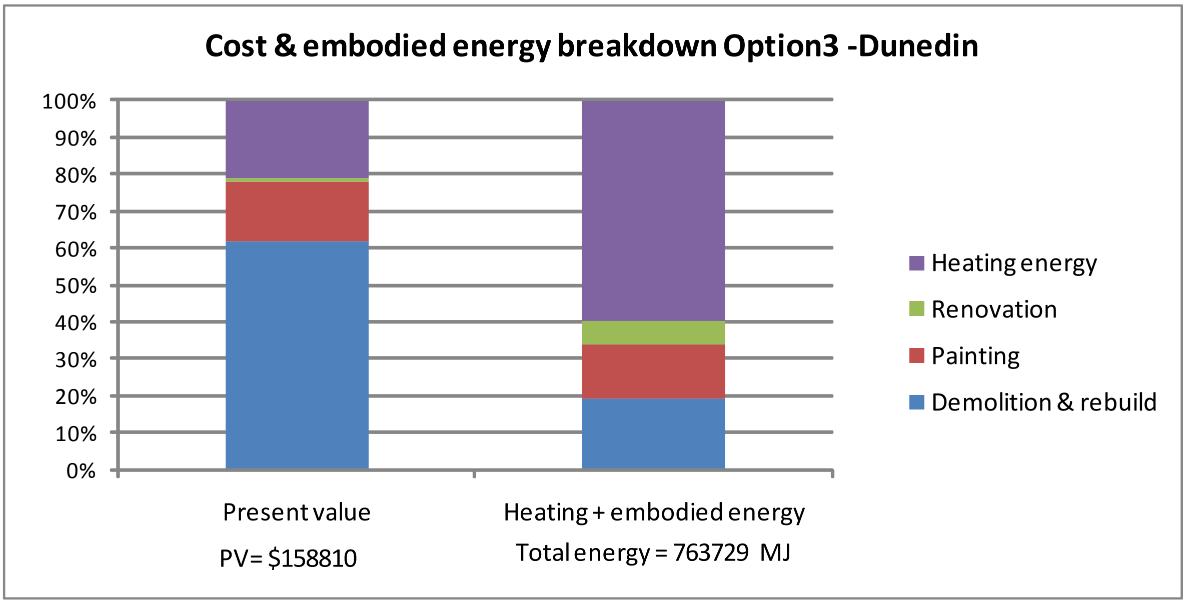


Figure 4. Main work components by cost and energy – Dunedin

The above charts indicate:

- The immediate re-build, Option 1, has the lowest total energy of the three options, whereas it has the highest life cycle cost.
- Option 2, which has the lowest life cycle cost, has the highest energy use.
- The embodied energy in construction renovation and painting is about 70% of total energy use in Auckland, down to about 45% of total energy use in Dunedin.

These findings are important because they show that decisions based on costs, even life cycle costs, may not give the best result from an environmental impact viewpoint. It demonstrates the importance of selection of materials, including durability and maintenance needs, because there is a significant proportion of total energy in the renovation and painting categories. Total energy has been used as a proxy for environmental impacts of buildings, which does not account for all impacts, but is probably the best measure available.

The main reasons why the two metrics favour different options is that life cycle costing discounts the value of future expenditure, so it is better to delay replacement as long as possible as per Option 2. In contrast, future energy use is not discounted in the environmental impact analysis, so it is better to replace immediately so operating energy costs are reduced at the start, as per Option 1.

The case for immediate demolition and rebuild is enhanced when materials from the demolished house are recycled. The earlier report indicated this was the case in about 70% of demolished houses where at least some, if not most, materials were recycled.

4.2 Multi-units rebuild versus renovation

This section examines the options available for redevelopment of multi-unit housing, in terms of life cycle costs and environmental impacts. As in the previous section the environmental impact is assessed using embodied and operations energy. The case study used is based on an article in the *ENZ Magazine*,[1] where Housing New Zealand Corporation (HNZC) has decisions to make on whether it should upgrade existing stock or demolish and build contemporary multi-units to higher densities. The specific example is:

Option 1 – Demolish 12 detached houses on adjacent sections and build 40 units on the same land.

Option 2 – Upgrade the 12 existing houses, purchase land sufficient for 28 new multi-units and build 28 units.

In either case 40 dwellings are provided and Table 1 shows a summary of the results. It indicates that Option 1 to demolish and rebuild to a higher density is both the cheaper option and better for the environment as measured by embodied energy. Details of the analysis are in the Appendix and a number of assumptions were made for costs and energy parameters (these are BRANZ assumptions rather than based on HNZC data).

[1] Institute of Professional Engineers of NZ. ‘Sustainable Habitat Challenge’ in *ENZ Magazine* 11/2: 30-32 (April 2010).

Table 1. Multi-unit redevelopment costs and environmental impact

Multi-unit housing redevelopment options.				
Life cycle costs	Initial cost (1)	Operating cost and maintenance $ $/yr/unit	PV $ all units	Total PV $
Option 1 demolish and rebuild 40 units	9,032,000	1,484	912,509	9,944,509
Option 2 Upgrade 12 existing hses, build 28 new units.	9,680,000	2,112	1,028,374	10,708,374
Embodied and operating energy	Initial embodied energy GJ	Heating & maint energy over 30 yrs Heating GJ	Mainten. GJ	Total GJ
Option 1 demolish and rebuild 40 units	8,828	7,862	1,320	18,010
Option 2 Upgrade 12 existing hses, build 28 new units.	7,613	10,125	1,452	19,191
(1) Option 1 and 2 rebuild $224,000 per unit. Option 2 upgrade, $60,000 per house, also land purchase for 28 units .				

In contrast to the single house example in Section 4.1, the option with the lower cost is also the option with the lower total energy use.

5. HOUSING RENOVATIONS BY AGE GROUP

What ages of houses commonly undergo renovation and additions? BRANZ collected data on the age of houses which had consented A&A work. The number of these consents per year is about 20,000. The detached housing stock is about 1.4 million houses and this gives a renovation rate of about 1.4% i.e. about 1.4% of the stock is altered/renovated/added-to per year.

The Part One report estimated that the major renovations rate would need to be about 40,000 houses per year within a few years (5-7 years), in order to maintain and extend the life of the housing stock. So a considerable expansion of work in the A&A sector is needed fairly soon.

The table indicates that no particular age cohort stands out as having high or low renovation rates. It is a little surprising that decade 2000 houses have a slightly higher rate than most other groups. The expectation was that older houses need more renovation, but apart from the 1900 decade the percentage of A&A carried out per year was constant across the age groups. The sample size at between six and 37 houses per decade is quite small and the error in the derived percentages is quite high for the earlier decades.

The table also shows the average value of work per job. This value often differs markedly from what is entered at the time of consent application. The actual work value was filled out by the builder on the BRANZ survey form, usually after the job is nearing completion. It is believed to be a more reliable indicator of work value than is given on the building consent. The average value for all ages is $105,000 per job and there is considerable variation between cohorts. The 1960s decade had one major $5 million project and if this is omitted then the average value for that decade is $47,000 per project.

Table 2. A&A consents by age group

Alteration & addition consents by house age					
Decade starting	Numbers in sample (1)	Scaled up for all consents (2)	Stock Numbers (3)	% of stock undergoing A&A per yr (4)	Ave value of work (000$) (5)
1900	6	557	26,147	2.1	66
1910	6	557	54,245	1.0	48
1920	10	928	78,874	1.2	126
1930	8	742	51,932	1.4	95
1940	10	928	78,196	1.2	80
1950	19	1762	181,831	1.0	39
1960	33	3061	219,223	1.4	198
1970	26	2412	188,848	1.3	82
1980	24	2226	144,474	1.5	83
1990	28	2597	186,581	1.4	83
2000	37	3432	197,000	1.7	56
	207	19200	1,407,349	1.4	105

(1) BRANZ Materials Survey, 3 quarters only, Dec 2009, Mar, Jun 2010.
Only 212 returns in the survey provided the house age.
(2) Statistics NZ 19200 A&A consents for year ending May 2010.
(3) Stock numbers are based on QVNZ data. Detached houses only.
(4) Col (2)*100/ col(3).
(5) Work value is as entered in the survey form, not the consent value. There was one $5 Million dollar project in the 1960 decade.

The same survey also asked if the existing house (not the additions, if any) was being retrofitted with insulation. It was expected that if owners were carrying out major A&A they would be likely to upgrade the existing house to the same insulation performance as is required in new work.

The results are shown in Table 3 where the survey indicates that about 0.5% of the pre-1980s stock is being upgraded per year with insulation. This rate is much less than the overall renovations/additions rate and shows that only about one-third of these jobs extend to an insulation retrofit in the existing house.

Table 3. Insulation retrofits of the existing house when renovations/additions are done

Retrofit of the existing house at the time of A&A						
Decade starting	Sample numbers scaled up for all consents (1), (2).			% of stock(3) having insulation retrofit by type		
	Wall (2)	Ceiling (2)	Floor	Wall	Ceiling	Floor
				Percentage per year (4)		
1900	278	186	93	1.1	0.7	0.4
1910	278	278	278	0.5	0.5	0.5
1920	186	371	186	0.2	0.5	0.2
1930	278	186	93	0.5	0.4	0.2
1940	278	371	278	0.4	0.5	0.4
1950	186	371	93	0.1	0.2	0.1
1960	278	278	278	0.1	0.1	0.1
1970	928	835	278	0.5	0.4	0.1
1980	835	1113	742	0.6	0.8	0.5
1990	371	557	186	0.2	0.3	0.1
2000	371	649	186	0.2	0.3	0.1
	4267	5194	2690	0.3	0.4	0.2

(1) BRANZ Materials Survey, 3 quarters only, Dec 2009, Mar, Jun 2010.
Only 212 returns in the survey provided the house age.
(2) Statistics NZ 19200 A&A consents for year ending May 2010.
(3) Stock numbers are based on QVNZ data. Detached houses only.
(4) Col (2)*100/ col(3).

6. RELOCATION OF HOUSES

The earlier report found that about half of all housing demolitions were due to economic or functional reasons. This included demolition for site redevelopment or because the house no longer provided the required amenity. In the latter cases the houses may have decades of life ahead with or without renovation, but decisions were made to demolish rather than relocate the existing houses. The above shows that renovation of detached houses may be the better choice from a cost viewpoint.

The Whats-On database was examined for house relocations. The database has a work descriptor in one field and analysis was done on descriptors with the relevant words such as “resite”, “relocate”, “relocation”, “relocated” and “transportable”. The database also has an identifier for new or A&A work. The “new” identifier is for transportable houses that have been newly constructed and 187 of these were identified over the 12 month period (see Table 4). The Other Category A&A includes the foundations and upgrade work on the house, and quite often additions such as decks and garages. Numbers of existing dwellings that are relocated far exceeds the new transportables. The number includes those relocated within the same site as well as those from off-site, and the average cost of the work is about $60,000 each.

Table 4. Relocation building consents

Relocation building consents for houses Year ending June 2008.		
	New dwellings	Existing dwellings
Relocation consents (number)	187	1726
Average value $	131,300	59,900
Source: Whats-On database.		

To obtain additional information on the characteristics of relocated houses, builders were surveyed who had taken out relocation consents for housing. A total of 113 responses were received and questions were asked on:

- age of house
- reasons for relocation
- work done at the relocation site
- sustainability features retrofitted to relocated house.

The results are shown in Table 5. Generally they tended to be small in floor area, particularly for the new houses. Apart from new houses the numbers of relocations are approximately in proportion to their incidence in the total stock.

The reasons for relocation are given in Table 6. The most common reason is affordability i.e. relocated existing houses are more affordable than building from new. However, the second most common relocation was for new houses built off-site (e.g. Keith Hay etc) and moved onto the site. A significant proportion of relocations were for rental purposes, usually with the original house remaining on the same site. Some houses were re-positioned on the same section, usually to accommodate new housing at increased housing density. In some cases the existing house was moved completely off-site to facilitate complete site redevelopment, either multi-unit residential or commercial.

About 33 of the cases in the survey involved new buildings, so about 30% of all relocations were imports of new housing. Another 50% involved existing housing, either being brought-in from off-site or relocated within the same site. The remainder were houses shifted into storage and usually the site was redeveloped into multi-units. This is a disproportionate number of new houses compared to the numbers from the Whats-On database where existing building locations were 10 times those of new housing.

Table 5. Characteristics of relocated houses

Age and size of relocated houses						
House age years	Numbers in survey	Total stock number	Survey numbers as % of total hse stock	Average area total stock sqm	Average area sqm in survey	Average (1) Value ($000) in survey
0	17	20,000	0.085	205	96	56
1-20	24	312,981	0.008	175	113	46
21-50	41	552,544	0.007	139	123	47
>50	22	477,099	0.005	128	156	66
	104	Average for existing houses=		145	128	52
(1) Average value of work after relocation.						

Table 6. Reasons for relocated houses

Relocated house survey	
Affordable existing house	27
Rental existing house	11
New house relocatable	20
New minor hse (granny flat, care-givers, etc)	7
Farm workers prefab	6
Redeveloped multi-units	11
Redeveloped commercial	2
Better location (flood, sun, views, etc)	5
Re-position on site	12
Sold off-site (to mover)	4
Other (old Villa saved, new highway)	4
Not stated	4
	113
BRANZ Survey 2009, response rate 34%.	

All relocated houses require foundation work at the new site. In addition, existing relocated houses often need other work to the house such as cladding and lining repairs. Table 7 shows the work types and indicates foundations are the most common work. Out of 101 responses to this question about 82% of houses were put onto timber piles. This may appear to be surprising as most new in-situ housing is constructed onto a concrete slab. However older existing houses (i.e. pre-1980) are mostly on timber foundations, and newly built transportables often have timber floors to retain the structural integrity of the building during relocation.

Repairs/replacement to roof and wall claddings after relocation are quite common and are important for extending the life of the buildings. Owners also take the opportunity to add garages and decks, since these are unlikely to be part of the transported house. All relocated houses will need connection to services such as water, waste and power, but quite often the plumbing and wiring is renewed as well.

Table 7. Work done after house relocation

Work types after relocation	
	Number of Occurrences
Piles/ poles	82
Add carport/ garage	40
Sheet metal roof	35
Add deck	26
Int & ext renovation	19
Repair/ replace weatherbds	17
Services (plumbing, elect,)	11
Repair/ replace fibre cmt claddings	10
Repair/ replace other claddings	7
Add bedroom/ laundry/kitchen	5
Other (1)	13
	252
(1) Other is mainly non-specified timber work.	
Sample size: 101 responses to work type question.	
Source: BRANZ Relocation Survey	

The survey asked about retrofitting existing houses with insulation and other 'sustainability" retrofits. The most common were ceiling, wall and floor insulation retrofits, and a high 46% had wall insulation retrofitted, which is a quite expensive. A surprising 19% of all existing relocated houses had no retrofits (see Table 8), although some may have already had ceiling insulation.

Table 8. Sustainability retrofits in relocated houses

Sustainability retrofits		
Type of retrofit	Number	% of houses
Ceiling insulation	37	63
Wall insulation	27	46
Floor insulation	22	37
Double glazing	6	10
Solar heaters	2	3
Heat pump	15	25
Ventilation system	5	8
none	22	19
Total responses to this question 59 existing house relocations.		

The conclusions from the relocation survey were:

- The main reason for use of relocated houses is affordability.
- Relocatables service the need for small accommodation at short notice (farm workers, granny flat etc).
- Significant numbers of relocatables come from redeveloped sites.
- Most existing houses have insulation retrofitted at the new site.

7. THERMAL INSULATION

The previous reports showed that many sustainability retrofits are cost effective for all locations. These include ceiling insulation, draughtproofing, solar water heating (when the existing cylinder needs replacing), energy efficient lights, wraps, low-flow shower heads and tap flow restrictors. Measures that are cost effective in some locations are wall insulation retrofits (South Island, possibly Wellington), and double glazing (South Island).

In this report further analysis is undertaken on the cost benefits of thermal insulation, extended to seven regions.

Major renovation of, or additions to, an existing house is an opportunity to assess the thermal performance of the house. A major reason for renovation is to improve the comfort levels within the house, and if possible to save money on heating bills.

The charts below show the financial outcomes for changes in a variety of thermal heating factors in a typical 1940s-1960s house, including:

- Retrofitting insulation and double glazing
- New heating appliances
- Changed comfort levels including increased temperatures and heating hours.

The results are expressed as a benefit-cost ratio, using a present value analysis. The benefits are energy savings and the costs are insulation and/or efficient heating appliances. The ratio needs to be over 1.0 for net benefits to arise over the analysis period.

Under what circumstances are there net benefits?

A typical situation before retrofit is a house with some (but minimal) ceiling insulation, heated to 18°C in the evening only using electric resistant heaters. In Figure 5 two levels of retrofit insulation are trialed, first additional ceiling insulation to bring it to R4.6, plus floor insulation. Second, wall insulation and double glazing is added as well as more ceiling insulation and floor insulation. The chart indicates there are net benefits with ceiling and floor insulation only in Hamilton and cooler regions. For Christchurch, Dunedin and Invercargill the addition of wall insulation and double glazing is also cost effective, but not in warmer locations.

In Figure 6 the heating appliance has been changed. Often owners will purchase a new appliance at the same time as upgrading the insulation. Now the economics become more favourable with a shift to a heat pump, compared to the original electric heaters. The initial cost of the heat pump is more than offset by the reduced energy bills compared to the original electric resistant heater over the period of the analysis. A full retrofit (ceiling, floors, walls and glazing) is cost effective in Hamilton and in cooler regions.

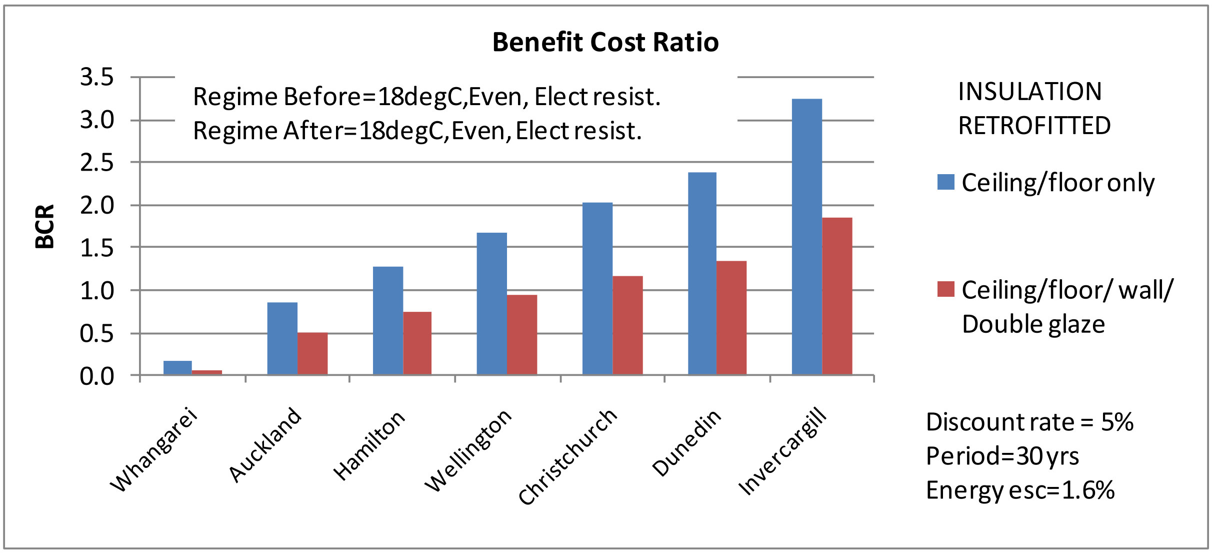


Figure 5. Insulation BCRs – same heating regime before and after retrofit

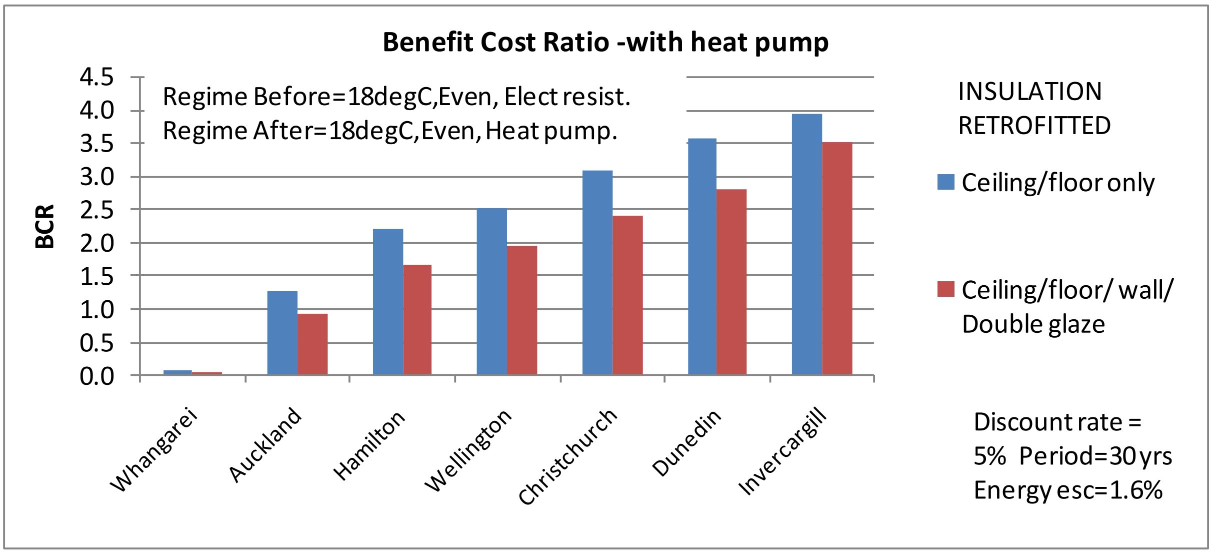


Figure 6. Insulation BCRs – same heating regime before and after, but heat pump retrofit

Often the occupants chose to swap any energy savings after retrofit for an increase in comforts levels. Figure 7 shows a rise in temperature from 16°C before retrofit to 20°C after retrofit, also assuming a new heat pump. The energy savings with a heat pump are offset by the extra energy needed for the rise in temperature. Even so, in Wellington and cooler regions the net cost over the analysis period (30 years) is lower (with ceiling and floor insulation at 20°C) than the status quo of 16°C heating with a resistant heater and no added insulation. In warmer regions the net costs are negative, but that is the price people will often pay for higher comfort levels.

Non-energy benefits have not been included, and when health cost savings are included then Hamilton and cooler regions have a net benefit with ceiling and floor insulation (see Figure 7). Health cost savings are estimated at $215 per household per year for the case when temperatures are raised from 16°C to 20°C. This is based on work described further in the Appendix.

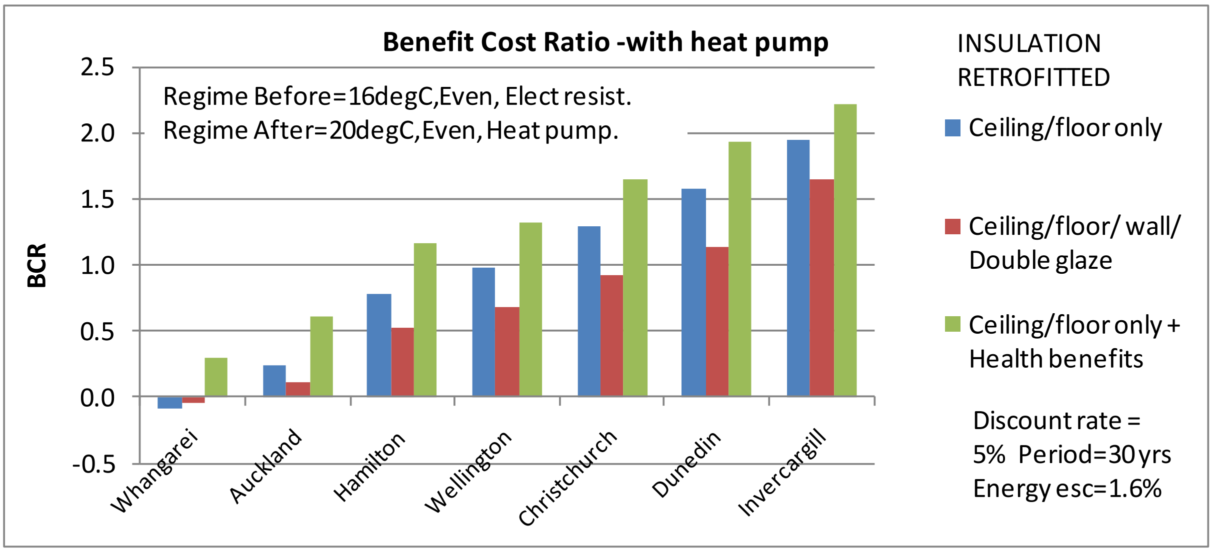


Figure 7. Insulation BCRs – higher temperatures after retrofit, including heat pump retrofit

Often households are prepared to pay more for comfort when they know that the retrofit has reduced the amount of heat losses and they have an efficient heating system. In that case the question to ask is how much will it cost per year to achieve better comfort levels (rather than using BCRs as the metric).

Figure 8 to Figure 11 shows the additional annual costs when the temperature is raised from 16°C to 20°C. The solid brown line is for electrical resistant heaters and existing minimal insulation (R1.5 ceiling only), and the blue lines are for ceiling insulation upgrade to R4.6, floor insulation and a heat pump appliance. The cost of the heating appliances is amortised over the period of analysis. The solid blue line allows for the government subsidy in the Warm Start programme, and the dotted blue line is without the subsidy.

For example, in Figure 11 for Invercargill the additional cost per year when the temperature is raised is about $1,000 per year for electric resistant heating (and no change in insulation). With retrofit insulation and a heat pump the additional annual cost, including appliance and insulation, is about $500 per year for a 10-year ownership period. In fact the payback is shorter at less than six years where the blue lines cross the no insulation line.

The charts show the no insulation lines gradually increase over time due to energy price escalation (1.6% per year). The retrofit and heat pump option has high annual costs for short analysis periods as the initial costs need to be recovered over a short time. As the analysis period increases these initial costs are spread over more years and the benefits of the lower heat pump energy cost becomes more important.

Owners generally have a quite short time horizon and want a payback within a few years. In Auckland (see Figure 8) owners are generally better off using electrical heating and not adding further insulation, because it takes over 20 years before the blue lines cross the no insulation line. In cooler regions the payback is quicker; in Wellington about eight years with the subsidy, and less in Christchurch and Invercargill. Health cost savings have not been included and will reduce the payback time.

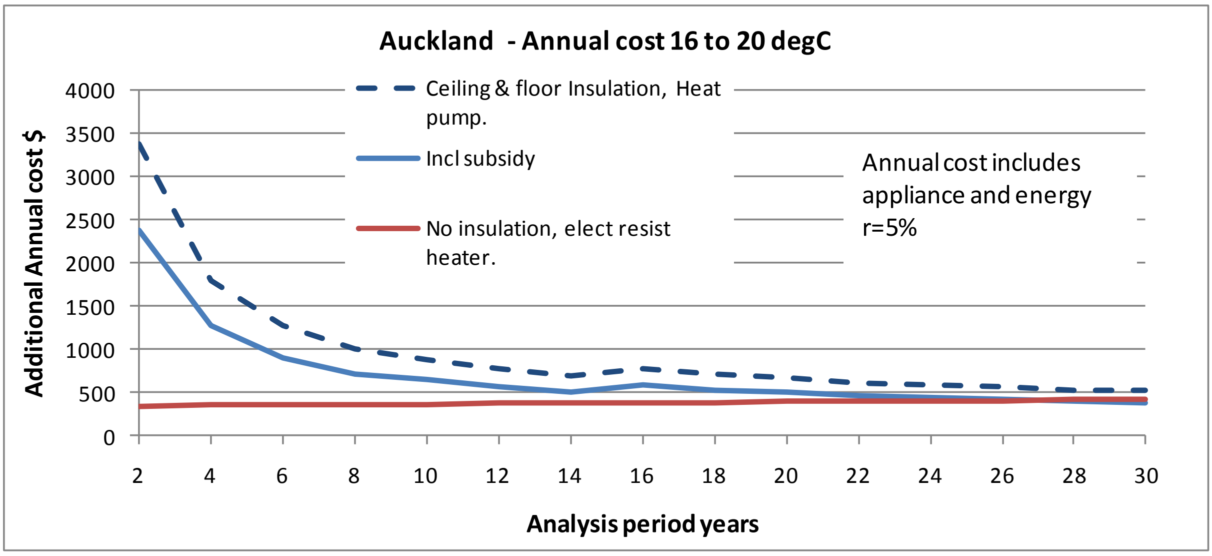


Figure 8. Energy and appliance costs – Auckland

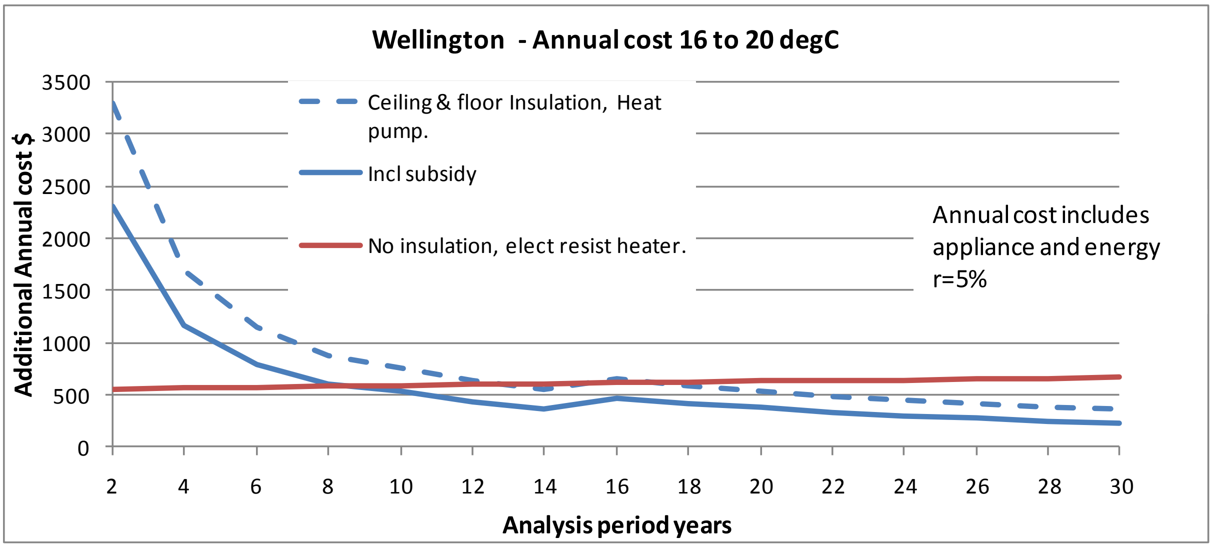


Figure 9. Energy and appliance costs – Wellington

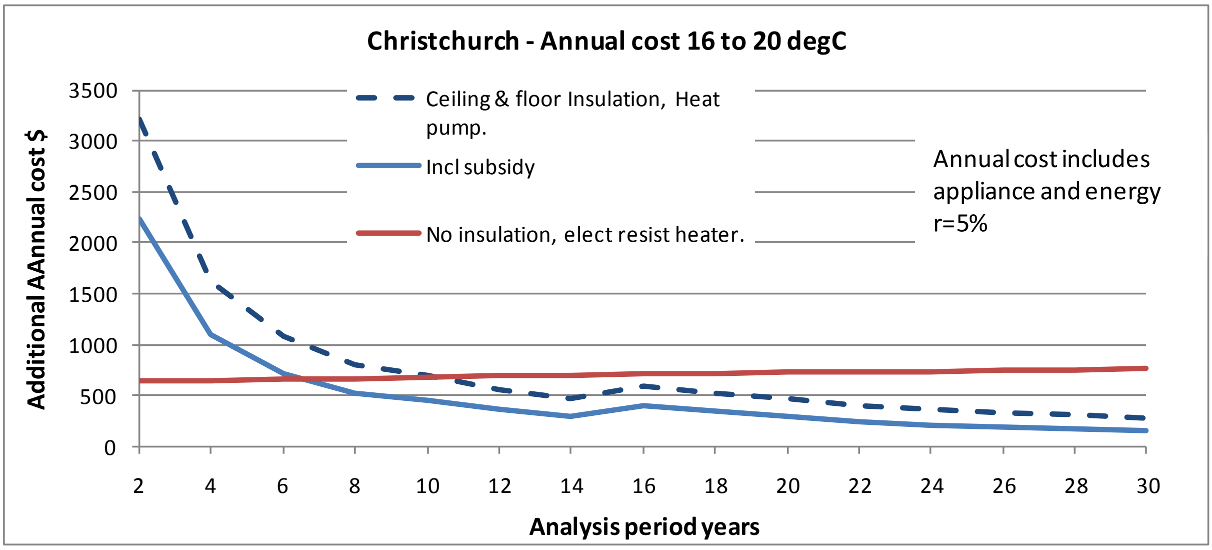


Figure 10. Energy and appliance costs – Christchurch

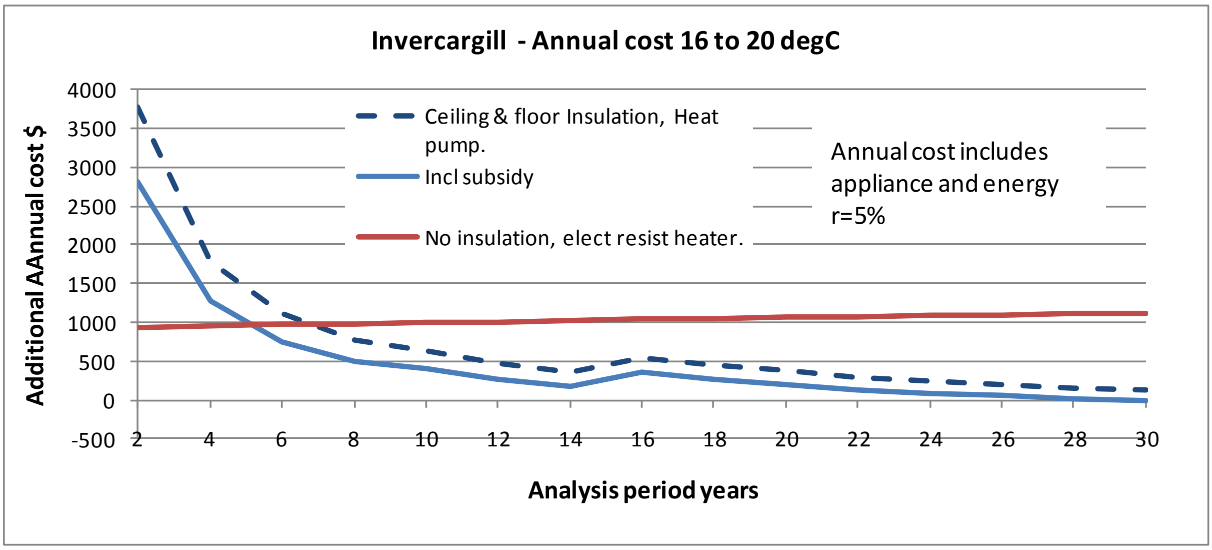


Figure 11. Energy and appliance costs – Invercargill

Note: In the above the Government Warm Up New Zealand: Heat Smart programme provides a 33% subsidy for the insulation cost, up to $1,300 (including GST), and another $500 (including GST) for a clean heating device e.g. a heat pump. The effect of the subsidy is the number of years to cross-over, as discussed above, are significantly reduced, making the programme quite attractive especially in the cooler regions.

7.1 Retrofit affordability

The ceiling/floor/heat pump retrofits shown in Figure 8 to Figure 11 have an initial cost of about $6,600 after deducting the government subsidy. How affordable is this type of expenditure? The 2007 Household Expenditure Survey from Statistics New Zealand (SNZ) gives a breakdown of household expenditure by items. An average of $3,001 per year is spent on house maintenance, A&A, including DIY and using contractor services.

SNZ do not provide a breakdown of maintenance expenditure by deciles so this has been derived in Table 9. The assumption is maintenance expenditure is in proportion to household income. This is likely to over-estimate the actual maintenance expenditure in the low income groups and under-estimate it in the high income groups. This is because a high proportion of household spending in the lower deciles is on essentials such as food, clothing and transport, leaving little to be spent on maintenance. The converse occurs in high deciles, where the actual maintenance expenditure is likely to be higher than shown in the table.

Table 9. Ability of households to afford retrofit

Household decile groups from 2007 HES.

Deciles (1)	Under $17,600	$17,600 to $25,799	$25,800 to $33,399	$33,400 to $44,899	$44,900 to $55,799	$55,800 to $67,999	$68,000 to $80,899	$80,900 to $98,799	$98,800 to $131,299	$131,300 and over
Median income $ per yr	15,000	21,700	29,600	39,150	50,350	61,900	74,450	83,400	115,050	150,000
Ave Maintenance expend $ (2)	647	936	1,277	1,689	2,172	2,670	3,211	3,597	4,962	6,470
Yrs to save 50% of initial cost (3)	20	14	10	8	6	5	4	4	3	2

(1) Income deciles $ thresholds are chosen to have equal numbers of households in each decile.

(2) Average property maintenance expenditure as derived by BRANZ, assuming expenditure is in proportion to income.
The average property maintenance expenditurefor all households is $ 3001 per year as per HES.

(3) Years to save for retrofit, assuming savings are 50% of previous maintenance expenditure.
The approximate cost of ceiling and floor insulation and a heat pump is $ 6600 after Govt subsidy.

If it is assumed that half the previous maintenance expenditure is used on retrofit then the table shows how many years of savings are required to purchase the retrofit package. Further assume that it would be unwise to divert half of maintenance expenditure for more than say six years. This then suggests the 40% of houses below $44,900 per year household income decile cannot afford the retrofit package unless expenditure on other goods and services is reduced.

8. REFERENCES

Boardman B. 2007. ‘Examining the Carbon Agenda Via the 40% House Scenario’. *Building Research and Information* 35(4). Taylor & Francis.

Herring H 2009. ‘National Building Stocks: Addressing Energy Consumption or Decarbonisation?’ *Research and Information* 37(2). Taylor & Francis.

Lowe R. 2009. ‘Policy and Strategy Challenges for Climate Change and Building Stocks’. *Research and Information* 37(2). Taylor & Francis.

Lomas K. 2009. 'Decarbonising National Housing Stocks: Strategies, Barriers and Measures'. *Building Research and Information* 37(2). Taylor & Francis.

Meijer F, Itard L and Sunnikka-Blank M. 2009. 'Comparing European Residential Building Stock: Performance, Renovation and Policy Options'. *Building Research and Information* 37(5-6). Taylor & Francis.

New Zealand Institute of Valuers. 1996. *The National Modal House: Plans, Specifications and Schedule of Quantities.* NZIV, Wellington, New Zealand.

Page I and Fung J. 2009. 'Housing Life Cycle and Sustainability – Part One'. BRANZ *Study Report 195*. BRANZ Ltd, Judgeford, New Zealand.

Pellegrine-Masini G, Bowles G, Peacock A, Ahadzi M and Banfill P. 2010. 'Whole Life Costing of Domestic Energy Demand Reduction Technologies: Householder Perspectives'. *Construction Management and Economics* 28:(Jan-Mar 2010). Taylor and Francis.

Plimmer F, Pottinger G, Harris S, Waters M and Pocock Y. 2008. *Knock It Down Or Do It Up?* The College of Estate Management, Reading, United Kingdom.

Pullen S. 2006. *A Tool for Depicting the Embodied Energy of the Adelaide Urban Environment.* Australian Institute of Building Surveyors, Sydney, Australia.

Stoecklein A and Bassett M. 1999. *ALF 3.1.* BRANZ Ltd, Judgeford, New Zealand.

Sustainable Homes. 1999. *Embodied Energy in Residential Property Development: A Guide for Registered Social Landlords.* Hastoe Housing Association, Middlesex, United Kingdom.

Thomsen A and van der Flier K. 2009. Replacement or Renovation of Dwellings: The Relevance of a More Sustainable Approach. *Building Research and Information* 37(5-6). Taylor & Francis.

Whats-On Report: Database for BRANZ. TF Stevens & Co Ltd, Auckland, New Zealand.

Willson RJ. (2006). *The Exemplar House: A Specific Example of Residential Costing.* Plans and Specifications Ltd, Auckland, New Zealand.

9. APPENDIX

This Appendix contains data on the materials composition of typical new houses and their embodied energy. This data was used in Section 4 for the environmental impact comparison between new and upgraded houses.

Further details of the multi-unit housing redevelopment analysis are also provided.

9.1 Materials and embodied energy composition of typical new houses

Figure 12 shows the material composition of a typical small new house. It is the NZIV modal house of a 93 sqm house (NZIV 1996). The embodied energy percentages are in Figure 13 and the values are tabulated in Table 10. As a check on the percentages, another house was examined, the Exemplar House (Willson 2006). It is a typical new two-storey house, with a 195 sqm floor area including garage. Similar data to the small house is shown in Figure 12, Figure 13 and Table 10 for the Exemplar House.

Note that the embodied energy per sqm of floor area is similar for both houses even though their sizes are quite different. The value of about 1570 MJ/sqm of floor area is comparable with UK housing, where 1000 MJ/sqm to 1800 MJ/sqm is a typical range for detached houses (Sustainable Homes 1999).

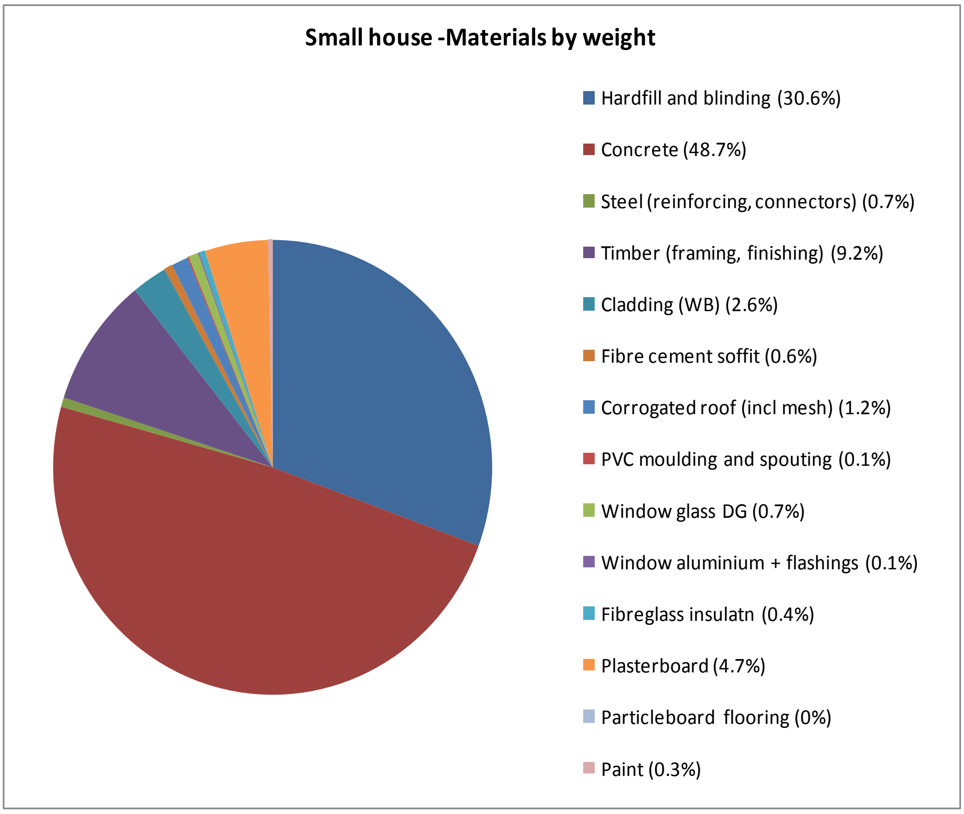


Figure 12. Small house materials by weight

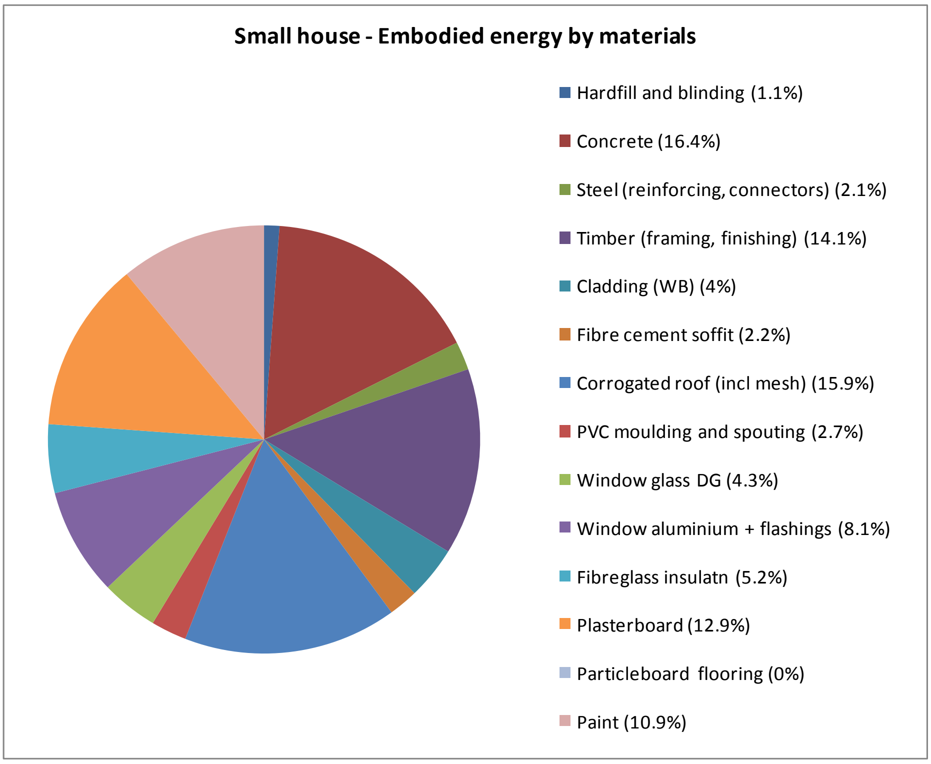


Figure 13. Small house materials embodied energy

Table 10. Embodied energy values – small house

Small house 93 sqm embodied energy			
	Weight	Embodied energy	
	kg	MJ/kg (1)	Total MJ
Hardfill and blinding	16722	0.1	1672
Concrete	26616	0.9	23954
Steel (reinforcing, connectors)	365	8.6	3140
Timber (framing, finishing)	5045	4.1	20683
Cladding (WB)	1422	4.1	5828
Fibre cement soffit	344	9.4	3235
Corrogated roof (incl mesh)	670	34.8	23315
PVC moulding and spouting	64	61	3887
Window glass DG	392	15.9	6236
Window aluminium + flashings	52	227	11860
Fibreglass insulatn	237	32.1	7614
Plasterboard	2555	7.4	18907
Particleboard flooring	0		0
Paint	180	89	15996
	54663		146326
		MJ/sqm=	1575

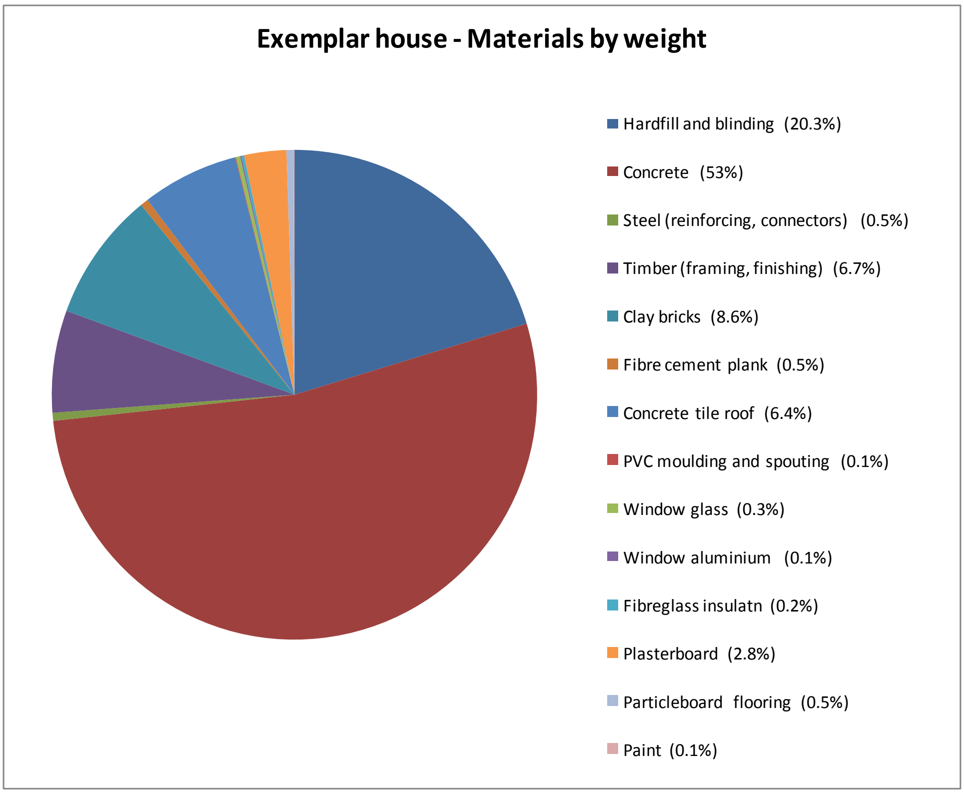


Figure 14. Exemplar House materials by weight

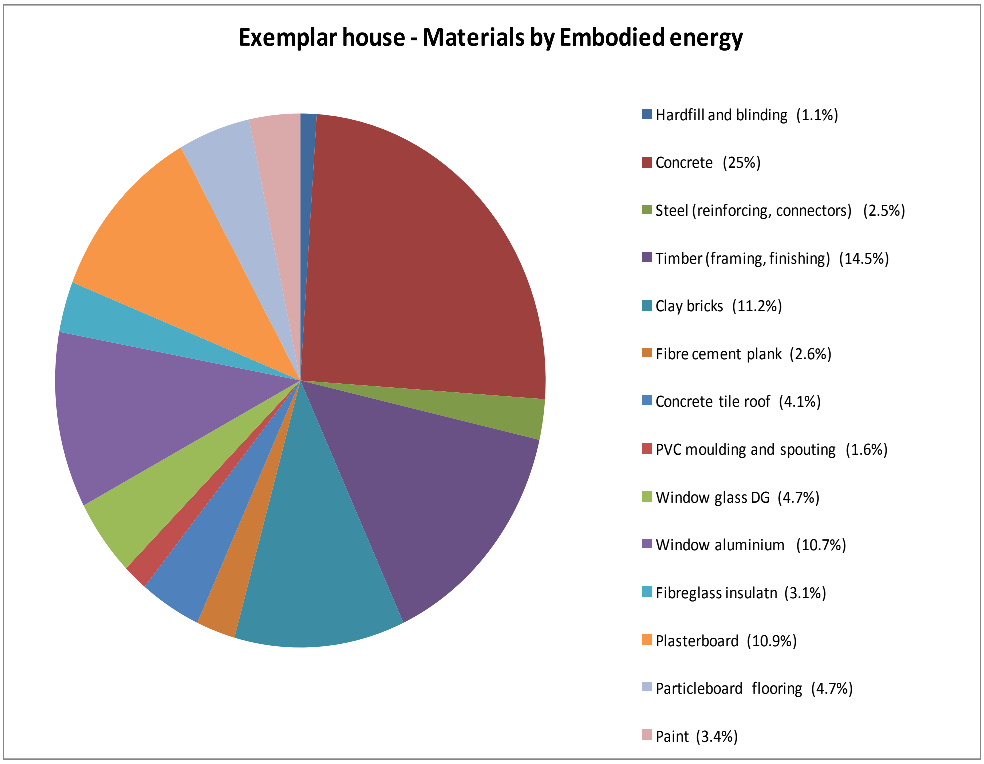


Figure 15. Exemplar House materials embodied energy

Table 11. Embodied energy values – Exemplar House

Exemplar house - Materials embodied energy 195 sqm 2-storey house			
	Weight	Embodied energy	
	kg	MJ/kg (1)	Total MJ
Hardfill and blinding	32714	0.1	3271
Concrete	57733	0.9	51959
Steel (reinforcing, connectors)	846	8.6	7279
Timber (framing, finishing)	14687	4.1	60217
Clay bricks	13780	2.7	37206
Fibre cement plank	840	9.4	7896
Concrete tile roof	10309	1.2	12371
PVC moulding and spouting	82	61	4985
Window glass DG	900	15.9	14310
Window aluminium	144	227	32709
Fibreglass insulatn	254	32.1	8157
Plasterboard	4518	7.4	33435
Particleboard flooring	727	20	14545
Paint	116	89	10287
	137650		298627
Wallpaper	38.4	36.4	1398
Bldg paper	71	25.5	1811
polythene DPC	38.925	70	2725
			304560
		MJ/sqm=	1562
(1) Source: Alcorn (2004).			

The breakdowns of total energy for the three options are shown in Table 12 for the small house.

Table 12. Demolition versus renovation options – embodied and operational energy

Demolish versus Renovation - Life cycle embodied energy and operations energy **Small house 93 sqm.**				
Total energy use MJ	Auckland	Wellington	Christchurch	Dunedin
Option 1 Demolish and rebuild with optimal orientation, passive solar,minor renovations at years 30 and 60.				
Demolish (1)	1463	1463	1463	1463
Rebuild	146326	146326	146326	146326
Painting 15yrs then 10 yrs intervals	127964	127964	127964	127964
Minor renovation (20% WB, roof, HWC).	48961	48961	48961	48961
Operating energy 90 yrs	123210	278640	324270	374310
	447,924	603,354	648,984	699,024
Option 2 Major renovation, another 30 years life, then rebuild with minor renovation year 60.				
Major renovation now	76744	76744	76744	76744
Painting year 15 then year 25.	31991	31991	31991	31991
Demolish year 30.	1463	1463	1463	1463
Rebuild yr 30.	146326	146326	146326	146326
Paint year 45 , then 10 yr intervals.	79978	79978	79978	79978
Minor renovation year 60.	48961	48961	48961	48961
Operating energy to year 30	47940	104370	122400	141210
Operating energy year 31 to year 90.	82140	185760	216180	249540
	515,543	675,593	724,043	776,213
Option 3. Do nothing now, demolish and rebuild year 10, minor renovations years 40 and 70 yrs.				
Demolish year 10.	1463	1463	1463	1463
Rebuild year 10	146326	146326	146326	146326
Paint year 25 and then every 10 years.	111969	111969	111969	111969
Minor renovation year 40 and year 70.	48961	48961	48961	48961
Operating energy year 1 to year 10	44150	87530	105210	122290
Operating energy year 11 to year 90.	109520	247680	288240	332720
	462,389	643,929	702,169	763,729
(1) Assume demolition ee is 1% of new construction				

Embodied energy in the structure and maintenance/renovation activities is a significant proportion of total energy use. For example, in Wellington it is 54% of total energy use in Option 1, 57% in Option 2 and 48% in Option 3. This illustrates the worth of using construction materials that reduce embodied energy use.

9.2 Multi-unit housing redevelopment

Further details of the calculations of costs and energy use in redeveloped multi-units are shown in Table 13 and Table 14. The assumptions include:

- An average unit size of 140 sqm.
- The required expenditure to upgrade an existing house is $60,000, including ceiling and floor insulation and kitchen and bathroom upgrades.
- In ALF 3.1 (Stoecklein et al 1999) thermal modelling was used to estimate the energy savings after retrofit of insulation, and differs for detached houses and multi-units.
- Maintenance costs per year were estimated at 0.5% of the building value for new units and 0.75% of the value of upgraded houses.
- Embodied energy of land development is not available for New Zealand, so Australian data was used.

Table 13. Life cycle costs – multi-unit redevelopment

Present value analysis - demolish & total re-build versus upgrade some units & re- build remainder.

	Initial costs $ ------------------------------->			Land	Operating costs/ maintenance (5)		Total
	Demolish (1)	Rebuild (2)	Upgrade (3)	purchase (4)	per yr per unit	PV $	PV $
Option1	72,000	8,960,000			1,484	912,509	9,944,509
Option2	0	6,272,000	720,000	2,688,000	2,112	1,028,374	10,708,374

Option 1 Demolish 12 detached houses & rebuild 40 multi-units on same land.) Example from ENZ magazine
Option 2 Upgrade 12 detached houses, purchase land for 28 multi-units & build 28 units.) April 2010.

(1) Demolition. Cost per house ignoring any salvage value =	6,000	$	BRANZ estimate			
(2) Build cost assume $1600/sqm, say 140 sqm per unit.	224,000	$ per unit	BRANZ estimate			
(3) Upgraded detached houses =	60,000	$ per house	as per ENZ magazine			
(4) Land purchase for 28 multi-units. Can fit 40 multi-units on 12 sections (say 800sqm each section).						
Hence for 28 multi-units need 12*800*28/40 =	6720	sqm of land				
Assume developed land cost $400 per sqm =	2,688,000	$ for 28 multi-units.		Maintenance $/yr	Energy $/yr	
(5) Heating/ maint, For new multi-unit =	1,484	$/yr	BRANZ est.	1120	364	$0.20/kWh
For upgraded detached houses =	2,112	$/yr	BRANZ est.	1680	432	

Table 14. Total energy use – multi-unit redevelopment

Embodied & operations energy - demolish & total re-build versus upgrade some units & re- build remainder.

					Energy (heating and maintenance embodied) used over a 30 year period.		
	Initial energy GJ --->			Land			
	Demolish (1)	Rebuild (2)	Upgrade (3)	developed (4)	Heating (5)	Maintenance (6)	Total GJ
Option1	26	8,802			7,862	1,320	18,010
Option2	0	6,161	713	739	10,125	1,452	19,191

Option 1 Demolish 12 detached houses & rebuild 40 multi-units.
Option 2 Upgrade 12 detached houses, purchase land 28 multi-units & build 28 units.

(1) Demolition, energy per house, assume 1% of build =	2,200	MJ	BRANZ estimate	
(2) Build embodied energy assume 1572MJ/sqm	220,041	MJ per house	BRANZ estimate	
(3) Upgraded detached houses (27% of new build)	59,411	MJ per house	Proportion of upgrade to new cost.	
(4) Embodied energy of land sections is approx	110	MJ per sqm section, Aussie data (Pullen 2006)		
Previous table 28 multi-units need	6720	sqm of land		Use ALF3.2
(5) Space heating in winter multi-unit=	1,820	kWh/yr	Assume 13kWh/yr/sqm, 18DegC M/E, Auckland.	
For upgraded detached houses =	2,160	kWh/yr	Assume 15.4kWh/yr/sqm, more external wall area.	
(6) BRANZ work indicates maintenance embodied energy over 30 years is about 20% of initial ee.				
Use 15% for new multi-unit and 20% for detached upgrades.				