PR240/3

Sustainable Homes National Value Case

Final

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About This Report

Title

Sustainable Homes National Value Case

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Reviewer

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Abstract

This report quantitatively assesses the National Value Case for a range of innovations related to the efficient and sustainable use of the country's resources in housing – Beacon's High Standard of Sustainability (HSS) for housing. The National Value Case is evaluated with respect to four types of HSS benefits: private economic benefits that accrue to households, environmental benefits, social and other private benefits, and national resource use efficiency. The results show that the strongest National Value Cases are for compact fluorescent lighting and instant gas hot water systems. Pellet burners and heat pumps for space heating, water metering and a package of three water saving measures also have a reasonably solid national value case. Retrofit insulation performs less well, and heat pump hot water systems have only a weak National Value Case.

Reference

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1 Executive Summary

This report was commissioned by Beacon Pathway Ltd (Beacon) to quantitatively assess the National Value Case for a range of innovations related to the efficient and sustainable use of the country's resources in housing – Beacon's HSS High Standard of Sustainability® (HSS®) for housing.

Data shortages prevent us from quantitatively evaluating all of the potential HSS innovations that Beacon has identified, so we confine our analysis to a selection of energy and water saving innovations. Innovations relating to waste reduction and neighbourhood design have not been analysed.

The national value case is evaluated with respect to four types of HSS benefits: private economic benefits that accrue to households, environmental benefits, social and other private benefits, and national resource use efficiency. Different approaches are used for evaluating the different types of benefit, but the final assessment of the national value case for an innovation is expressed as a weighted score. Associated with this score is a complementary assessment of the scope for government intervention. That is, some innovations have a strong national value case, but may face barriers to adoption by households. In such instances government intervention may be appropriate.

Our results show that the strongest national value cases are for compact fluorescent lighting and instant gas hot water systems. Pellet burners and heat pumps for space heating, water metering and a package of three water saving measures also have a reasonably solid national value case. Retrofit insulation performs less well, and heat pump hot water systems have only a weak national value case. It is important to note, however, that all of these innovations are evaluated from the perspective of the average household or from the perspective of the nation as a whole – the national value case. Overall, the larger scale heating and water innovations deliver the housing HSS targets.

If all of the innovations that we rate as Medium Weak or better are combined, and spreading installation costs over 20 years, they generate a direct private gain to households equivalent to 1% of GDP by 2017. From the perspective of national resource use efficiency, however, this result is somewhat misleading as it does not allow for the fact that the macroeconomic gain is equal to the difference in the productivity of resources being released from activities such as energy generation and moving into activities such as restaurant meals or movies, or whatever is the target of the household sector's marginal dollar. Nevertheless, even allowing for this, the selected innovations deliver a net gain (after installation costs) in real private consumption of 0.35%. This corresponds to about $106 per person per annum. The non-monetary benefits of healthier and more comfortable homes represent additional gains in consumer utility.

Direct savings in household energy consumption amount to almost 22 PJ per annum. Most of the savings are in electricity use which implies a 9% reduction in total CO_2 emission or about 3600 kt per annum. However, take-back effects in the form of warmer and healthier homes, more spending on travel and so on, reduce the net economy-wide CO_2 savings to approximately 1600 kt per annum.

Direct water savings amount to 81 litres per person per day, or about 130 million m^3 per annum in aggregate.

Projecting an average 25,000 new homes per annum implies that by 2017 dwellings built since 2007 will constitute about 17% of the total dwelling stock. Assuming similar behaviour by consumers, similar family sizes and so on, there will be a slightly higher benefit for residents of new houses because of the lower capital costs of insulating during construction rather than by retro-fitting. Offsetting this to some extent, however, is the larger size of new dwellings compare to the existing stock.

Many HSS innovations will perform better in certain climatic zones, or for certain household types. For example the case for retrofit insulation is stronger in Southland than in Northland. Water saving devices will be more cost effective where water consumption is directly priced, and in larger households. An innovation with a poor national value case may have still considerable merit in particular circumstances.

The report has two main parts. Part 1, comprising sections 1-3, presents the assessment framework, including a theoretical model for understanding the sources of HSS innovations, a reasonably comprehensive list of potential HSS innovations, and how the benefits of the innovations are evaluated. Part 2, comprising sections 4-6, presents detailed analysis of the private economic benefits and resource use efficiency effects of a selected subset of innovations. Section 6 combines the results of this analysis with an assessment of the environmental and social benefits, to produce overall scores for the national value case for each innovation. The appropriateness of government intervention and the forms of intervention that could be appropriate in each instance are also discussed.

The analysis in this report is not the final word on HSS innovations for sustainable homes. In particular, the following caveats should be noted:

1) Relative prices change over time, so benefit-cost ratios can change and hence too the national value case for an innovation.
2) Even if prices are constant over time they may differ across regions or across suppliers, or with economies of scale. Again this can affect the national value case.
3) Some innovations will be worth pursuing in particular circumstances (such as regions or household types) even if their national value case is doubtful. We look only at national average effects.
4) The weights that we have applied to each of the four benefit types; household economic benefits, environmental benefits, social and other private benefits, and national resource use efficiency, are merely our assessment of plausible values. We stress that have not been derived from any community consultation or surveying. They need to be carefully validated.
5) Where possible the analysis takes into account economies of scale and the efficiencies of doing multiple installations rather than one-offs installations, for innovations that relate to

broadly the same area. However, we have not considered possible savings from combining say ceiling insulation with the installation of low flow shower heads.

6) While the evaluation of national resource use efficiency effects allows for upstream effects such as the mix of electricity generation at the margin, the energy needed to pump reticulated water over long distances, the differences in using gas directly versus using electricity generated from gas, and so on, it is implicitly assumed that the prices of all of these goods and services reflect the true opportunity costs of the resources involved. This may not always be true. For example we include a price on CO_2 emissions, but we cannot claim that it is the correct price.
7) While our conclusions about the national value case for any given innovation are expected to be reasonably robust, major changes in relative prices or in the weights for the various types of benefits could change the results. Sensitivity analysis is recommended following a discussion about priorities.

2 Part 1: Assessment Framework

2.1 Theoretical Model

Sustainable housing is about reducing the adverse effects of housing on the environment while at the same time making houses more comfortable and healthy, and doing both in a nationally cost-effective manner. This means that we need to evaluate what might happen in housing in an economy-wide context.

Following Bruvoll and Medin (2000) the following equation presents a decomposition of economic output in terms of the impact on the environment through resource use and emissions of waste.[1]

$$E = \sum_w \sum_i \sum_j \frac{E_{wij}}{R_{wij}} \cdot \frac{R_{wij}}{R_{ij}} \cdot \frac{R_{ij}}{R_j} \cdot \frac{R_j}{Y_j} \cdot \frac{Y_j}{Y} \cdot \frac{Y}{P} \cdot P \qquad (1)$$

E is a measure of entropy which could be waste, emissions from the combustion of energy, pollution, harm to the environment, harm to species, ecosystems and so on[2];
R is a measure of resource use, this could be the consumption of energy, the utilisation of raw materials, land use and so on;
Y is consumption or production;
P is a measure of population or households;
w is the technology specific resource use method, for example with energy use it could be the combustion method;
i: is the resource type, e.g. oil, building materials.
j: is the industry or sector, e.g. farming or energy.

Effectively the equation is simply an identity – all the terms on the right hand side of the equation cancel out except for $\sum_w \sum_i \sum_j E_{wij}$, which of course equals the left hand side.

Our focus is on one sector, housing, so we are not directly concerned with the environmental effects of production in other sectors or industries, such as the emissions generated by pastoral

[1] This model has also been used by Infometrics in a report to the Ministry of Economic Development for assessing the economic development potential of environmental technologies.
[2] While the term, E, can be interpreted in a very broad sense as covering all ways that human economic and social activity impacts on the environment beyond the consumption of resources (R), for expositional simplicity we will refer to E as a measure of emissions.

farming. However, we are concerned with indirect effects such as the effect on the composition of electricity generation from a reduction in household energy use.

Hence we can work with a simplified form of Equation (1) which omits the j subscript for industry, effectively subsuming it within the resource type i. Resource use (*R*) now relates entirely to housing. We also add an extra term *H* for the consumption of housing services (the shelter, comfort and enjoyment from living in a dwelling).

$$E = \sum_{w} \sum_{i} \frac{E_{wi}}{R_{wi}} \cdot \frac{R_{wi}}{R_i} \cdot \frac{R_i}{R} \cdot \frac{R}{H} \cdot \frac{H}{Y} \cdot \frac{Y}{P} \cdot P \qquad (2)$$

Returning to the previous example, a reduction in energy use by households corresponds to a change in R/H (assuming no offsetting increase in other inputs). If there is a change in the composition of electricity generation we can think of this as substitution between two types of electricity or a change in R_i/R.

We define an innovation as an event – technological, policy or external shock – that changes the numerator of a ratio in Equation (2). In Table 1 below we provide a description of the different types of innovations that could be investigated. We adopt a general to specific approach beginning with the right hand term, *P*, and move on to terms to the left. We presume in our exposition that an innovation at an aggregate level (i.e. to the right in the equation) occurs independently of more specific technology innovations (i.e. to the left). That is we are defining innovations by the source of the innovation not by any indirect or flow-on effects.

Table 1: Sources of innovation

	Innovation Source	Title	Description
1	ΔP	Population growth	Could occur for a variety of social, economic or environmental reasons, but can be considered outside the scope of the current exercise.
2	$\Delta Y/P$	Per capita growth in total consumption	An independent innovation in per capita consumption, could occur from changes in changes in income etc. Again these changes are outside the scope of this study.
3	$\Delta H/Y$	Change in housing share of total consumption	A change that could be driven by changes in the age composition of the population, or a reduction in housing costs.

4	$\Delta R/H$	Change in total resource intensity of housing	An innovation that might originate at the aggregate level of resource use such as the amount of building materials per dwelling. For example both the Now Homes have reduced their resource intensity due to more careful design and use of standard material sizes.
5	$\Delta R_i/R$	Change in mix of resources used	This would represent an integrated advance, such as the development of effective insulation.
6	$\Delta R_{wi}/R_i$	New technology for use of a given resource	A new approach for delivering an established service, such as a more efficient hot water cylinder (including simple wrapping).
7	$\Delta E_{wi}/R_{wi}$	Emissions / waste control technology	An improvement to the environmental impact of an existing technology, such as lower particulate emissions from a wood burner. Reuse of waste such as composting.

However, indirect multiplier effects may well exist. That is, reductions in resource use under terms 4 - 6 could push out the economy's production possibility frontier, generating greater output or consumption – captured in the second term (*Y/P*). These effects will be analysed with a general equilibrium model in a later section.

The interaction of these factors is presented schematically in Figure 1.

3 Part 1: Assessment Framework

3.1 Theoretical Model

Sustainable housing is about reducing the adverse effects of housing on the environment while at the same time making houses more comfortable and healthy, and doing both in a nationally cost-effective manner. This means that we need to evaluate what might happen in housing in an economy-wide context.

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We define an innovation as an event – technological, policy or external shock – that changes the numerator of a ratio in Equation (2). In Table 2 below we provide a description of the different types of innovations that could be investigated. We adopt a general to specific approach beginning with the right hand term, P, and move on to terms to the left. We presume in our exposition that an innovation at an aggregate level (i.e. to the right in the equation) occurs independently of more specific technology innovations (i.e. to the left). That is we are defining innovations by the source of the innovation not by any indirect or flow-on effects.

Table 2: Sources of innovation

	Innovation Source	Title	Description
1	ΔP	Population growth	Could occur for a variety of social, economic or environmental reasons, but can be considered outside the scope of the current exercise.
2	$\Delta Y/P$	Per capita growth in total consumption	An independent innovation in per capita consumption, could occur from changes in changes in income etc. Again these changes are outside the scope of this study.
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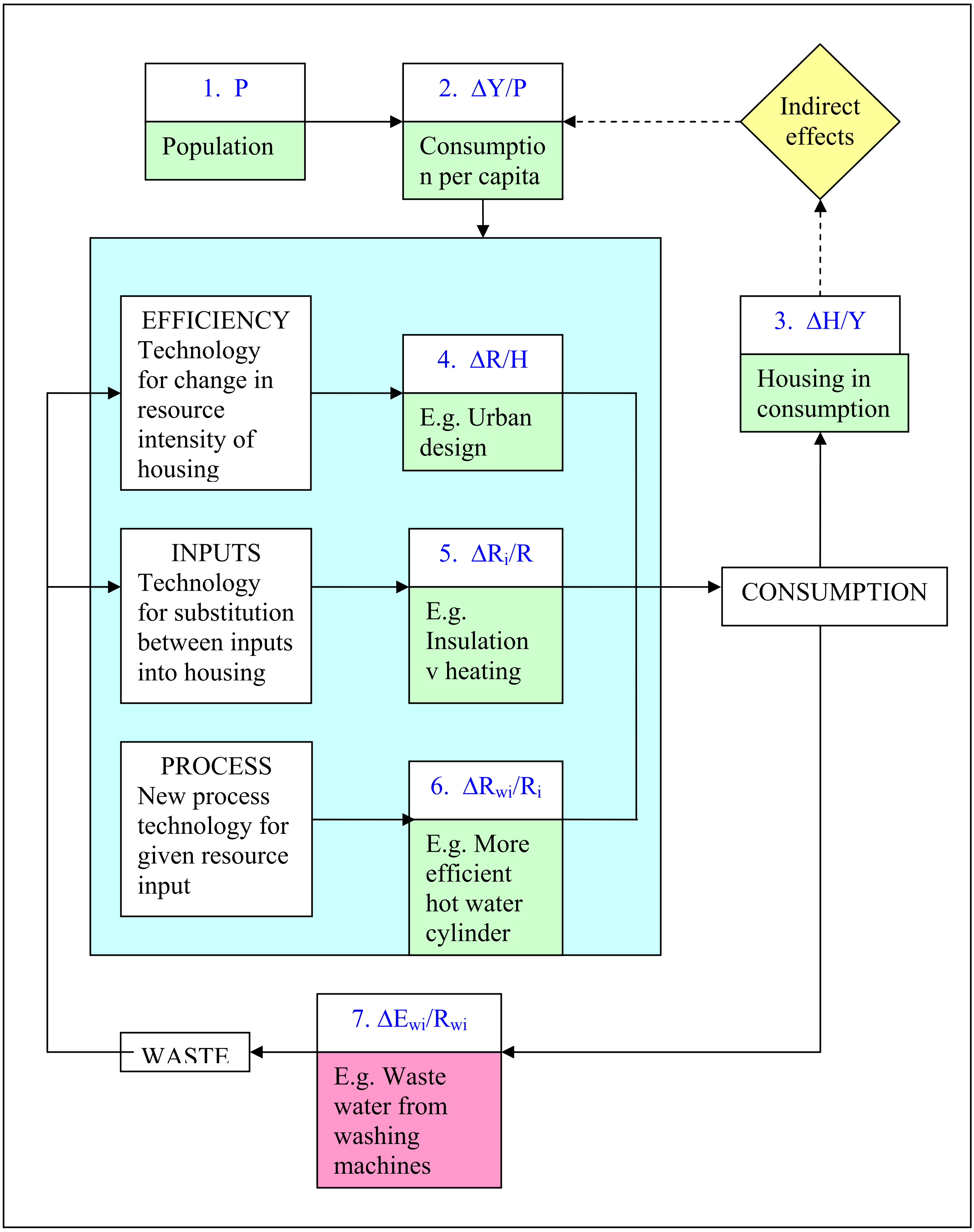
However, indirect multiplier effects may well exist. That is, reductions in resource use under terms 4 - 6 could push out the economy's production possibility frontier, generating greater output or consumption – captured in the second term (*Y/P*). These effects will be analysed with a general equilibrium model in a later section.

The interaction of these factors is presented schematically in Figure 1.

Figure 1: Consumption of Housing Services



From an environmental outcomes perspective the focus is probably on terms 5 and 6, although these may also be transmitted into changes in 4 and 7 respectively. Irrespective of their source, environmental dividends from innovations arise only if there is a reduction in the nation's resource utilisation intensity of housing (ie R/H) and/or its environmental impact through waste and emissions (ie $\sum_w \sum_i E_{wi}/R_{wi}$). We would like to see reductions in emissions and waste produced by any given technology or the selection of technologies that have low emission/waste rates, (ie lower *E*). However, unless a decrease in emissions (E_{wi}) is associated with an increase in the consumption of housing services (*H*), it is unlikely that households will adopt the less wasteful technology voluntarily. The adoption of technologies that contribute to sustainable homes is likely to be unambiguously positive for the national economy if $cor(Y_{wi}, E_{wi}) \leq 0$. Presumably in most situations where this is the case, private returns will also be sufficiently large to not require a major public policy role.

The economic impact or national value case of a technology that reduces emissions is likely to be greater if it also improves the efficiency of resource utilisation. Households will be encouraged to adopt an emission or waste reducing environmental technology if they perceive that they can make costs savings from reduced resource costs or, alternatively, derive greater utility from the technology. This is likely to be the case if either $cor(E_{wi}, R_{wi}) \geq 0$ or $cor(R_j, Y_j) \leq 0$.

3.2 Sustainable Housing Innovations

Table 3 below provides an initial qualitative assessment of a range of sustainable housing innovations in terms of the benefits that they could generate. Benefits are classified into four areas: private (economic and non-economic), government (central and local), national resource use efficiency, and the environment. The benefits in the latter two categories are also classified into the appropriate source component of the assessment model outlined above.

Also shown are possible reasons (barriers and/or externalities) why the innovations are not being pursued by private interests. In this regard there are potentially four types of innovation:

1) Those that generate a net improvement in economic efficiency which accrues directly to households. In this instance the role of public policy would be small (confined to say education and information to overcome apathy and ignorance) as private incentives will be aligned with achieving the goal.
2) Those that generate a net improvement in economic efficiency, but where externalities exist that hamper their introduction. In this instance the role of public policy would be critical, but the justification for the required policy changes is quite straightforward.
3) Those that generate an improvement in the quality and sustainability of the housing stock, but at a net economic cost (or where it is difficult to quantify the intangible benefits). In this instance there is potentially a role for policy if one can provide cogent arguments that

the environment or social improvements (such as health gains) justify the economic costs of the policy. These will be areas where more effort is required to justify a policy change.

4) Those that generate an improvement in the quality and sustainability of the housing stock that is not sufficient to justify a policy response. The economic cost required to implement the initiative does not justify the perceived benefits. These are initiatives that should not be pursued, the chances of success are low and, if pursued, have the potential to undermine the ability of Beacon Pathway to achieve its overarching goals.

The left hand column of Table 2.1 is a preliminary assessment, based on a scan of the Beacon documents and other literature, to rank the various innovations into (at this stage) three groups; a strong (A), medium (B) or weak (C) national value case. Essentially the national value case depends on the benefit to the nation exceeding the costs; that is, resources need to be used more efficiently in the consumption or production of housing services, or be allocated more efficiently between activities, and/or deliver social and environmental benefits in addition to economic benefits.

Detailed evaluation of a selected sub-group of innovations is addressed Part 2 of the report. Note that the benefits of some initiatives are path dependent. That is they may be higher if introduced along with other benefits, or they could be lower. For example more efficient space heating will have a quicker pay back period in houses that are not insulated, although this does make it an optimal strategy – or there may be economies to be gained from simultaneous installation of a number of water saving measures.

Table 3: Sustainable Housing Innovations

Likely national value case for Existing housing ad New housing	
A	Strong
B	Medium
C	Weak

Numbers in [ ] under 'Resource use efficiency' and 'Environmental benefits' correspond to innovation sources listed in Table 2.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
E	**N**	**ENERGY**						
A		Retrofit ceiling insulation (up to the current 2007 code.	More comfortable home. Better health. Energy cost savings. 1/3 of hh energy is for space heating. Take-back for comfort occurs because current retrofits are inadequate.	Lower (or redirected) health expenditure. Less absenteeism in the national workforce which is thus more productive	Less investment in large energy generation. Fewer work days lost through illness. [5]	Lower greenhouse gas (GHG) emissions from less thermal generation, and perhaps lower PM10s. Use of waste materials in insulation. [4]	Credit constraints. High discount rate. Insufficient information. Inability to capture sufficient benefits. Lack of roof cavity.	≈1m homes built before 1979 and 1.6m before 2007. Crown owns ≈70,000 units, most retrofitted to 1978 standards. Need retrofitting to at least 1992 code levels, if not 2007.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
B		Retrofit floors and walls			[5]	[4]		Is the floor suspended or is it a slab on the ground?
C	**A**	Double glazing	Less noise and improved amenity. Less condensation and dampness.		[5]			Limited benefit without insulation.
A		Space heating: heat pumps and pellet fires.	Log burners (and pellet burners if have a battery) raise resilience to power cuts. More comfort.		[5,6]	Lower (GHG) & particulate emissions. Reuse sawdust waste. [4,7]		Limited benefit without insulation. Take-back – greater comfort, lower energy savings.
C	**B**	Solar, heat pump, wetback, water heating	Energy cost savings. Solar hot and wetbacks increase resilience to power cuts. But long payback period.		Less investment in large energy generation. Reduction in GHG emissions. [5,6]	Less thermal generation at margin.	High capital cost.	1/3 of hh energy is for water heating.
A	A	Instant gas water heating	As above		Direct use of gas. No cylinder	As above. Could raise GHG emissions.		

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
C	**B**	Energy efficient appliances	Energy cost savings		[6]	Lower ozone depletion as some appliances made in China still have CFCs as the refrigerant.		Accelerated replacement probably not economic
A	**A**	Energy efficient lighting using Compact Fluorescent Lamps	Energy cost savings		[6]	Lower thermal generation.		LED technology is developing rapidly. Halogen lights are not an energy efficient lighting option and interfere with ceiling insulation.
B	**B**	Energy efficient lighting using LED lights			[6]			
	B	Passive solar design – Eaves (new buildings are often missing these)	Energy cost savings. More comfortable indoor environment. Better weather tightness		Less investment in large energy generation [5]	Lower thermal generation.	Some District Plans – smaller sites and height in relation to boundary controls mean new houses are often built without eaves.	In hotter climates lack of eaves leads to air conditioning being installed.
	B	Passive solar design – thermal mass	Energy cost savings. More comfortable indoor environment. Easy to maintain.		Less investment in large energy generation. [5]	Lower thermal generation.	Sloping sections	Slab of insulated concrete to absorb heat and release heat overnight.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
	B	Passive solar design - minimise glazing on southern (and western to some extent) facade	Energy cost savings. More comfortable indoor environment. Walls are cheaper than windows.		Less investment in large energy generation. [5]	Lower thermal generation.	Urban design issues in some instances e.g. where street frontage is to the south; some consumer resistance if south facing views.	Glazing too evenly spread around the house. Maximise northward glazing and minimise south facing glazing. West facing glazing can cause over-heating due to the low angle of western sunlight.
		WATER						
C	**B**	Rainwater capture	Lower water fees or rates	Less local govt spending on new water supply, stormwater transport, treatment and disposal.	Less use of reticulated water [5]	Less damming of waterways & less stress on aquifers. Less damage & contamination from stormwater discharge to streams & coast, but	Many HH not directly face price of reticulated water. Health regulations may conflict.	Need to segment by rainfall zone and whether metered already (Auckland, Tauranga, Nelson). Possible negative effect if discharges are more concentrated.
A	**A**	Water use: low flow devices	Less energy use with low flow devices on hot taps & with low flow shower heads	As above.	Less water use from technical efficiency. [6]	Less wastewater discharge to receiving environments. Less damming of waterways & less		Could be marked comfort trade-off, but not for toilets.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
A	A	Water metering, (potable and waste)	Financial impact could be +ve or –ve, depending on the way fees are set.	As above. Better leak detection.	Less water use from price signal [4]	stress on aquifers.	Introduce a price signal. Perceived social issue for low income households with a large number of occupants.	Anecdotal evidence of strong effect.
C	C	Collection of grey water.	Lower water fees or rates	Less spending on local govt wastewater transport, treatment and disposal.	Less use of reticulated water. [5]	Less waste into waterways. [7?]	HH not directly face price of waste water removal. Probably viable only in dry or un-reticulated areas or where constraints on wastewater disposal exist.	Chemical build-up in garden? Synergy with rainwater capture if in dry area and/or high watering of gardens.
A	A	No in-sink waste disposal unit	Power savings. Disbenefit of more waste handling with more composting.	As above	Less water use [5]	Less waste into water-ways		
		WASTE						
B	B	Composting of green waste v landfills	Lower charges for rubbish collection	Less local govt spending on land-fills and cost of collection and transport of waste.	Less energy use transporting waste. [5,7]	Fewer landfills. Fewer emissions (local air and greenhouse gas) from transporting waste.	Some Councils have user charges, but many in general rates.	Possible loss of electricity generation. Larger regional landfills have better env, stds but more waste is moved. E.g. Whangarei & Akl refuse to Waikato.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
C	B	Space for recyclables storage	Lower charges for rubbish collection.	Less local govt spending on land-fills.	Waste returning back into the consumption stream. [5,7]	Fewer landfills.		Particularly an issue for apartment and medium density housing developments.
		BUILDING MATERIALS						
C	**B**	New homes made of sustainable materials. Also apply to renovations to older homes.	Health benefits from use of materials with low Volatile Organic Compounds.		Less resource use to make the materials. [5]	Less hazardous waste input to the environment.	Building Act issues in some cases.	Only apply to verified/certified materials based on cleaner production components and minimisation of hazardous inputs.
C	**B**	Reduce construction waste going to landfills	Prefabrication may lower costs as does use of standard material sizes.	Less local govt spending on land-fills.	Less energy use from transporting waste. Less embodied energy in materials going to landfill. [5]	Fewer emissions from transporting waste and embodied energy in materials	Waste disposal may not be priced below the true social cost.	The Now homes produced 2.5 tonnes instead of average 4 tonnes for a new home – largely as a result of design using standard material sizes.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
		INDOOR ENVIRONMENT						
C	**B**	Ventilation: active mechanical in wet areas	More comfortable home. Lower maintenance. Better health. Energy cost savings.	Lower (or redirected) health expenditure	Fewer work days lost through illness. [5]		As for retrofit insulation	Synergy with insulation, but double glazing could raise humidity
	B	House orientation	Warmer home. Less cost to heat. Better amenity of living space.		Lower energy use [4]	Lower energy use	Needs to be considered at the individual house & subdivision design level – developer resistance.	In Australia there is a regulatory requirement for East-West subdivision layout cf North-South.
	A	Passive vents	More comfortable home. Better health. Lower maintenance.	Lower (or redirected) health expenditure	Fewer work days lost through illness [6]			Passive vents reduce mould growth and poor indoor air quality.
B		Removal of unflued gas heaters	More comfortable home. Better health. Lower maintenance.	Lower (or redirected) health expenditure.	Fewer work days lost through illness. [5]		Perception that is a low cost form of heating and thus favoured by low income households.	CEA research indicates pellet burners have the lowest running cost of any heating method.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
		NEIGHBOURHOOD						
Outside scope		Access to public transport	Cheaper transport	Possible reduction in expenditure on new road capacity, but more on road maintenance.	Less fuel use. Net roading expenditure unclear [3]	Lower CO_2 emissions.	Requires urban density and dominant travel routes.	Very dependent on frequency, reliability and comfort.
		Siting of dwellings in relation to one another	More privacy. More community spaces. Lower crime.	Less policing	Less policing? [2]		Cost of land	Refer *The Value Case for Urban Design* (MfE).
	C	Multi-purpose dwellings & functional flexibility	Disbenefit from sub-optimal floor plan if try to build whole house for both domestic and commercial use.		Less use of building materials. [4]	Less use of building materials.	Future needs difficult to predict – how much flexibility to build in.	Apartments overseas are often designed so that walls are easy to move, to accommodate changing needs.

		Initiative	Private benefits	Fiscal benefits	Resource use efficiency	Environmental benefits	Externalities and barriers	Other
Outside scope		Higher density land use	More affordable house prices. Disbenefit from more crowding	Councils gain through more efficient use of infrastructure e.g. public transport.,	More efficient use of land. [3]	Less pressure from expansion of cities on natural resources unless intensive housing pushed into natural areas.	¼ acre section and suburban dream	Only appropriate where services exist. Higher density land use in sparsely populated areas is not efficient. Good design is essential.

3.3 Evaluation of Innovations

As discussed in Section 1 there are four main sources of environmental innovation associated with sustainable housing.

Table 4: Main Sources of Environmental Innovation

$\Delta R/H$	**Change in total resource intensity of housing**	**E.g. re-use of waste materials or use of standard material sizes.**
$\Delta R_i/R$	Change in mix of resources used	E.g. more use of insulation and less use of energy, or using tanks for water supply.
$\Delta R_{wi}/R_i$	New technology for use of a given resource	E.g. a more efficient hot water cylinder.
$\Delta E_{wi}/R_{wi}$	Emissions / waste control technology	E.g. lower particulate emissions from a wood burner.

Our next step is to design a means of evaluating how the main sources of innovation identified in Table 3.1 can deliver benefits, which we classify into four types:

5) Environmental (e.g. less pollution)
6) Social and private non-economic benefits (e.g. warmer homes)
7) Private economic benefits (e.g. lower household energy costs)
8) National efficiency of resource use (e.g. less waste).

From an evaluation perspective we do not separately assess fiscal benefits as we assume that they are converted into private benefits such as lower property rates or lower taxes.

We divide the evaluation into two components:

9) An assessment of the four types of benefit.
10) An assessment of whether the innovation is likely to occur or be adopted, either with or without government support.

3.3.1 Assessing the Benefits

In order to allow benefits with different units of measurement to be combined, we assign a weighting to each of the four types of benefit. Each innovation is given a score that measures how well it contributes to each type of benefit. The weighted average score is an overall measure of the benefits of the particular innovation. The reader is referred to any of the accompanying innovation-specific spreadsheets.

We have tentatively assigned weights as follows – they should add to 100%:

- Environmental (20%)

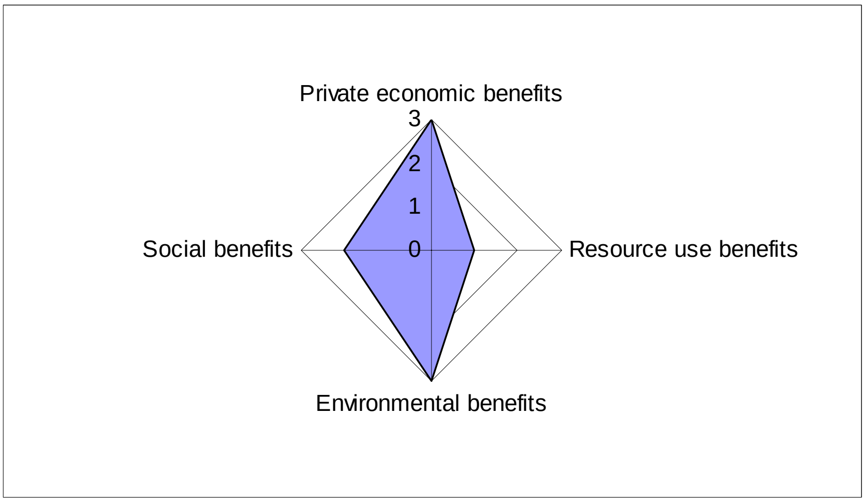
- Private non-economic benefits and social benefits (20%)
- Private economic benefits (30%)
- National efficiency of resource use (30%).

The above weights need to be investigated, as although we consider them to be plausible, we cannot claim that they reflect the community's marginal benefit preferences. Various methodologies could be used to establish a better set of weights. One option is to use carefully structured surveys to ascertain how consumers value marginal changes in each type of benefit and thus impute indifference curves. Another option is to estimate a monetary value for the non-monetary benefits by constructing a mapping that converts ordinal quality scales into monetary equivalents. See for example Van Praag and Baarsma (2004).

We recommend the use of multiple methods.

Calculation of an explicit weighted score can be avoided by plotting the score for each of the four benefit types on an x-y axis, where the area of the shaded polygon depicts the size of the total combined benefit. Figure 2 illustrates. Note, however, that this implicitly assumes equal weights.

Figure 2: Benefit Polygon



3.3.2 *Environmental benefits*

Table 3 describes four sources of sustainable housing innovations, but those four sources also constitute four ways in which the environment may benefit – fewer resources being used, more sustainable resources being used, resources being used more efficiently and less pollution from resource use. Thus an innovation is simply graded yes/no (1/0) against these four types of environmental benefit according to where it delivers.

The algorithm then assigns a score of 3 if three or four innovations are relevant, with scores of 2, 1 and 0 applied linearly thereafter.

Care needs to be taken to avoid double counting. For example, a reduction in CO_2 emissions may be counted as an environmental benefit, but if the assessment of national resource efficiency (refer below) includes an explicit and adequate carbon price, emissions should be excluded from environmental benefits.

3.3.3 Private non-economic benefits and social benefits

Three types of social and private non-economic benefits have been identified to date:

- More comfortable homes
- Better health
- Better (more pleasant and safer) neighbourhood

Again better health and more comfortable homes are intended to be benefits that occur in addition to any associated economic benefits such as less expenditure on health care, which are captured elsewhere.

An innovation is simply graded yes/no (1/0) according to where it delivers. Thus the score for private non-economic and social benefits lies in the range 0-3.

3.3.4 Private economic benefit

Private economic benefit is measured by the internal rate of return (IRR) for each innovation, calculated over a twenty year period. The IRR measure is preferable to say NPV, as it is more cognisant of other spending opportunities that are open to households and less dependent on the current level of prices. Against the background of rates of return available on risk free term deposits, scores are awarded as follows:

IRR	Score
$\geq$ 10%	3
$\geq$ 5% & < 10%	2
$\geq$ 0% & < 5%	1
< 0%	0

3.3.5 National efficiency of resource use

There is another type of effect that is incorporated in the model presented in Section 1; indirect effects, captured by the term Y/P in Equation (2). This corresponds to the increase in economic welfare that is generated by the flow-on effects of an innovation, in the form of a more efficient use of the nation's resources. This includes both productive efficiency (the amount of output obtainable from a given quantity of inputs) and allocative efficiency (when the value that consumers place on a good or service equals the cost of the resources used in its production). Taxation impedes allocative efficiency by distorting relative prices. With regard to sustainable housing innovations, consider the following example.

An innovation that replaces energy with more use of insulation in dwellings might have the direct effect of reducing household expenditure on energy. If insulation requires fewer of the nation's resources to deliver a given output – a warm home – than heating it to the same temperature, there is national gain in productive efficiency. If a warmer home also leads to better health and thus less demand for tax-funded health services, a reduction in taxation would be possible. That is, a rise in allocative efficiency.

Such indirect effects are not easily evaluated by consideration of the innovation alone. Consumer behaviour and inter-industry linkages in the wider economy need to be taken into account. For this purpose an economy-wide model is appropriate. We use the ESSAM general equilibrium model of the New Zealand economy to calculate the economy-wide, resource use effects of sustainable housing innovations.[5] Like any model, the ESSAM model is an abstraction and simplification of reality. Thus there will always be discussion around the validity and reliability of its results in any given application.

The resource use efficiency effects are obtained by comparing two solutions of the model; one without the innovation – essentially a Business as Usual scenario, and one where the model is 'shocked' with an innovation.

We have selected Private Consumption as the desired welfare metric by which to measure resource use efficiency. An obvious alternative is Gross Domestic Product (GDP), which might ostensibly avert a focus on the short term at the expense of a larger gain in the longer term. However, the model's equations prevent such an outcome. Further, there is little point in increasing other components of GDP such as exports, if this does not eventually raise private consumption.

Household expenditure on energy and water accounts for 3-4% of private consumption, depending on the value placed on water 'sold' via property rates. Even adding other dimensions of sustainable housing such as less waste, it is unlikely that sustainable housing innovations will affect more than 5% of private consumption. Indeed, given that sustainable housing innovations are directed at changing resource use, a relative impact of 20% (which is substantial) would impact total private consumption by only 1%. The impact of any single innovation would probably be an order of magnitude less.

As with private benefits, from a national perspective we are interested in whether the gain in private consumption from a sustainable housing innovation exceeds the loss in private consumption from having to devote resources to implementing the innovation. For example, if retrofit insulation leads to lower energy use, does the gain from having fewer of the nation's resources tied up in energy generation exceed the loss from having more of them tied up in housing capital stock?

We propose the following scoring system for national efficiency of resource use:

[5] ***A description of the model is presented in Appendix A.***

Private Cons. B/C ratio	Score
≥ 10	3
≥ 5 & < 10	2
≥ 1 & < 5	1
< 1	0

3.3.6 Weighted score

The score for each of the four benefit types is then multiplied by its weight, and aggregated. With the top score being 3 in all categories and the weights adding to unity, the aggregate score – the National Value Case – will lie in the range 0-3. An overall qualitative rating for an innovation, consistent with Table 2.1 is produced by the model using the following mapping:

Aggregate Score	Aggregate Benefit	Table 2.1 colour
< 1.0	No benefit	
≥ 1.0 & < 1.5	Weak	yellow
≥ 1.5 & < 2.0	Medium weak	green
≥ 2.0 & < 2.5	Medium strong	green
≥ 2.5	Strong	blue

Note that there is no guarantee that the aggregate score for any given innovation will correspond to the initial grades given in Table 2.1, though any major discrepancies should be investigated.

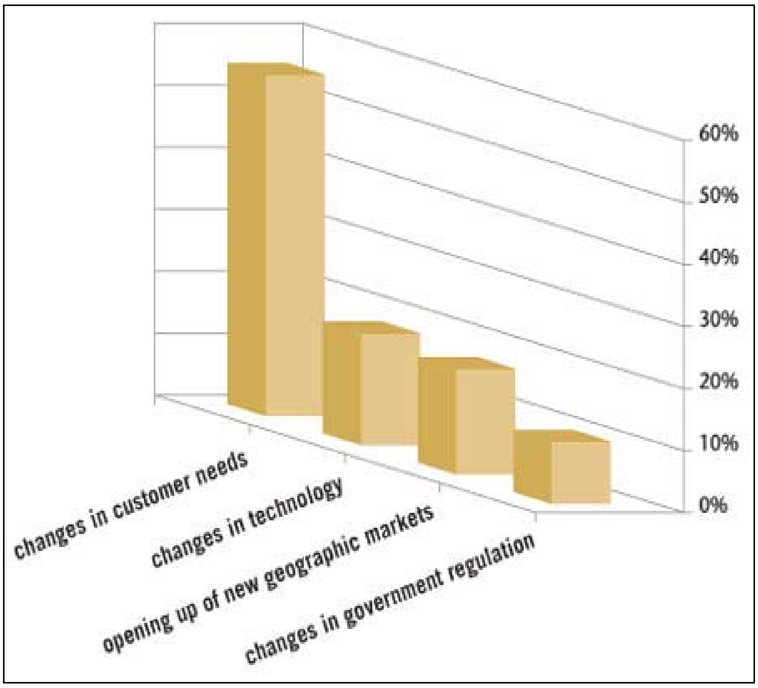
3.3.7 Assessing the Case for Intervention

3.3.7.1 The likelihood of adoption

As discussed in Section 2, private economic benefits may not be sufficiently strong for an innovation related to sustainable housing to be adopted. The factors shown in Figure 3.2 are reported in European Commission (2003) as key drivers of demand for innovation. Using these as a basis, we propose evaluating both demand and supply side factors, with each allowing for a possible role for government regulation.

The degree to which each factor is met is denoted by a grading from poor (1) to excellent (5). A low grade should be given when the likelihood of meeting a criterion is seriously in doubt.

Figure 3: Key Drivers of demand for Innovation



Demand factors

11) *Underlying current and future growth rate of the market due to changes in income.* An annual growth rate of 2-4% per annum is about average and so would merit a score of 3. Negative growth rates should be scored a 1, and growth rates above 10% per annum a 5.
12) *Potential for higher growth in future due to consumer environmental awareness.* To what extent might the penetration of the innovation be enhanced by increasing consumer awareness of the environment? We suggest a score of 1 for no likely impact from increasing consumer environmental awareness, through to 5 where prospects are excellent.
13) *Potential for higher growth due to regulatory changes.* Are there regulatory standards, especially environmental standards that would place the innovation in a competitive position? (The building code has just been amended as regards thermal performance. Higher insulation standards and double glazing requirements are being phased in progressively over the period October 2007 to September 2008, beginning with climate zone 3.) Scoring this criterion is analogous to the previous one; 1 for no prospect of any favourable effect through to 5 for excellent prospects.
14) *Demand sensitivity to price.* How sensitive is the projected volume of sales to price? Complete insensitivity to price should receive a score of 5, an elasticity of around -1 a score of 3, and anything more negative than -1.5 a score of 1. Elasticities may need to be estimated from interview data, be derived from international studies of the demand for similar products, or simply be informed guesses.

This brings us to the supply dimension. Consumers may desire the technology, or may be persuaded or legally obliged to purchase the technology, but can it be delivered efficiently and reliably? From Infometrics (2004) which involved surveying businesses involved in environmental technology, the following supply-side considerations are suggested:

Supply factors

15) *Supply of appropriately skilled labour.* Would the viability of the innovation be endangered by a shortage of suitably skilled labour? A score of 1 should be given for skills where supply is extremely tight. At the other extreme a score of 5 is warranted where no special skills are required and labour supply is plentiful.
16) *Opportunities for economies of scale.* To what extent might widespread adoption (including internationally) of the innovation be enhanced by economies of scale? Scoring here would ideally be dictated by industry knowledge. A reasonable proxy is the ratio of fixed to variable costs defined over a period of up to 1-5 years. Some experimentation is probably necessary to determine an appropriate mapping, but provisionally a score of 1 should prevail if fixed costs constitute less than 10% of total costs, rising to 5 if fixed costs constitute more than 90% of total costs.
17) *Reliability of distribution networks.* Success of the innovation may depend on reliable, secure, and efficient distribution systems, from the source of production to the final consumer. Scoring should be along the lines of a 5 for existing distribution networks that are known to be efficient, reliable and secure, down to a 1 for untested networks. Information should be secured from industry, including the transport industry.
18) *Supply of natural resources.* Is the viability of the innovation threatened by a limited supply of natural resources? For example, might the production of timber from sustainable forest plantations be in short supply, or might extraction of a mineral be unreasonably delayed because of regulations? A score of 1 should apply if resources are severely limited or if access to them is very difficult for legal or technical reasons. We would expect a score of 5 where resources are abundant and easily obtained.
19) *Current development status.* How far is the innovation from commercial production? A 5 is warranted if commercial production is imminent (within 12 months). A 3 would apply where the innovation has been tested and known to work, with likely customers identified. Where the innovation has yet to be tested a 1 should be awarded.

By assigning each criterion a weight ranging from say 1-3, and a score (as explained above), an overall score for the sustainable housing innovation is determined. While this presents a means by which the likelihood of innovations being adopted by households without the support of any new government initiatives can be ranked and compared, small differences in scores should be considered in perspective as weights and scores, even if founded on considerable expert knowledge, are subjective and therefore not likely to be totally accurate.

This is unavoidable, but it is precisely why this framework has been developed. It makes subjectivity transparent, provides an easy mechanism for alterations and clearly shows the sensitivity of an assessment to changes in assumptions. Sensitivity analysis is advised, especially if different projects emerge with similar scores.

3.3.7.2 Government intervention

One of the reasons for establishing a framework for evaluating the national value case for sustainable housing is so as to ascertain where a role for government intervention might exist.

Intervention is a broad term encompassing many different forms of government action. There is certainly no assumption that intervention should take the form of grants and subsidies.

For any of the criteria listed above it may be possible for an innovation to secure a higher score as a result of government action. The second column in the spreadsheet model requires each criterion to be re-scored on the assumption that government intervenes in some appropriate manner. Following the discussion in Section 2, the areas where government might intervene are as follows:

- Externalities such as air pollution exist.
- Markets are incomplete, such as where there is asymmetric information or high transaction costs.
- Imperfect competition prevails, such as frequently occurs in the provision of energy infrastructure.
- Public goods or merit goods exist.
- Regulations and international agreements exist that can be changed or effected only by government.

All of the above are concerned with some form of facilitation or market failure. There are also other justifications for government intervention such as income distribution and access to justice, but these areas are unlikely to be particularly relevant to sustainable housing innovations as there are more efficient ways to address such concerns.

Even if there are *a priori* grounds for government intervention, any intervention should consider the cost of intervening in relation to the cost of not intervening. The costs of intervention include not only the direct cost, but also the broader deadweight loss and crowding out that might arise. For this reason it is important to look at actions that minimise negative impacts, perhaps by devising interventions that also generate benefits beyond the area of immediate concern or those that provide a leveraging effect.

Some generic examples relevant to sustainable housing innovations are suggested below in Table 5, with interventions for particular innovations being deferred until Section 6.2.

Table 5: Government Interventions for Sustainable Housing

Government Lever	Benefits
Information/Education at two levels: To consumers on costs and benefits	Currently there is lack of perceived value and understanding of energy savings amongst consumers. Therefore educating consumers about costs and benefits of energy efficiency measures, how to improve energy efficiency and reduce energy consumption are important first steps. This involves pushing information onto the market so that energy efficiency becomes part of consumer decision making when buying homes.
Disclosure requirements such as energy ratings	This would build awareness and extend consumer understanding of issues relating to sustainability.

Remove regulatory barriers More Acceptable Solutions Drinking water provisions	Currently the Building Code sets performance standards at a relatively high, outcomes level. In order to enable the territorial authority to apply these standards, the Department has developed an Acceptable solutions framework. However, many sustainable approaches to building are not included with the Acceptable Solution Framework. This poses a regulatory barrier to sustainable building Guidance provided by the Health Act appears to be creating an implementation barrier to rainwater and greywater re-use within the household. *(How does the new subdivision on Kapiti Coast get around this?)* However, the new regulatory framework to be introduced looks at the issue of safe drinking water and sets standards from a public health perspective. This could still pose barriers to sustainable building (e.g. rainwater capture while easy solution to implement may not meet safety standards set by the new Health Act if water to be used for drinking)
Strengthen existing regulatory requirements Increase Building Code performance requirements[6] Resource Management Act	The Auckland City Council study notes that: "*measures recently introduced into the Resource Management Act will allow a regulatory approach to be developed around energy efficiency and the benefits to be derived from the use and development of renewable energy. This has the potential to be used as a significant incentive to encourage for example new development, or redevelopment beyond a threshold, to be required to meet high levels of energy efficiency, or to include solutions such as solar hot water systems.*"[7] District plans can act as barriers or incentives to the development of sustainable buildings.

[6] In the UK there is a requirement where if more than 50% of the floor area is affected by renovation, the entire house must to brought up to current code standards.

7 Easton et al (2006)

Establish new regulatory requirements Extend upgrade provisions of Building Act to include requirements for retrofitting say insulation in ceilings Introduce obligations on landlords, such as by linking payment of the accommodation supplement to insulation standards.	Currently for commercial properties, application for upgrades or renovation includes a number of related obligations that must be fulfilled. Applying this to household units would mean that any consideration for renovation triggers other requirements that must be met relating to sustainability. This could post a barrier to renovation work leading to reducing value of household stock Requiring landlords under the Residential Tenancy Act to implement insulation measures
Central Government taking a leadership and facilitative role in areas where the local government is the decision maker.	Facilitating change in the environmental climate in which these issues are discussed and considered.
Suspensory loans for retrofitting of existing household units	Self explanatory
Subsidise costs of retrofitting existing household units	Self explanatory
Pricing of externalities	Transparent pricing of energy using market based instruments that address negative environmental externalities, such as tradable pollution permits and carbon taxes.
Setting standards for quality for solar heating	Currently hard to install, expensive, quality is variable
Accreditation of insulation installers	Highly influential in consumer's decision to adopt insulation. Satisfies consumer's concern about the quality of installers

More general options include input focused policies such as research grants or tax concessions; and output focused policies such as assistance with proof of concept and marketing; and government being first buyer of a technology to demonstrate to the wider community that the technology works, and perhaps helping to achieve economies of scale in its production. It is likely that more than one type of intervention will be useful for any given innovation.

The evaluation model makes it possible to examine where government intervention could have the most leverage. For example regulations that mandate the installation of solar water heating in new dwellings would clearly raise demand, but might also reduce the unit cost of production and installation; or perhaps additional training of labour would be required.

However, the model is not sophisticated enough to determine the overall net benefit of a specific government action. That would need to be addressed on a case by case basis. As a guide, we would expect the cost of government action that is intended to assist sustainable housing innovation to be small in relation to the expected benefit of the innovation.

4 Part Two: Analysis of Selected Innovations

4.1 Private Economic Benefits (Cost Benefit Analysis)

The sustainable housing innovations listed below are selected for further analysis on the basis of two criteria:

1) They are usually tentatively coded as having a strong national value case in Section 2, Table 3.
2) Beacon Pathway Ltd. or others have provided enough information on which to base a reasonably robust cost-benefit analysis.

We consider innovations in only the areas of energy and water as there are no innovations in the areas of waste, indoor environment and neighbourhood that are sufficiently well specified to be examined with cost-benefit analysis. The cost-benefit analysis is undertaken from the perspective of the private household. Analysis from a national macroeconomic perspective is undertaken in Section 5.

Energy

- Retrofit ceiling (and floor) insulation
- Space heating: heat pumps and pellet fires
- Energy efficient lighting using compact fluorescent lamps
- Water heating using gas, solar or heat pump systems.

Water

- Low flow devices and appliances
- Water metering and pricing (potable).

One area we would have liked to investigate is that of ventilation in relation to indoor air quality (a subset of Indoor Environment in Table 3). However, within the resources available to this project we have not been able to assemble a sufficiently robust set of estimates of the welfare gains associated with improved indoor air quality, specifically through better passive and active ventilation. We have scanned a number of articles and reports, mostly relating to overseas jurisdictions.[8] A range of air quality issues are discussed including environmental (second hand) tobacco smoke, volatile organic compounds (e.g.formaldehyde), biological contaminants (e.g.mould), and combustion products (e.g.PM10s).

Adverse effects on human health include respiratory illnesses, cancer, SIDS (sudden infant death syndrome), lethargy, and allergic reactions. Many studies cite economic and social costs

[8] ***Amongst others: Fisher et al (2007), various American Lung Association Fact Sheets, Beacon Pathway TE220 (2007), CSPA (2004), Rhode Island Department of Health (2007), Rudge and Nicol (2004), Shannon et al (2003).***

for these conditions, but none appear to have robust estimates of the effect that better household ventilation would have on health, and via this on individual and national welfare. Robustness is important: most research is based on 'before and after' type studies which means that proper control groups, careful monitoring and reporting (allowing for Hawthorn effects), and skilful statistical analysis are essential. Another common approach is to compare the health status of people living in warm and dry homes with that of people living in cold and damp homes, without allowing for confounding factors such as income and diet.

Studies seem to face two main difficulties which researchers struggle to overcome:

1) Isolating the relative contribution of different sources of exposure, notably between home, work or school environments. Even for babies and infants, for whom most exposure to indoor pollutants is presumably in the home, good studies on the effects of household air quality on their health seem to be scarce. For example, estimates of the effect of second hand smoke on SIDS and asthma in young children are frequently reported, but without distinguishing between exposure to second hand smoke in the home environment and exposure from mothers smoking during pregnancy. This illustrates the second main difficulty;
2) Identifying the extent to which better ventilation might reduce the level of pollutants in the home. For example household cleaning behaviour, such as whether or not vacuum cleaners with HEPA filters are used, has a major effect on indoor air quality.

We shall demonstrate in Section 5.1.1 that warmer and drier homes can have a significant effect on individual and national welfare. We do not doubt that less air pollution in the home would also improve welfare. Unfortunately the type of information that we need to undertake either an individual or a national benefit-cost analysis of better home ventilation does not seem to be readily available, though a more comprehensive literature review than we have undertaken would doubtlessly uncover some useful information.

Nevertheless, Beacon's TE220 report expresses the current situation well:

> *A significant project that needs to be undertaken to quantify the magnitude of unhealthy homes is a comprehensive field investigation of the health effects and concentrations of pollutants found in New Zealand homes*. (p67)

In all of the analysis below we are cognisant that a large scale roll-out of any particular innovation could significantly reduce unit costs, but on the other hand supply bottlenecks could raise prices. On balance we have endeavoured to use installation costs that allow for a significant market size.

4.1.1 Energy

4.1.1.1 Retrofit Insulation

We examine six scenarios, each a combination of retrofitting ceiling insulation and under-floor insulation as described and costed in Beacon report TE106 (2007), but with a few adjustments as explained below. Scenario G considers the addition of wall insulation.

Table 6: Retrofit Insulation Scenarios

	Base R[9] value (ceiling)	New R value (ceiling)	Adjustment to TE106	% hh energy saving	Mean IRR (20 yrs) (Ele: 20c/kWh) %
A	0.0	Max IRR	yes	9.8	12.6
B	1.0	Max IRR	yes	5.3	3.0
C	0.3	Max IRR	yes	7.9	8.0
D	0.3	Max IRR	no	7.2	6.7
E	0.3	Compliance	yes	8.1	7.0
F	0.3	Exceed compliance	yes	8.3	6.0
G	0.3	Max IRR	yes	10.7	-0.3

The first issue is to decide on the base level of ceiling insulation to which improved insulation is being compared. Something in the range R0-R1.2 seems sensible, but taking into account the degraded insulation that is thought to exist in many homes and to provide continuity with existing Beacon reports, the R0.3 value reported in TE106 was used as a base case, In terms of potential energy savings, using R0.3 is likely to overestimate the national benefit – but only relative to the current status of the housing stock. It is considered a more realistic option than zero insulation.

The TE106 analysis is undertaken for eight towns/cities in New Zealand.[10] Weather differences mean that the economics of retrofit insulation in each town vary with the degree of insulation, and also with local costs. We analyse two options where insulation of a given standard is installed, and four options where the insulation standard for each town is the one that generates the highest internal rate of return (IRR). In all cases the results are weighted by population and energy use in order to produce a national scenario.

In order to develop a range of scenarios, the ALF [1] software programme was used to model the base case presented in TE106, with subsequent adjustments made to the type of insulation

[9] ***The R-value is a measure of the thermal resistance, or insulating value of a material and has units of K m^2 W^{-1}. The higher the R-value, the better the insulation.***

[10] ***Auckland, Gisborne, Rotorua, Masterton, Wellington, Christchurch, Dunedin and Invercargill.***

added. The energy savings predicted from our ALF model for increasing ceiling insulation were typically 25% higher than reported in TE106, translating into national savings about 10% greater than predicted from TE106 data. However, without access to the original ALF settings (of TE106), we were unable to determine the reason for this difference.

Ceiling insulation values were based on commercially available fibre-glass segment insulation. The impact of under-floor insulation was based on the installation of 100mm sag foil to a base case where no under-floor insulation has been fitted.

Scenarios A-D all assume a retrofitted insulation level determined within the TE106 report to give the highest IRR for the homeowner in each town. Scenarios A and B illustrate the effect of assuming different base case ceiling insulation values, corresponding to no insulation and insulation with an R1.0. Scenarios C and D both consider a base case ceiling R0.3, with C based on our simulated ALF model, and case D using the data available from TE106.

Scenario E proposes the level of ceiling insulation that is required to comply with the NZ building code, specifically the requirements of NZ4218:1996. The South Island and the central plateau of the North Island require a minimum insulation of R2.5, and the remaining part of the North Island, excluding the central plateau, a minimum of R1.9.

Scenario F proposes insulating the ceiling above the minimum code compliance level (NZS4218:1996) of scenario E (for fibreglass segment insulation), corresponding to installed insulation of R2.6 in zones 1 and 2 and R4.0 in zone 3.

Scenario G represents the addition of wall insulation using a foaming technique, in addition to the insulation presented in scenario C. [11] Installation is via drilling and filling holes, either from the inside or from the outside. An estimated 700,000 NZ homes have little or no wall insulation. While the energy savings are significant, the IRR is negative owing to installation costs of over $7000 compared to about $2500 (in the comparable Scenario C) for under-floor and ceiling insulation.

From a private household perspective, wall insulation is clearly not cost-effective. Ceiling and under-floor insulation, with an average IRR of 8%, is cost-effective from a purely energy-saving perspective, but is not that much better than the current net rate of return on bank term deposits. Furthermore, the IRR has been calculated on an assumed energy price of 20c/kWh which, whilst reasonable for standard electric (resistance) heaters, is probably higher than the average price of energy used for space heating (refer TE106, p37). Accordingly, while there will be locations and dwelling types where a higher IRR would exist, it seems likely that some form of inducement will be required to see the bulk of New Zealand's housing stock properly insulated. Such inducement may be as straightforward as educating consumers about the health benefits of insulation.

[11] ***There is concern that water ingress through an external wall could precipitate acid hydrolysis of formaldehyde in some types of foam, resulting in formaldehyde emissions.***

4.1.1.2 Space Heating

Two options have been proposed by Beacon as efficient methods of space heating – heat pumps and wood pellet burners. Heat pumps and pellet burners deliver much the same amount of dollar savings relative to a standard electric heater, but their mechanisms are different. Heat pumps deliver their benefit by being much more thermally efficient than a regular heater, while pellet burners deliver their benefit by using a lower cost fuel, although they also deliver an efficiency gain if used in place of standard wood and coal burners.

The following information is from TE106, p37.

Table 7: Space Heating

	Cost (c/kWh)	Use Efficiency	Effective Cost (c/kWh)	Relative Saving	Cost (labour + materials)	IRR (20 yrs)
Regular electric heater	18-21	100%	18-21			
Heat pump	18-21	220-300%	7-9	60%	$3000	20.6%
Pellet burner	6-8	75-92%	7-9[12]	60%	$4700	12.1%

The options in the table are not exhaustive and the baseline of a standard (instantaneous resistance) electric heater means that the 60% savings would not apply in all cases. Similarly for the IRRs. There are other thermally efficient space heating options such as gas-fired central heating and other cost efficient options such as enclosed wood burners. Of course there are also other inefficient options such as open fires and unflued portable gas heaters, both of which have even higher effective costs than standard electric heaters.

Another point to consider is that a pellet burner typically has about twice the output capacity (kW) of the average heat pump. From that perspective the IRR for the pellet burner is misleadingly low, but it is based on a given amount of heating (kWh) being delivered by different means. Any consequential increase in the demand for heating is part of the take-back effect. If that occurs then a pellet burner has lower marginal costs.

On balance the IRR's should provide a reasonable guide to the payback available to most households that would consider switching to one of the two options.

12 Note that a pellet burner uses a small amount of electricity.

4.1.1.3 Lighting (CFL)

From TE106 lighting is estimated to account for nearly 9% of household energy consumption. Most of it is incandescent lighting which if replaced with compact fluorescent lighting (CFL) would deliver savings of around 80%. Unfortunately not all lamp fittings are compatible with all CFL bulbs – halogen lamps for example and lamps with dimmers.

Estimates of the eventual penetration of CFL into household lighting cover a wide range from 25% to 50%, due as much to unknown consumer reticence and behaviour as to uncertain technical compatibilities. We assume a mid-point of 37.5%, although we concede that this is rather arbitrary and probably too low especially if there is an education/marketing campaign. Given that assumption the amount of electricity currently used for household lighting could fall by 30%. Over all households this implies a national saving of 1.8 PJ or 500 GWh per annum.

The cost of CFL bulbs is about three times more than that of an incandescent bulb, although various subsidies can reduce the cost to consumers substantially. Considering also the longer life of CFL bulbs, it is probably reasonable to assume that the capital costs of CFL and incandescent lighting are much the same over the course of a year. This means that the IRR of CFL relative to incandescent lighting approaches infinity. Hence from a private economic perspective CFL bulbs should be used wherever possible – the payback period is zero.

4.1.1.4 More efficient water heating

The TE106 report sets out the relative costs of different types of hot water heating. There are three efficient options; solar heating, a heat pump and instant gas heating, all considered relative to a traditional electric hot water cylinder (HWC) system.

Weighting the TE106 regional estimates yields energy savings of 83.5%. 65.6% and 15.2% respectively. However there are a number of caveats:

- The TE106 analysis assumes that the same amount of energy is required for water heating in all locations (temperature zones), although it does allow for the efficiency of heat pumps and solar heating to vary with location.
- Gas is cheaper than electricity, so even though energy savings are only 15%, cost savings are over 60%.
- There is some anecdotal evidence that instant gas systems generate quite a significant take-back effect in the form of longer showers. Thus maximum benefit from this innovation might depend on the simultaneous introduction of water metering.

Looking at the cost side, relative to an electric HWC the capital cost of a solar water heating system is around $5100, with a heat pump system at $3900, and an instant gas system at only about $400. These estimates assume installation only when existing systems need replacing and that a property is already connected to a gas supply, whether reticulated or bottled. The difference in capital costs leads to vastly different IRRs; 5.9%, 6.3% and 79.8% respectively, assuming an electricity price of 20c/kWh and a gas price of 8.6c/kWh. See Appendix C.

4.1.2 Water

4.1.2.1 Low flow shower head, dual flush toilet and efficient washing machine

We look at three technical innovations that reduce water use, as outlined in Table 8.

Table 8: Water Saving Innovations

Innovation	Saving	Explanation	Cost
Low flow shower heads	8.4%	Low saving due to due high proportion of low pressure systems and assumed take-back of flow rates less than 9 litres/minute – see appendix B	$50 material and $118 labour, for 34.8% of dwellings
Dual flush toilets	54.5%	5 litres versus 11 litres	No extra cost
Efficient washing machines	60%	60 litres per wash compared to 150 litres	$60 above standard machine

Source: Beacon Pathway TE106 (2007) and Appendix B

The low flow shower head produces aggregate savings that are less than those estimated in TE106. This is because we limit their adoption only to dwellings that have flow rates of more than 9 litres/minute, and then reduced their flow rates to 9 litres/minute with the low flow shower head – although this can equally be interpreted as a lower flow rate with a compensatory take-back in shower duration.

Dual flush toilets are assumed to be installed only in new dwellings and when old toilets need replacing. There is no additional cost compared to a single flush system.

Similarly, water efficient (AAA) washing machines are purchased for new dwellings and when old ones fail, but in this case there is an additional cost of $60 over the cost of a standard machine.

The three measures combined reduce per person usage from 241 litres to 177 litres. Placing a value on these savings is not straightforward as many households do not pay directly for water. We estimate an implicit average price of $1.30/m^3, but recognise that this contains a wide error margin. We assume an average of 3 people per household.

The IRR for the three measures combined is 40.0%[13] – at least for those households with water meters or where they are otherwise compensated by water supply authorities for installation of these measures, such as by lower property rates. Such a high IRR may well help to advance the argument for water metering.

[13] ***Capital cost of $228 and water savings per household per annum of (241-177)*365*3 people per household, at $1.30/m^3.***

Lower water use in showers also means lower energy use. Heating water from say 12ºC to 40ºC requires 118 kJ of energy (at 4.2 kJ/l). Given the 8.4% saving in water, a fuel mix for water heating of 84% electricity and 16% gas,[14] with efficiencies of 95% and 80%, the consequent savings in household electricity and gas use are 1.3 and 2.2% respectively.

These energy savings are worth approximately $30/year to a household, assuming prices of 20c/kWh for electricity and 10c/kWh for gas. This raises the overall IRR for the package of three water saving innovations to 52.7%.

4.1.2.2 Water pricing

The main reason for introducing water meters is to provide a price signal to consumers so that they have an incentive to reduce wastage through leaks and dripping taps etc, and to generally ensure that decisions at the margin are cognisant of the true economic costs of delivering water to the household. Charging for water use through property rates, even if via a uniform water charge, removes the consumer from the price signal and leads to suboptimal water consumption.

For reasons of both equity and efficiency a multi-part pricing regime is preferred. In Victoria (Australia) for example, a three-part tariff is used:[15]

- Step 1 (0-440 litres/day) Aus$0.78/kl;
- Step 2 (441-880 litres/day) Aus$0.92/kl;
- Step 3 (881+ litres/day) Aus$1.36/kl.

In New Zealand explicit charging for household water use is not widespread. Where it does exist there is typically only a single price or a price that declines with consumption.

Based on experience with a widespread roll out of meters in Nelson in 1998, the cost of a water meter including installation is estimated at approximately $200.[16]

The private economic benefit to the individual household depends on the extent to which their explicit bill for water is offset by lower property rates. Note that we are not suggesting that current water supply reticulation systems should be abandoned. What is of interest is whether, when an existing system needs to be expanded or replaced, a better option might be the introduction of water metering to reduce demand.

We are not aware of any New Zealand studies that have looked at the change in demand for water consequent to the use of water meters. However, from above, average water consumption is approximately 241 litres/person/day. For a typical household of three people this implies 264 m^3/year. For different prices and for different amounts of water saved the IRRs are as follows (all over 20 years):

[14] ***Source: TE106. Other fuel sources are negligible. See also Table 6.1.***
[15] ***GHD (2006).***
[16] ***This was for a residential manifold with dual check valves to prevent backflow, meter box and (concentric) manifold meter all installed, with driveways etc reinstated.***

Table 9: Water Metering IRRs

% saved	IRR at $1.00/m^3	IRR at $1.30/m^3	IRR at $1.60/m^3	IRR at $2:00/m^3
2%	-5.4	-3.3	-1.6	0.5
5%	2.8	5.8	8.5	11.8
10%	11.8	16.3	20.6	26.1
15%	19.2	25.5	31.5	39.5

A tentative analysis of data for Nelson city, adjusting only for rainfall and population, suggests that water consumption has fallen by about 8% per person since the introduction of explicit charging. The current price for water is $1.602/m^3 for consumption between 10,000 and 100,000 m^3, and $1.263/m^3 for consumption above over 100,000 m^3, per annum. For a three person household using around 264 m^3 per year, the IRR for a water meter costing $200 is 11.9%.

It is not possible to impute a price elasticity of demand for water from this data. The percentage change in demand is finite (8%), but the change in price is infinite – from 0 to $1.60. We do not know whether there was any associated deliberate reduction (or slower rate of increase) in property rates, let alone whether households were even aware of such a link.

4.1.3 High Standards of Sustainability

Table 2.1 presented numerous innovations that potentially contribute to a high standard of sustainability (HSS) in housing, most of which unfortunately have insufficient data to investigate thoroughly. For those that we have analysed above, however, to what extent do they contribute to Beacon's targets for housing HSS? Table 4.5 summarises the results. Details are given in Appendix D.

4.1.3.1 Energy

Caveat: Beacon report PR109 (2006) is the main reference for HSS, but its estimate of total household energy consumption does not align completely with the estimate in the TE106 report. As the latter is more recent and more comprehensive we apply a small scaling factor to the former, but this does not affect the relative improvement required to meet the target HSS. The TE106 data (p38) is also used to estimate the split of energy by end use. This too is not entirely consistent with the calculations of energy savings from various innovations in the body of the TE106 report (as also used in Section 4.1 above), primarily because the savings calculations are based on dwellings that have below average insulation or space heating.

All of this serves to emphasise that the high standards of sustainability are not final; likewise estimates of the precise degree to which any particular innovation might satisfy those standards. Error margins around estimates of household energy (and water) consumption are too wide to draw definitive conclusions. However, we are confident that the general flavour of the conclusions is robust.

Table 10: Energy and Water Percentage Savings

ENERGY*	**kWh/hh/yr**	**% change**		
Base Consumption	13524			
HSS Target	11204	17%		
Space heating	Insulation	Heat Pump	Pellet Burner	
No insulation		21.9%	-6.4%	
Ceiling insulation	4.6%	26.5%	-1.8%	
Underfloor	3.7%	25.6%	-2.7%	
Wall	3.6%	25.5%	-2.8%	
Ceiling/floor	7.9%	29.8%	1.4%	
Ceiling/floor/wall	10.7%	32.6%	4.3%	
Water heating				
Cylinder wrap	1.0%	(5.1% of water heating energy)		
Solar water heating	22.9%	(83.5%)		
Heat pump	18.0%	(65.6%)		
Gas instant	4.2%	(15.2%)		
Lighting (CFL)	1.8%	(20% of lighting energy)		
Appliances				
Fridge/freezer	2.4%	(25% of fridge/freezer energy)		
WATER	l/hh/d	l/p/d	l/hh/yr	% change
Base Consumption	900	300	328,500	
Reworked Base	723	241	263,895	
HSS Target**	540	180	197,100	-25.3
Package				
Washing machine			32,850	12.4%
Toilet			32,847	12.4%
Shower head			4,507	1.7%
			70,204	26.6%

2000 litre tank			153,866	58.3%
7500 litre tank			165,185	62.6%

* Weighted over three climatic regions
**Interim

Insulation on its own is not sufficient to reduce household energy consumption to the HSS target, but with the addition of a heat pump the target is easily met. Indeed a heat pump on its own can deliver the target, although it is probably not the best option. A pellet burner is less efficient than electricity and so produces negative energy savings relative to standard electric heating. However, this example illustrates the folly of using a using a single indicator to measure sustainability. As shown in Section 4.1.2, the lower unit cost of energy delivered via wood pellets (which are made largely from waste products) means that pellet burners have a competitive IRR of about 12%.

In effect, the HSS from using a pellet burner is manifested not in lower household energy use, but in less resource use upstream from the household sector, which is reflected in the fuel price. That is, the production of pellets has a lower opportunity cost than the production of electricity. Furthermore, as will be shown in the following chapter the pellet burner option leads to a greater reduction in CO_2 emissions than the heat pump option.

With regard to water heating, switching to either a heat pump or solar system produces a reduction in energy use that brings total household energy consumption within the HSS target. As space heating and water heating can each meet the target on their own, perhaps the HSS target is too high, although admittedly its realism depends as much on timing – that is, when it is to be achieved – as on what is economically feasible.

Gas instant water heating is possibly in a similar situation to pellet burners. Because it is primarily end use inter-fuel substitution, overall household energy consumption changes little and thus looks worse against the HSS objective than solar or heat pump systems. Direct use of gas, however, is more thermally efficient than using it to generate electricity. It also means fewer CO_2 emissions per unit of delivered energy. Accordingly it is possible that instant gas water heating systems are just as sustainable a use of resources as heat pump and solar systems. Again we explore this in the following chapter.

Other energy saving options such as more energy efficient appliances and lighting generate only small savings in total household energy use, but are significant in their own domains. Taken together they could make a worthwhile contribution to reducing domestic power costs.

4.1.3.2 Water

The HSS for household water consumption is uncertain as in PR109 it is based on average consumption of 300 litres per person per day (l/p/d). While we do not claim that the 300 l/p/d is incorrect, we have had difficultly in reconciling it to plausible values for various particular water uses such as for showers and washing machines. Hence we work from a revised baseline of 241 l/p/d (refer Appendix C). However, we have retained the PR109 absolute HSS target for household water consumption of 180 l/p/d, so this means that the relative reduction in consumption required to meet the target is lower, namely 25% instead of 40%. This needs to be revisited once more accurate consumption data is available.

The package of three water consumption innovations; low flow shower heads, dual flush toilet cisterns and AAA washing machines, reduces water consumption by almost 27% and brings consumption within the HSS target.

Installing a water tank produces no direct reduction in water consumption, but does produce a significant reduction in the use of reticulated water. In fact this is really what the water HSS target is about. Reducing one's consumption of water (or indeed energy) is not the main objective. The real objective of a high standard of sustainability is to ensure that the nation's resources are used in an efficient manner – along their whole life cycle from extraction and production, through to final consumption and eventual disposal. Reducing water consumption *per se* makes no sense, but not wasting water, ensuring it is allocated efficiently across different users and that it is delivered to users in a truly resource efficient manner (which may mean by household water tanks instead of reticulation), does make sense.

So, household water tanks do reduce water demand from reticulated systems (as does the package of water saving innovations) and in this sense meet Beacon's HSS. As with pellet burners, however, there may be other effects external to the household sector that reinforce or detract from the sustainability of water use when sustainability is viewed from a broader perspective. This takes us to Section 3.2.

4.2 National Resource Use Efficiency (General Equilibrium Model Analysis)

This section assesses the sustainable housing innovations examined in Section 4 for their effect on national resource use efficiency, in contrast to the traditional benefit-cost analysis undertaken from a household perspective presented in Section 4.

For this purpose we use the ESSAM general equilibrium model. Details of the model and issues to which it has previously been applied are provided in Appendix A. Briefly, the ESSAM (Energy Substitution, Social Accounting Matrix) model is a general equilibrium model of the New Zealand economy. It takes into account most of the key inter-dependencies in the economy, such as flows of goods from one industry to another, plus the passing on of higher wage costs in one industry into prices and thence the costs of other industries.

Some of the model's features are:

- Forty-nine industry groups.
- Substitution between inputs into production - labour, capital, materials, energy.
- Substitution between four energy types: coal, oil, gas and electricity.
- Substitution between goods and services consumed by households.
- Social accounting matrix (SAM) for tracking financial flows between households, government, business and the rest of the world.

As discussed in Section 3, we use the change Private Consumption as our measure of the welfare effect of changes in national resource efficiency. Separate model runs are used to look at the welfare effect of the cost of a given innovation (such as the cost of retrofit insulation) and the welfare effect of the benefit of the innovation (such as energy saving). The consequent benefit-cost ratio for the changes in private consumption provides the overall welfare measure for any given innovation.

This benefit-cost ratio is not discounted. It is important to understand the difference between standard cost-benefit analysis such as used in Section 4, and general equilibrium analysis. In the latter we are not comparing the actual cost of an innovation with the benefits to private consumption; rather we are comparing the cost of the innovation in terms of private consumption foregone, with the benefit to private consumption.

Consider retrofit insulation: a hypothetical long run equilibrium in which all houses are insulated would be characterised by:

- Housing with a greater capital intensity, as the insulation becomes part of the capital stock of the dwelling, and
- Savings on energy required for space heating (assuming no take-back).

This applies in any year once all dwellings are insulated. That is, there is an ongoing gain in private consumption from energy savings, but there is also an ongoing loss to private consumption from having more capital tied up in housing. Discounting both effects does not change the benefit-cost ratio.

Clearly, the private consumption benefit-cost ratio will be higher, the lower the opportunity cost of an innovation. In this sense it is intuitively similar to the traditional cost-benefit analysis of Section 4. The key difference is that a general equilibrium model takes into account indirect effects and feedback effects that could either enhance or offset the benefits that accrue to a single private household.

Having said that though, general equilibrium modelling is most useful where costs or changes are being imposed on the economy in such a way that the overall 'equilibrium' effect is not immediately obvious (for example a carbon tax being imposed, with varying impacts across sectors) and modelling can illuminate the net effects of various small interacting adjustments by a number of economic agents sectors. Modelling a relatively straightforward housing intervention such as retrofitting insulation is likely to offer relatively few distinctive insights. The cost is direct, and the benefit impact is relatively straightforward.

4.2.1 Energy Saving Innovations

4.2.1.1 Retrofit insulation

We select Scenario C from Section 4. Apart from Scenario A which has a rather unrealistic base level of insulation, it has the highest IRR and thus the greatest likelihood of occurring.

As discussed above we look at separate model runs for the cost of the insulation and the benefits of the insulation. We ignore the installation programme itself as that is purely a transitional phase.

Of course not all dwellings are amenable to retrofit programmes, but we assume that this affects both sides of the equation equally. That is, if 20% of dwellings cannot be retrofitted, then energy savings are 20% lower, as are annual retrofit costs. We will consider the obvious counter-examples later.

Run 1: Increase in housing capital intensity

In Scenario C the cost of retrofitting is an average $2482 per dwelling, covering materials and labour. This implies that an additional 1.4% is added to the cost of an average dwelling. In the model this is simulated as a reduction in housing capital efficiency of 1.4%. At this stage no recognition is given to the fact that housing services may increase in quality. We look only at the cost side of the innovation.

The modelling results are shown in the table below, expressed as a change relative to 'business as usual' (BAU). All model runs assume no change in aggregate employment, so any gains to labour are manifested as changes in wage rates. Retrofitting is not a national employment expansion programme, albeit that local effects may occur. There is also no change in the economy's total capital stock, implying that more investment in housing means less investment elsewhere. The flow-on effects of this throughout the wider economy, such as on the manufacture of insulation and building materials, are automatically tracked in the model. All runs include a charge of $25/tonne on CO_2 emissions.[17]

As note above, this scenario does not measure the economy-wide impacts of the installation programme itself. They are likely to be very small as installation essentially involves resources (such as labour) being moved from a range of activities into insulating houses.

The results show that raising the amount of capital tied up housing has a negative impact on the economy, which is of course not surprising given the imposition of a what is effectively a negative change in efficiency. More resources have been put into housing without generating any benefit – like gold plating pipes under the house. Private consumption and GDP are both lower by more than 0.2% relative to BAU.

Run 2: Energy savings

The location-weighted energy savings in Scenario C (Section 4) are 1267 kWh per dwelling. This corresponds to an estimated saving of 21.7% of heating energy, or 7.9% of total household energy. We simulate this in the model as if savings of 7.9% of household energy use could be achieved at no cost – that is, without requiring the additional investment in housing simulated in Run 1. Energy savings are distributed pro rata by fuel according to existing use for space heating.

Table 11: Retrofit Insulation Scenario (percentage change on BAU)

	Run 1	Run 2	Sub-total	Run 3	Total
	Increase in housing capital	Energy savings	Run 1+ Run 2	Health benefits	Runs 1-3 combined
	%Δ	%Δ	%Δ	%Δ	%Δ
Private Consumption	-0.26	0.02	-0.24	0.27	0.03
Govt Consumption*	0.00	0.00	0.00	-0.30	-0.30
Gross Investment	-0.20	0.01	-0.19	0.14	-0.05
Exports	-0.18	0.03	-0.15	0.28	0.13
Imports	-0.12	0.03	-0.09	0.18	0.09
GDP	-0.23	0.02	-0.21	0.19	-0.02
Private Cons (B/C)			0.1		1.1
CO_2 emissions	-0.12	-0.46	-0.58	0.30	-0.28

- exogenous

[17] ***The figure of $25/tonne is taken from IRD (2005). It is not a forecast.***

As shown in Table 11, Run 2, insulation delivers macroeconomic gains from energy savings, but they are much smaller than the cost of the extra capital that is tied up in housing (Run 1). Why are the benefits from retrofitting so small when the cost-benefit analysis produces an IRR of 8%?

The model actually asks a different question. The macroeconomic effect is not the gross value of energy saved by households. Rather it is the gain that arises from an increase in energy end-use efficiency in an economy-wide context. The energy used by households (excluding energy for transport) represents about 10% of the nation's primary energy use, and the value-added in energy industries constitutes around 1.6% of GDP. So a 7.9% saving in household energy use is analogous to about 0.013% of the economy's factor inputs being freed for use elsewhere – as dictated by household preferences. Differences in the efficiency with which different industries use resources mean that the freed resources can increase private consumption or GDP by 0.02% (±0.005%).[18]

What we may infer therefore from combining Runs 1 and 2, is that the retrofit insulation of floors and ceilings, as defined by the above microeconomic cost and benefit input parameters, does not produce a macroeconomic benefit when measured in terms of the gain in private consumption. The benefit-cost ratio for private consumption is only 0.1 (0.02/0.26). Recall, however, the caveat expressed above that the increase in capital intensity in housing is assumed to offer no change in the quality of housing services – for example no change in comfort and no change in personal health.

Clearly if comfort levels increase by 1.4%, there is no change in housing productivity as the benefit received by consumers equals the cost. In that case, the energy savings have zero opportunity cost and the private consumption benefit-cost ratio would be about 1.1.[19]

Recall too that the above analysis is concerned with the retrofitting of all dwellings. There are other less extreme scenarios:

- If only new houses are fitted with insulation, the cost per unit is presumably less than for retrofitting. Thus in relations to Runs 1 and 2 aggregate costs decline by more than aggregate energy savings, thus improving the B-C ratio.
- If retrofitting is confined to areas where the absolute energy savings are greatest, aggregate energy savings decline by less than aggregate costs, relative to the results in Runs 1 and 2.

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18 Note that the increase in household energy efficiency means that same amount of utility is being obtained from a lower level of consumption. Therefore when the freed resources are used elsewhere aggregate private utility rises. A forced movement of resources from energy industries to other industries would not deliver this result as the principles of allocative efficiency mean that the loss in utility from less energy consumption would exceed the gain in utility from more consumption of other goods and services.

19 In fact the gain in private consumption from energy savings means that comfort need improve by about 92% of 1.4% in order to exactly offset the higher capital-output ratio in housing.

For example, the coldest 50% of dwellings (by location) are estimated to deliver about 2/3 of the aggregate energy savings from insulation. Again the B-C ratio improves.

Runs 1 and 2 combined also show a net reduction in CO_2 emissions of about 0.6%. The model's underlying projection year is 2016/17, by which time a 0.6% reduction in emissions is expected to correspond to about 250 kt in absolute terms. The net reduction in GDP is about 0.21% or $435m in 2016/2017 (in 2005/06 prices), yielding an implicit price on carbon of about $1700/tonne CO_2. Thus whatever other benefits retrofitting may generate, the efficient reduction of carbon emissions is not one of them.

Run 3: Warmer homes (a speculative scenario?)

Run 3 presents a somewhat speculative scenario which looks at the health benefits of warmer homes.

Howden-Chapman et al (2004) report on a targeted study of the effect of retrofitting insulation in houses which had at least one inhabitant who suffered from some type of respiratory disease. They estimate various health effects of a warmer and drier home by comparing the before and after situation of a target group against that of a control group. While this might suggest a considerable degree of take-back of potential energy savings, the research revealed that most of the health benefits came from the elimination of the effects of very cold and very damp days, rather than from a general increase in ambient temperature.

Health effects were estimated using odds ratios. Odds ratio express the relative likelihood of an event occurring. The odds ratio for days off work is estimated at 1.7. Assuming that utilised sick leave averages five days per year, a 70% difference implies two more working days per person. Because of the bias in the sample we assume only one more day. The average person works say 235 days per year, so one more day is effectively equal to a productivity increase of about 0.4%.

Howden-Chapman et al also estimate an odds ratio of 3.7 for visits to hospital for respiratory conditions. Hospital discharge statistics (for 2002/03) show 424,000 days of hospital care for diseases of the respiratory system. The odds ratio implies a saving of 300,000 days, but again we conservatively assume a lower saving of 100,000 days. Scott et al (2004) estimate a daily cost of $1095 for pneumonia, implying a total saving in public health care costs of $110m. We model this as a reduction in Government Consumption. The model assumes an unchanged fiscal balance between runs, with personal tax rates being the default equilibrating mechanism. Hence lower government consumption permits a reduction in personal income taxes, although other fiscal closure rules are available.

These two innovations – higher labour productivity and lower government consumption – define Run 3. Again this is a stand alone run; it does not include the higher investment in housing, nor the energy savings that such investment generates.

The results show an increase in private consumption of 0.27%, offsetting the negative effect of the reduction in capital productivity in housing (in Run 1). The right hand column of Table 11 shows the result when all three runs are combined. For small changes the model is approximately linear, so the results may be added across runs. This yields a private consumption benefit-cost ratio of 1.1 ([0.27+0.02]/0.26). However, whether in reality the energy savings and the benefits of higher labour productivity may be linearly combined is unclear, as some of the latter may depend on a degree of take-back in the former.

Conclusion

The key inference we draw from the modelling is that if the only benefit from retrofit insulation is a saving in household energy consumption, it is unlikely to deliver a net gain in aggregate economic welfare as measure by private consumption. Net costs are certainly lower if retrofit insulation is more selectively applied, but if it delivers even modest health benefits an overall net positive economic benefit is likely.

Hence the case for Beacon's healthy homes is exactly that – healthy and more comfortable homes, not energy savings or CO_2 reductions (although the combination of Runs 1-3 result delivers both). Whilst not wishing to undervalue the benefit of healthy homes to the inhabitants, most of the economic benefit of healthy homes is captured more widely in the form of less spending on health maintenance and greater worker productivity. Because of this misalignment between private benefit and private costs there is an a priori case for government intervention, though our model is silent on the best form of such intervention.

The implicit assumption in the modelling above is that individuals have either acted voluntarily to retrofit their homes or the government has mandated them to do so. Our model is probably not the best means of assessing the finer points of policy design, but it may be possible to analyse fairly broad options such as the provision of consumer education (home energy/comfort ratings, more information on the link between health and dampness, etc) and straight subsidies for retrofitting.

There may be other benefits that reinforce the above analysis. For example the effect on children – less night coughing and respiratory inflammation, and fewer days absent from school. International literature suggests that an extra year of education (without any extra qualification) raises future earnings by 6-8%,[20] but to interpolate this relationship down to the level of few days is probably not realistic.

Finally casual observation suggests that the demand for healthy homes is income-sensitive. That is, as incomes rise the demand for healthy homes rises more. If true it means that policies that raise real incomes across society could be effective at delivering healthy homes, although probably not as effective as those targeted specifically at this objective.

[20] *Norton et al (2000).*

4.2.1.2 Space heating

Drawing on the analysis in Section 4.1.2, the two cost efficient space heating options; heat pumps and pellet burners, both generate cost savings of about 60% when compared to standard electric heating. Heat pumps deliver this purely by an increase in efficiency, while the pellet burners rely on both gains in efficiency (when displacing open fires for example) and on the use of a lower cost fuel (when displacing electric heaters for example).

For modelling purposes we assume that the least efficient 50% of space heating systems by each main fuel type (coal, gas, wood and electricity) are converted to either heat pumps (Run 5) or pellet burners (Run 7). This is a fairly arbitrary assumption but hopefully allows for households which already have an efficient space heating system being unlikely to change to a heat pump or pellet burner, or if they do, that the wider economic impacts of different efficient space heating systems are an order of magnitude smaller than the effect of shifting from inefficient systems to efficient systems.

This approach is admittedly somewhat different from the retrofit insulation scenario, where the effect of all dwellings having insulation was examined. However, "all insulation is equal" – it is just a timing issue as to when it's installed. Space heating is different. There is little point in looking at all dwellings switching to heat pumps or pellet burners when other cost efficient options exist. That is, it is more than just a timing issue.

Heat pumps are assumed to have an average effective coefficient of performance of 2.5, while pellet burners are assumed to be 85% efficient (TE106, p37)). In contrast, open coal and wood fires have efficiencies of 10-14%. Inefficient gas heating (flued heaters) is about 65% efficient.

Under these assumptions, a heat pump and a pellet burner both save about 48% of home heating energy. Cost savings depend on relative fuel prices.

We model the switch to heat pumps as a reduction in the use of coal, gas and wood, an increase in the use of electricity, and an increase in the end-use efficiency of electricity. Total electricity use for space heating falls as the efficiency effect outweighs the fuel substitution effect.

The same approach is applied to pellet burners, but in this case there is a net increase in the use of wood as the fuel switching effect exceeds the efficiency effect, albeit that what is meant by ‘wood’ changes from ‘firewood’ to pellets. Pellets are purchased from the Wood Processing industry.

With regard to installation costs, we once again treat the presence of a heat pump or a pellet burner as raising the value of investment in housing, on the assumption that they remain in the dwelling if the owners move. Respective costs, including installation are $3000 and $4700. However, these are applied only to the most energy-inefficient 50% of households using each fuel type.

Table 12: Space Heating Scenarios (percentage change on BAU)

	Run 4	Run 5	Run 6	Run 7	
	Heat pump		Pellet burner		Health benefits 50% of Run 3
	Increase in housing capital	Energy Savings	Increase in housing capital	Energy Savings	
	%Δ	%Δ	%Δ	%Δ	%Δ
Private Consumption	-0.11	0.04	-0.19	0.09	0.13
Govt Consumption*	0.00	0.00	0.00	0.00	-0.15
Gross Investment	-0.08	0.01	-0.14	0.04	0.07
Exports	-0.08	0.28	-0.13	0.29	0.14
Imports	-0.05	0.20	-0.09	0.20	0.09
GDP	-0.10	0.05	-0.16	0.09	0.10
Private Cons (B/C)					
heat pump		0.4			1.5
pellet burner				0.5	1.2
CO_2 emissions	-0.05	-1.32	-0.08	-3.08	0.15

* exogenous

In neither scenario does the gain in private consumption from the use of more efficient space heating systems outweigh the loss from having more capital tied up in housing, although there are significant reductions in CO_2 emissions, especially in the pellet burner scenario.

It is also likely that cheaper space heating could lead to some degree of take-back in the form of warmer homes, especially as the energy savings are more than double those obtained from retrofit insulation, although as noted above most of the health benefits seem to be attributable to the eradication of very cold internal temperatures – which is a passive outcome of insulation as opposed to a deliberate outcome from switching on a heater.

The last column in Table 12 shows the macroeconomic effects of assuming that half of the health benefits estimated in Run 3 would be achieved by cheaper space heating. Again in the absence of better information this is an arbitrary assumption, but hopefully captures welfare gains such as health benefits arising from the removal of unflued gas heating. The elimination of very cold and damp days is unlikely to markedly affect energy savings. Adding the health savings to the energy savings produces benefit-cost ratios for private consumption of 1.5 ([0.04+0.13]/0.11) for heat pumps and 1.2 ([0.09+0.13]/0.19) for pellet burners. Thus both space heating options deliver a net beneficial macroeconomic effect.

4.2.1.3 CFL lighting

From Section 4.1, it is estimated that compact fluorescent lighting (CFL) has the potential to reduce the amount of electricity used for residential lighting by about 30%. We simulate this in the model as an increase in appliance efficiency. As a proportion of total household electricity use the effect of the CFL innovation is about 3.7%.

The results are shown in Run 13 in Table 13. As discussed in Section 4.1, the longer life of CFL bulbs means that there is effectively no difference in capital costs relative to incandescent lighting. Hence the private consumption benefit-cost ratio cannot be calculated, but is certainly high. Effectively this means that CFL presents a “free lunch”. There is no significant opportunity cost.[21]

Table 13: Lighting & Hot Water Scenarios (percentage change on BAU)

	Run 13	Run 14	Run 15	Run 16	Run 17
	CFL Lighting	Hot Water Heat Pump		Hot Water Instant Gas	
	Energy savings	Increase in housing capital	Energy savings	Increase in housing capital	Energy savings
	%Δ	%Δ	%Δ	%Δ	%Δ
Private Consumption	0.01	-0.43	0.04	0.00	0.02
Govt Consumption*	0.00	0.00	0.00	0.00	0.00
Gross Investment	0.01	-0.32	0.02	0.00	0.01
Exports	0.02	-0.29	0.09	0.00	0.06
Imports	0.01	-0.19	0.06	0.00	0.04
GDP	0.01	-0.37	0.04	0.00	0.02
Private Cons (B/C)	>10		0.1		5-10
CO_2 emissions	0.23	-0.20	-1.08	0.00	-1.91

[21] ***There may be an issue around disposal of CFL bulbs, but without reliable information we have not been able to investigate this.***

4.2.1.4 Efficient hot water heating

Three options were assessed in Section 4.1 for more efficient water heating; solar water heating, a heat pump system and instant gas heating. Given the operational similarities between solar heating and heat pumps, and the low IRR of the former, we analyse the resource effects of only the heat pump option and the instant gas option. We look at each in isolation as if every residential hot water system might one day be based on either a heat pump or instant gas. This is just for illustrative purposes. At best some mixture of the two will eventuate although there will probably always be other reasonably efficient alternatives such as solar hot water heating and wet-back systems linked to wood burners.

The heat pump option is simulated as an increase in household electricity end use efficiency of 19.7%, which is based on savings of 65.6% in electric hot water heating (Section 4.1) and electric hot water heating constituting about 30% of total household electricity use.

The instant gas option corresponds to a reduction in household electricity use of 30%, but an increase in gas use of 181%. The latter figure is somewhat deceptive as it is calculated on a relatively small base – overall there is still a net reduction in final energy use, and of course a reduction in costs as gas is cheaper than electricity. There may also be an additional reduction in the economy's total energy use through the displacement of relatively thermally inefficient gas-fired electricity generation with the direct use of gas.

This option is simulated partly as fuel substitution (gas displacing electricity) and partly as an increase in end use efficiency, as less gas than electricity (for a hot water storage system) is required to deliver a given amount of hot water at a given temperature. This is because the instant gas system has no standing losses associated with hot water storage.

Runs 15 and 17 in Table 13 show the results. The difference in end use efficiencies between the two options suggests that the gain in private consumption from the heat pump system should be at least four times larger than the gain from the instant gas system, other things equal. However, the measured change is only about double, implying that the upstream increase in efficiency from using gas directly rather than converting it to electricity is quite significant (as reflected of course in the consumer price difference between gas and electricity). Further evidence of this is apparent in the reduction in CO_2 emissions, which is greater in the gas scenario.

Runs 14 and 16 show the opportunity cost of more resources being tied up in household water heating systems. In Run 16, for instant gas systems, the macroeconomic effects are too small for the model to analyse. This is because the cost premium for an instant gas system is low (about $400) relative to a traditional electric cylinder system, and relative to the value of the output produced. Thus from a resource use perspective the case for instant gas systems is very strong. It may well justify government assistance with regard to getting more dwellings connected to the gas reticulation network.

In contrast, heat pump systems at an additional cost of around $3,900 over a standard electric system are an order of magnitude dearer, but produce about the same level of savings to the consumer as an instant gas system. From the perspective of national resource efficiency there is no gain to the replacement of traditional electric systems with heat pump systems. The private consumption benefit-cost ratio is less than unity. This result is not altogether surprising as the

IRR for the heat pump system is only 6.3% (Section 4.1). Note that that same argument applies to solar water heating.

What we have not considered here is the possibility of using a single heat pump for both hot water heating and space heating. The combination of economies of scale in capital costs (if they exist) and the health benefits that probably ensue from a warmer home may be sufficient to raise the private consumption benefit-cost ratio above unity.

4.2.2 Water Saving Innovations

4.2.2.1 Lower water usage

Our first scenario looks at a package of three technical innovations that reduce water use, as discussed in Section 4.2. Combined savings are 64 litres per person per day, representing 27% of consumption. In aggregate, this is about 96 million m^3 per annum. The financial savings from less water use are simulated as a reduction in property rates, given that most households are not explicitly charged for water. We look in Run 11 at the effect of water pricing.

The cost of the three measures is estimated at $228, with $168 for the low flow shower head, an extra $60 for a water efficient (AAA) washing machine and no extra cost for a dual flush cistern. As with the retrofit insulation analysis, we model the cost to consumers as an increase in the capital intensity of housing. Technically this is incorrect for washing machines, as appliances are not part of housing services. However the difference is not significant. As seen in Table 14, Run 8, the costs are too small (being less than 0.005%) to simulate in a general equilibrium model. Hence from a macroeconomic perspective the water savings are virtually costless.

The macroeconomic effect of the three water saving measures, examined in Run 9, is to raise private consumption by about 0.01%. As with most of the energy saving scenarios this is a small gain.

Table 14: Water Saving Scenarios (percentage change on BAU)

	Run 8	**Run 9**	**Run 12**	**Run 10**	**Run 11**
	Water Use Savings			Water Pricing	
	Increase in housing capital	Water savings	Energy savings	Increase in housing capital	Water savings
	%Δ	%Δ	%Δ	%Δ	%Δ
Private Consumption	-0.00	0.01	0.01	-0.02	0.22
Govt Consumption*	0.00	0.00	0.00	0.00	0.00
Gross Investment	-0.00	0.01	0.00	-0.02	0.16
Exports	-0.00	0.02	0.01	-0.01	0.28

Imports	-0.00	0.01	0.01	-0.01	0.19
GDP	-0.00	0.01	0.01	-0.02	0.20
Private Cons (B/C)		5-10	5-10		10.5
CO_2 emissions	-0.00	-0.08	-0.08	-0.01	0.20
Household water use		-26.6*			-6.7

*exogenous

Value-added in the water industry accounts for about 0.2% of GDP, so a saving in household water use of 24% (with water use by households accounting for about 45% of total reticulated supplies) means that about 0.02% of the country's factor inputs can be used elsewhere. The model results show that GDP rises by only about half this amount. This result is partly driven by how the scenario is simulated. Reducing property rates imparts a price bias that makes housing services relatively cheaper than other household goods and services, but housing is one of the most capital intensive of consumer goods and services.

Direct charging for water, whereby consumers would directly observe the value of water saved, would probably lead to a different result.

Because low flow shower heads use less hot water, they also deliver energy savings. From Section 4 these are estimated to reduce household gas consumption by 3.1% and household electricity consumption by 1.2%. In the model these reductions are simulated as increases in the end-use efficiency of water heating, in the sense that less energy is required to produce a given service – a shower. Run 12 in Table 14 shows that the resultant gain in private consumption is worth as much as the gain arising from lower water use. Furthermore, there is no additional capital cost.

Another indirect benefit of lower water consumption is less discharge of waste water, but ignorance of the quantitative impacts in terms of the required capacity of drainage networks and waste treatment plants has prevented us from modelling such a benefit. Less waste flowing into natural water-ways is another possible benefit – refer Table 3.

4.2.2.2 Water tanks

The cost benefit analysis for water tanks in TE106 is provisional. Our interpretation of the calculations is that a 2000 litre water tank would cost $1690 on average, while water savings would amount to 26.5% (of the base amount prior to the above usage savings).

Assuming that the cost of the water tank is again treated as an increase in the capital intensity of the dwelling, we can deduce from the retrofit insulation scenario that the effect on private consumption would be around -0.18%. As the water savings are only a little higher than those obtained from the three usage savings, we may infer that there would be no net gain in private consumption; that is the private consumption benefit-cost ratio would be less than one. Thus from a national perspective a 2000 litre water tank option is not cost effective.

It should be noted, however, that the TE106 analysis is based on water consumption and rainfall data for eight towns in New Zealand.[22] It is possible that for less urbanised regions where reticulated water systems are often uneconomic, a water tank may well be a viable option. In general though the analysis does not support the fitting of water tanks to a large proportion of New Zealand homes – or at least not on economic grounds. Indeed even the TE106 report has low or negative internal rates of return for water tanks.

A scenario where water tanks could produce a net economic benefit is if water reticulation systems are damaged by natural disasters such as earthquakes. The benefits of tank water could be significant, but the national value case would have to be weighted by the probability of a disaster of sufficient magnitude. Examining such a scenario is beyond the scope of this research.

4.2.2.3 Water pricing

As discussed in Section 4.2, direct pricing of household water through metering is thought to lead to significant savings, with the incentive to save water depending on the marginal price faced by the consumer.

At this stage we do not have any estimates of the price elasticity of demand for water, so we assume the default value in the model for housing services of -0.80, although we suspect that a smaller elasticity would be more realistic.

In Run 11 we do not impose any particular price or price structure for water. We only change the way in which household consumption of water is modelled – from an implicit price embedded in property rates or rents, to explicit pricing, presumably via metering. The results show a reduction in household water use of 6.7% and an increase in private consumption of 0.2%, an order of magnitude greater than the gain from the three water saving measures examined in Run 9.

Rightly or wrongly the model projects a real increase in the real price of water over the next decade of about 9.4% – relative to the CPI. The price elasticity of demand would suggest a reduction in residential water use closer to 7.5% than the 6.7% actually recorded, but the elasticity is not constant along the full length of the demand function.

While the average price elasticity of demand for water is probably quite low, at the margin a value of around -0.8 may not be too unrealistic. Given a multi-part water tariff that prices the more essential needs for water at a low price, the model results suggest that consumer welfare would rise if consumers are directly exposed to the price of water. This gain comes about because of present inefficiencies caused by over-investment in reticulated water supplies, itself caused by consumers not facing the true cost of such investment in their decisions about how much water to consume.

From Section 4.2, the cost of water meters is estimated at around $200 including installation. As before, if we treat this cost as an increase in the capital intensity of housing with no off-

22 Auckland, Gisborne, Rotorua, Masterton, Wellington, Christchurch, Dunedin and Invercargill.

setting benefit, the cost in terms of lost private consumption is about 0.02% (Run 10), well below the benefit of more efficient water use. Indeed the private consumption benefit-cost ratio is around 10.5.

Comparing water meters with the package of three water saving measures, the former has a lower IRR (15% compared to 40%), but a much higher economy-wide resource use efficiency effect. These two innovations demonstrate that private and public benefits can diverge quite markedly. Water metering presents the stronger case for government intervention, although the gain to the consumer from the three water saving measures would be clearer – and thus more likely to be pursued – if water use is explicitly priced.

Note that a fall in demand for water of around 7% relative to BAU, over the next decade or so, is likely to delay investment in new supply and reticulation capacity, rather than make existing capacity redundant. There is no assumption that the maintenance costs of existing infrastructure would be lower.

4.2.3 Sensitivity Tests

Any economic model is a simplification of reality. Equations may be mis-specified and parameter values are not measured with certainty, implying that model output may not be as robust as one would like. Sensitivity analysis helps to improve one's level of confidence in the results. There are of course many sensitivity tests that could be undertaken, many more than the scope of this project allows.

We cannot even be certain which parameters and assumptions are the most crucial. In general, however, the macroeconomic resource use effects are driven primarily by the microeconomics of the innovations. In particular, capital and installation costs tend to be important determinants of an innovation's IRR and net economy-wide impact, more so than say small changes in energy prices. In contrast, water prices, which are less commonly observed in the market and consequently have much wider error margins, affect the robustness of the IRR for water meters – as shown in Table 5. Local effects can also be important; for example energy savings from retro-fit insulation in Invercargill versus Whangarei. Finally, we know little about how consumer preferences might develop over the next decade. Might there be an increasing awareness of the health benefits of warmer homes?

At the macroeconomic level, results may hinge on aggregate consumer price and income elasticities of demand. For example to what extent does water consumption respond to price signals? Beyond the household sector, whether the marginal unit of electricity is generated from renewable or thermal sources could be important in determining the national case for more efficient space heating. In this connection we examine a different carbon charge below.

4.2.3.1 Higher carbon price

We begin with the price of carbon. As mentioned earlier, all model runs contain a carbon price of \$25/tonne CO_2. Run 7 (pellet burners) produced the largest reduction in CO_2 emissions of 3.1% and a positive change in private consumption. What happens if the carbon price is doubled to \$50/tonne, which is closer to the current price within the European Emissions Trading Scheme for the Kyoto First Commitment Period. (See www.pointcarbon.com).

The increase in private consumption that occurs in Run 7 relative to BAU is slightly higher, but only in the third decimal place – it is still about 0.09%. That is, as expected a higher price on energy does enhance the gains from an energy saving innovation measure, albeit by only a small amount in this scenario. The IRR for the individual household would rise a little as a change in the carbon price of $25/tonne CO_2 would raise electricity prices by about 1.5c/kWh.[23]

More interesting is the result that under a higher carbon price the cost to private consumption of the installation of pellet burners (materials plus labour) is also slightly higher relative to BAU. Why is this?

A higher carbon price in the BAU scenario discourages households from purchasing carbon intensive goods and services. One of the least carbon intensive goods is housing, so a carbon price favours the consumption of housing. Consequently a greater proportion of the nation's resources are used in housing, as opposed to in activities such as electricity generation.

An increase in housing consumption is manifested as larger houses with more bedrooms and living space. There is no change in the efficiency of resources used in housing, only in the quantity of resources used.

Our modelling assumes that a switch to pellet burners has the same proportionate effect as before. That is, more rooms means more heating. Therefore, the installation of pellet burners also requires a greater absolute outlay than if dwellings are smaller. Hence, a bigger proportionate reduction in total private consumption is required to enable resources to be used in the manufacture (or import) and installation of pellet burners.

There is, however, another scenario. Greater consumption of housing may not entail larger houses. It may instead be manifested in the form of higher quality fittings, a remodelled kitchen and so on. Indeed in a climate of rising real energy prices this may be the more realistic scenario. In that case there would not be a pro-rata rise in heating requirements, and hence the proportionate impact of a pellet burner on the value of housing capital stock would be less than in Run 6.

Overall though, given the small changes involved, we may infer that the national resource use effects of a switch from inefficient space heating to pellet burners are not sensitive to plausible values for a carbon price. Stern (2007), however, suggests a price of US$85/tonne of CO_2 as the approximate social cost of carbon. At that sort of price there may significant behavioural changes which the model does not take into account.

On a peripheral note, under the doubled carbon price, the installation of pellet burners reduces CO_2 emissions by 3.14% compared to 3.08% in Run 7. However, the BAU scenario re-run with a doubled carbon price has 5% lower CO_2 emissions. That is, changing the price of carbon has a measurable effect on emissions, as would the widespread adoption of pellet burners, but the two measures have a negligible joint effect on emissions.

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[23] ***Based on an assumed 600 t CO_2 /GWh for the 'average marginal' increment in supply.***

5 Overall Assessment

In this section we combine the results of various innovations that have been examined with cost-benefit analysis and general equilibrium modelling – which together present the economic case for sustainable housing – with the environmental and social (including private non-economic) benefits generated by the various innovations. Performance against these four criteria determines the national value case, which we split into four categories:

- Strong (those coded blue in Table 3).
- Medium strong (the stronger innovations amongst those coded green in Table 3).
- Medium weak (the weaker innovations amongst those coded green in Table 3).
- Weak (those coded yellow in Table 3).

The reader is referred to the Evaluation Model in the accompanying spreadsheets and the discussion in Section 3.

To reiterate a point made earlier, all of the innovation assessments are based on national averages. There will almost always be innovations that have a weak or marginal national value case, but under particular circumstances – locations or household types, they could deliver strong gains. Equally, innovations that have a strong national benefit case on average, could perform poorly in certain circumstances.

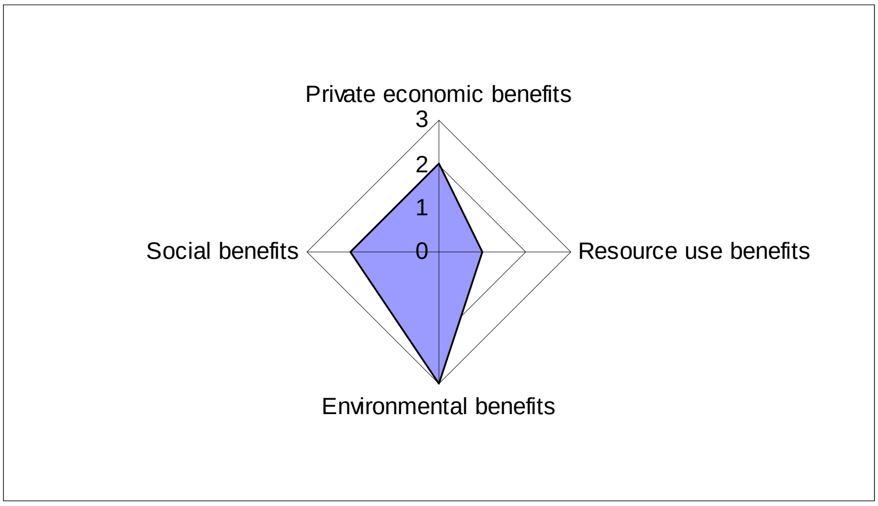
5.1 Benefits

The results for the innovations examined in Sections 4 and 5 are summarised in Table 15.

Retrofit insulation

Retrofit insulation has a reasonable IRR and performs well on environmental grounds by promoting more sustainable consumption and less pollution (such as less air pollution from coal-fired generation) affects health,[24] as well as using recycled materials in the manufacture of some types of insulation. It also scores 2 out of 3 for other benefits by producing better health (net of the economic benefits) and a more comfortable home. Overall though, its national value case ranks only 'medium weak' as its net contribution to resource use efficiency is marginal. This is because of the opportunity cost of the additional capital that is tied up in the housing stock. As seen in Figure 4, this is the axis where the polygon is closest to the origin.

Figure 4: Benefits of Retrofit Insulation



[24] *See for example Fisher et al (2007)*

Table 15: Assessment of Sustainable Housing Innovations National Value Case

	Retrofit Insulation	**Heat Pump**	**Pellet Burner**	**CFL**	**Hot Water Heat Pump**	**Hot Water Gas Instant**	**3 Water Measures**	**Water Metering**	**Total Medium Weak or better**
Private cost	\$2482	\$3000	\$4700	negative	\$3923	\$425	\$228	\$200	
Private benefit	\$253	\$634	\$634	\$66	\$350	\$339	\$91	\$27	
	1267 kWh @ 20c	3172 kWh @ 20c	5287 kWh @ (20c-8c)		1749 kWh @ 20c	2665 kWh @ 20c v 2260 kwh @ 8.6c	70,014 ℓ @ \$1.30/m^3 + 130 kWh ele @ 20c & 29 kWh gas @ 8.6c	8% of 264,000 ℓ @ \$1.263/m^3	
% Δ Private consumption (net)	0.052**	0.045 (mean)		0.01	x	0.02	0.02	0.20	0.35%
% Δ Net CO_2	-0.28**	-2.12 (mean)		0.23	x	-1.91	-0.16	0.19	-4.05%
% Δ Energy	-7.9**	-17.7 (mean)		-2.7	x	-3.0	-1.2	-	-32.5%
% Δ Water							-27.0	-6.7	-33.7%
Benefits									
Private economic	IRR=8.0%	IRR=20.6	IRR=12.1	IRR=∞	IRR=6.3	IRR=79.8	IRR=52.7	IRR=11.9	
National resource efficiency	B/C=1.1	B/C=1.5	B/C=1.2	B/C=10*	B/C=0.1	B/C=10*	B/C=10*	B/C=10.5	
Environmental	3 out of 4	2 out of 4	4 out of 4	3 out of 4	2 out of 4	3 out of 4	2 out of 4	2 out of 4	
Social & private non-economic	2 out of 3	2 out of 3	2 out of 3	1 out of 3	0 out of 3	1 out of 3	0 out of 3	0 out of 3	

Overall National Value Case	Medium weak	Medium strong	Medium strong	Strong	Weak	Strong	Medium strong	Medium strong	
Intervention case (out of 5)^	Eg						Eg		
Inherent									
Demand	2.3						2.4		
Supply	4.1						4.6		
Overall	3.2						3.5		
With intervention									
Demand	3.6						3.9		
Supply	4.2						4.7		
Overall	3.9						4.3		

* This is approximate.
** For new houses assume 50% of capital costs for retrofit, and 25,000 new dwellings per annum.
^ The intervention scores for retrofit insulation and the water efficiency package are only indicative.

Space heating

The two space heating options, heat pumps and pellet burners, have high private rates of return and good social and non-economic benefits. The only significant difference between the two is that pellet burners score higher in terms of environmental benefits. See Figures 5 and 6. As discussed in Section 5.1.1, however, energy savings alone do not deliver national resource use benefits. Including health benefits (50% of those obtained from insulation) enables both space heating options to secure a 'medium strong' rating.

Figure 5: Benefits of Heat Pumps

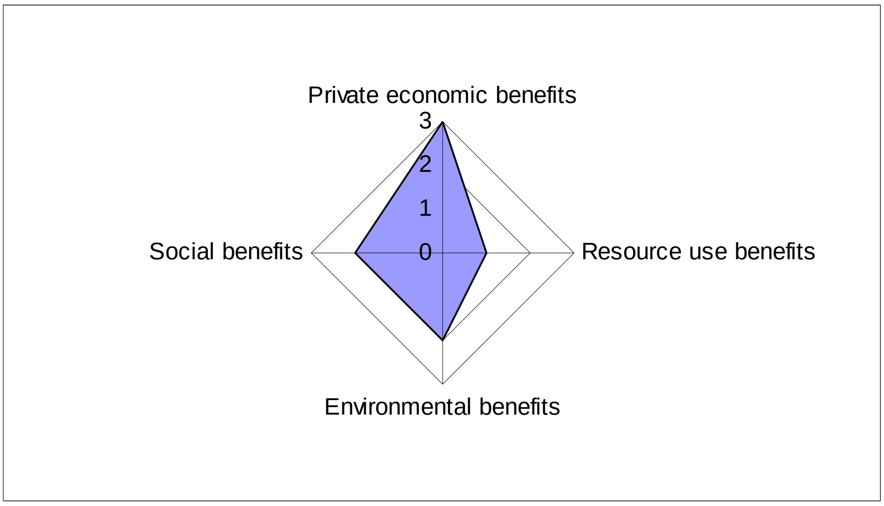
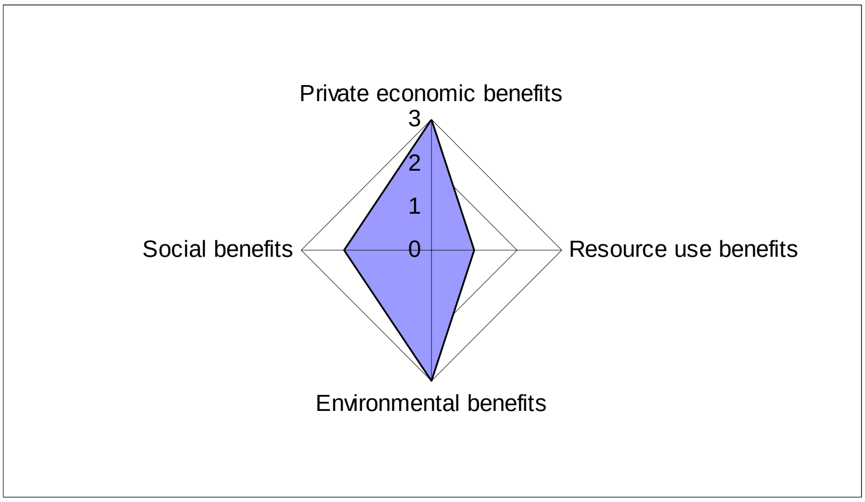


Figure 6: Benefits of Pellet Burners

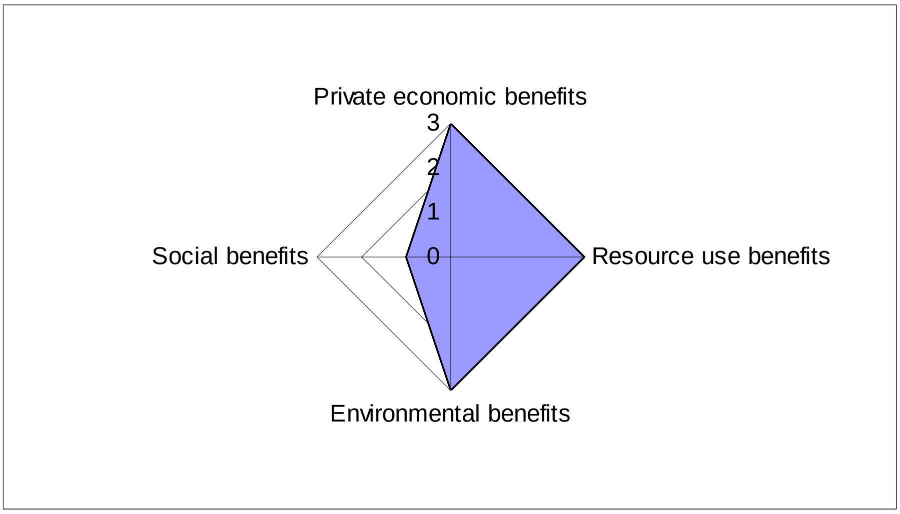


Efficient lighting

Compact fluorescent lighting (CFL) manages a 'strong' rating. As illustrated in Figure 7, it scores a perfect 3 in three of the four benefit domains – resource use efficiency (more efficient light bulb), more sustainable consumption (fewer bulbs required over time), and less waste and pollution (less thermal generation). The only area where CFL performs poorly is with regard to social benefits.

The private consumption benefit-cost ratio (national resource efficiency score) is set at 10 as CFL has essentially zero incremental cost relative to incandescent lighting. For the same reason its IRR is infinite.

Figure 7: Benefits of CFL



Water heating

The two efficient water heating systems have markedly different national value scores, with instant gas having a 'strong' rating, but heat pump systems managing only a 'weak' rating.

Instant gas has a very high IRR and, with incremental costs relative to a standard electric element system being too small to model, the private consumption benefit-cost ratio is at least ten. Environmental benefits are significant with an increase in end-use efficiency, direct use of gas instead of for electricity generation, and less thermal generation. Gas systems also generate a private non-economic benefit in the form of greater flexibility of shower times as the supply of hot water is effectively unlimited (although not its flow rate). This feature perhaps also leads to a higher probability of take-back in the form of longer or more frequent showers. To the consumer this is a benefit, but conceptually we should offset this against the estimated energy savings. The ability of some systems to supply water of different temperature to different locations in the house is another benefit, but we have not counted this as extra cost would also be entailed. The net benefit is unknown.

Heat pump systems score reasonably well on environmental grounds, but their high cost depresses both the IRR and the private consumption benefit-cost ratio.

Figure 8: Benefits of Instant Gas Water Heating

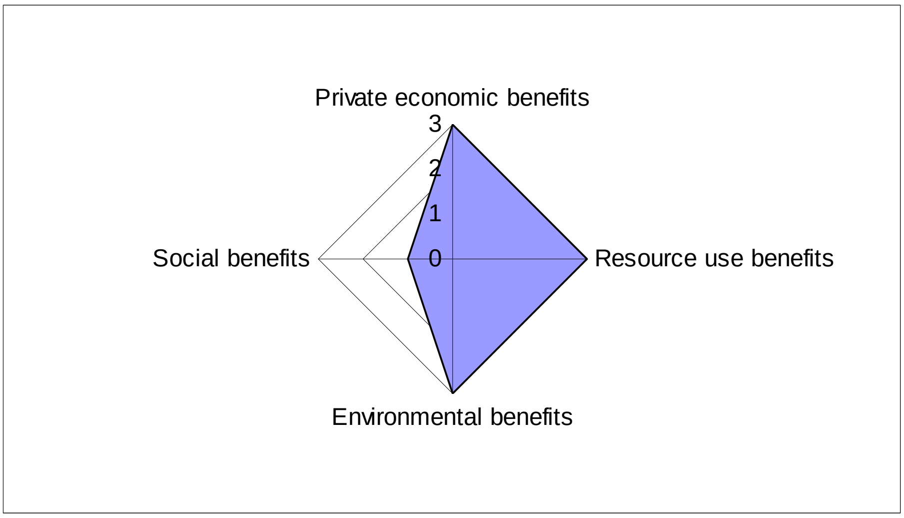
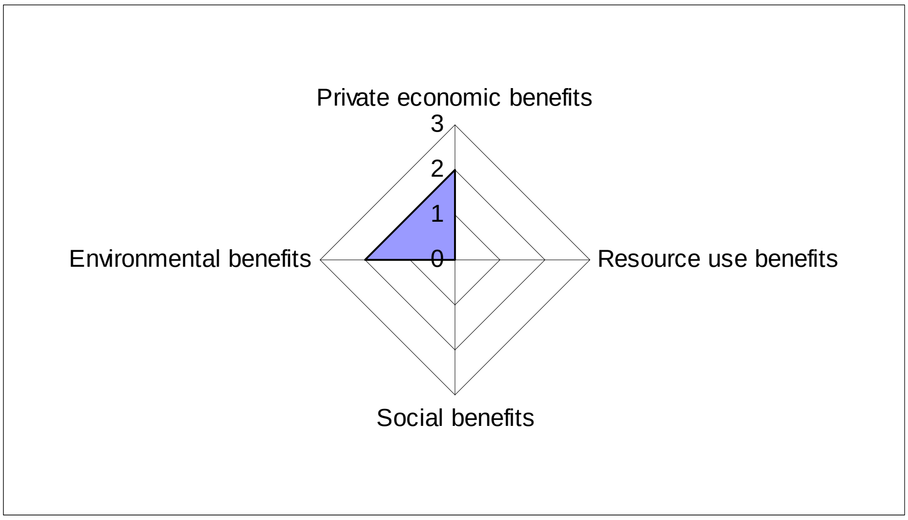


Figure 9: Benefits of Heat Pump Water Heating



*Note re-arrangement of axes

Water efficiency

The three water efficiency measures (low flow shower heads, dual flush toilets and water efficiency washing machines) are illustrated in Figure 10. The package has a very high private IRR as it yields both water savings and energy savings (with regard to low flow shower heads). Being almost costless it produces a private consumption benefit-cost ratio over 10. These attributes are sufficient to rate the package as 'medium strong'. The lack of social benefits prevents a 'strong' rating.

Water pricing (see Figure 11) delivers similar benefits and also secures 'medium strong' rating. This partly hinges on a relatively low cost for water meters which, as the Nelson experience shows, is possible if meters are introduced en masse. Individuals acting alone may face a higher cost.

The take-up rate for both innovations would be increased under government action, especially if directed at the demand side. See Section 6.2.

Figure 10: Benefits of Three Water Saving Innovations

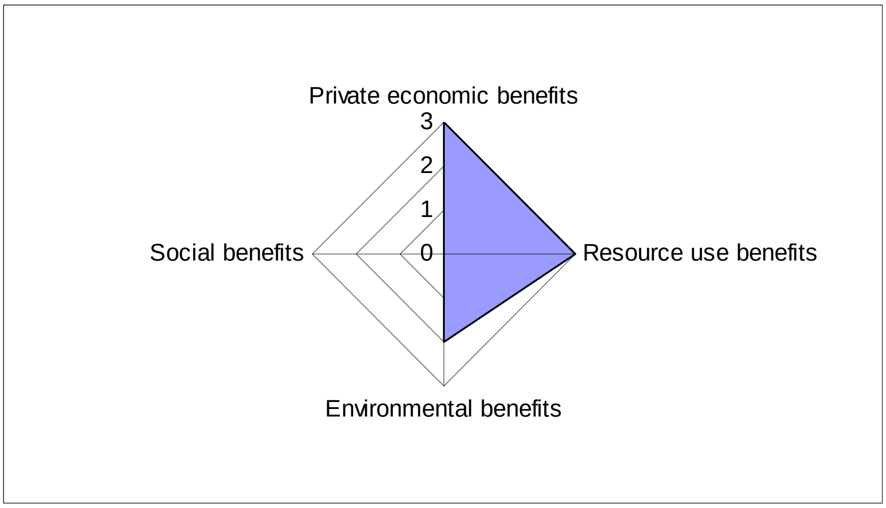
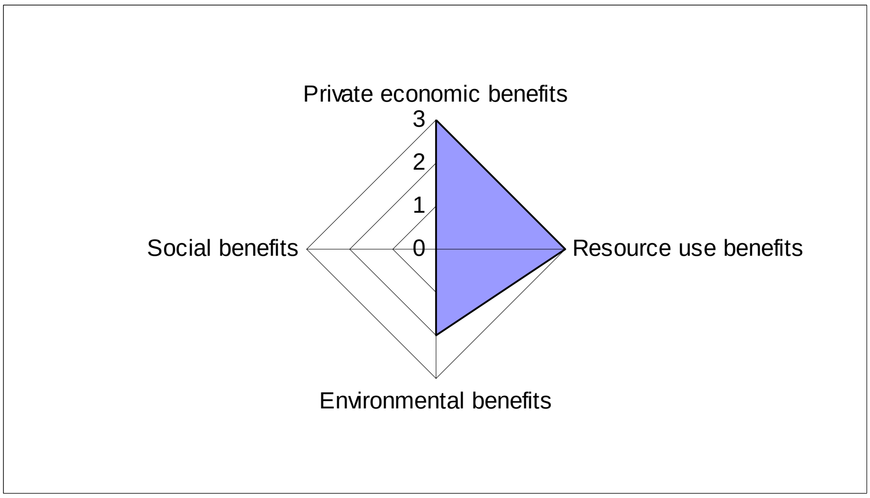


Figure 11: Benefits of Water Pricing



Combining all of the innovations that we rate as Medium Weak or better generates a net gain (after installation costs) in real private consumption of 0.35%. This corresponds to about $106 per person per annum. The non-monetary benefits of healthier and more comfortable homes represent additional gains in consumer utility.

Direct savings in household energy consumption amount to more than 32% or almost 22 PJ per annum. Most of the savings are in electricity use which implies a 9% reduction in total CO_2 emission or about 3600 kt per annum. However, take-back effects in the form of warmer and healthier homes, more spending on travel and so on, reduce the net economy-wide CO_2 savings to approximately 4% or 1600 kt per annum.

Direct water savings amount to 81 litres per person per day, or about 130 million m^3 per annum in aggregate.

5.2 The Case for Intervention

Normally people act in their own best interests. They balance the cost of goods and services against the quality of the service provided by their purchases. Although there may be exceptions to this generality, widespread irrational behaviour is rarely, if ever, observed. The implication is that in most human activities there is not a need for policy intervention in order to improve national wellbeing. The combined evidence of low quality standards in New Zealand's housing stock along with evidence that a higher standard would improve national welfare in many cases implies that there is potentially a role for policy intervention with regards to sustainable housing.

For policy intervention to be successful it is important that one has a clear understanding of the nature of the problem. In this regard it is probably useful to consider direct and indirect impacts separately. Direct impacts occur when people's housing decisions seem to be at odds with their own best interests (e.g. they use expensive and inefficient heating options, do not insulate their houses adequately, etc). Indirect impacts occur when the benefits or costs of the actions of individuals accrue to third parties or to society in general (e.g. the impact of water wastage in the absence of direct water billing, the impact on the environment from housing decisions etc).

When dealing with direct impacts, the key policy question is: what is preventing people from acting in their own best interests? Are there other disincentives or factors obstructing individuals acting in what we think is their own best interests? Alternatively, are we ignoring other factors that might be influencing their decisions? There might be other less tangible factors such as time, convenience, comfort and even image that might offset the adoption of more sustainable housing choices. For example, irrespective of cost, the inconvenience and disruption associated with house alterations will discourage the adoption of beneficial improvements. Likewise there might be some unfavourable side-effects associated with certain products: the noise of certain appliances (e.g. pellet burners), there may be space constraints, and people may value aesthetics ahead of functionality.

Another major issue is the sunk cost of previous decisions and existing structures. Although there might be little difference in the price between more or less efficient appliances, the gains in efficiency are unlikely to be sufficient to encourage the early replacement of existing appliances. The pace of improvements in the quality of the housing stock will be limited by the rate of replacement of existing structures and appliances. It is also more difficult to implement quality improvements in a partial way, and the net benefits can be lower. For example, adding on a room to a house, does not make it any easier to improve the quality of the existing house. The new room might be well insulated, but the benefit of this might be limited by the poor insulation in the rest of the house.

Overall then, there are often logical explanations for what on the surface might appear to be irrational behaviour of individuals: there are hidden costs that limit the speedy adoption of better performing housing capital. This means that forcing people, say via a regulatory approach, to improve the quality of their houses is likely to be an inequitable approach to improving the quality of the housing stock. Many households will, as a result, have lower levels of net welfare.

5.2.1 Information

The one area where there is potential for genuine market failure is with respect to information. People may make sub-optimal decisions due to a lack of awareness of the benefits of sustainable housing options. The critical issue here, from a policy perspective, is what is preventing people accessing the relevant information? One would expect suppliers of genuinely beneficial products to be very willing to advertise the merits of such products. If information is a barrier, it has to be in cases where it is not in the interests of parties to provide full disclosure.

The area where there are incentives for sellers to be less forthcoming about housing quality is when it is the house itself that is being transacted. It is not in the financial interest of sellers or landlords to be forthcoming about shortcomings associated with the house. To some extent the responsibilities of due diligence do lie with purchasers, but information about insulation quality, heating costs, water efficiency etc are not necessarily readily available to purchasers or prospective renters. This is a situation, where some form of information disclosure requirement (e.g. power bills, water usage) would improve purchase and renting decisions and provide house owners with the right incentives to invest adequately in maintaining/improving living conditions.

Even with full information, some people may yet place a lower priority on housing quality than others. This might reflect preferences or income inadequacy. With regard to the latter housing quality is a “normal” good; people will tend to spend more on housing quality as incomes increase. The policy implication here is that measures that improve national wealth will typically, but not always, have positive benefits on housing quality. In one sense this implies that housing quality will generally improve over time as national wealth improves. It also suggests that income support can act as a partial substitute for housing policies. But perhaps most important, is that housing interventions with net national costs will have counter-productive indirect impacts on housing quality. Forcing the nation to over-invest in housing quality will encourage some offsetting behaviour – people will reduce their levels of voluntary investment in housing quality.

5.2.2 Externalities

When individual preferences are at odds with social preferences, policy makers are interested in the externality imposed on society and what might be influencing the sum of individual behaviour to be at odds with social preferences. The analysis of energy saving innovations (presented here in Section 5.1) offers an interesting example of how individual actions can be at odds with national interests. The model analysis indicates that the benefits to individual households, via lower energy costs, are not sufficient to encourage most households to voluntarily undertake insulation retrofits. Yet when the national savings associated from improved health consequences are included, there is a more compelling case for the promotion of retrofitting improved insulation in the existing housing stock. However the benefits of these gains do not necessarily accrue directly to the individual households. Instead the benefits accrue via lower national health costs and higher labour productivity. Individuals benefit from feeling healthier, but the main gains go to the government via lower health costs and to businesses that have lower overheads due to fewer days lost due to sickness. This seems to be a classic case where some policy intervention is warranted.

5.2.3 Type of Intervention

Who should intervene and how? Decisions on who intervenes are usually linked to the nature and level of the externality or spillover involved. In the discussed example, the spillover benefit accrues largely at the national level via a reduction in the national health bill (and potentially also via an increase in the national corporate tax take). This suggests that the intervention should be organised and funded at the national level, although implementation might be more efficient at the local level.

In general most environmental externalities impact at the local level, e.g. within a catchment area, and this is the logical level of intervention for most environmental issues. This is also the logic behind the spread and responsibilities of regional councils in New Zealand. There are a number of areas where a national focus is better suited. For example, climate change is a global phenomenon that requires national direction. Likewise there might be areas where local solutions might be guided by national guidelines or co-ordination. For example, water supply seems to be an issue that squarely lies within the local or regional domain. Yet this need not prevent the national government from providing information and guidance on the merits of different approaches, such as water metering.

The conditions necessary for affecting widespread and meaningful change are that:

- Individuals are exposed to the benefits and costs of their decisions – and face incentives to make desirable changes
- Individuals have the information they need to make appropriate decisions
- There is sufficient supply of desired alternatives at reasonable prices
- Central government through the exercise of its various policy, regulatory and leadership roles can work to create and environment conducive to more environmentally sustainable housing. It can:
- Lead and communicate the case for change

- Develop and implement appropriate policy frameworks and associated regulations ensure that consumers face the full environmental and other costs and benefits of their decisions
- Effect change through its direct ownership of approximately 80,000 household units and related property maintenance and purchase decisions
- Regulate to mandate the installation or use of particular technologies
- Communicate and provide information to inform consumer choices and explain the case for change

In practice, successful policy and its implementation usually requires a mix of the above, rather than reliance on a single intervention. We set out below the options for the main innovations assessed in previous sections.

Retrofit ceiling insulation

Homes built before 1979 do not benefit from the same standards of thermal performance as those built today. This is because the Building Code, a regulation made under the Building Act that specifies the performance standards required of building work including for thermal resistance did not exist prior to 1979 and was recently reviewed and strengthened in 2007. Given that the majority of the nations housing stock were built prior to 2007 and 1979, there are significant potential gains from retrofitting ceiling insulation in older homes.

In understanding the case for public interventions, it is useful to consider why many home owners do not take it upon themselves to retrofit ceiling insulation in older homes, given the amenity and economic advantages of doing so. Each of the following is significant, and a possible reason for further public policy intervention:

- The economic benefits are longer term and are often outweighed by short term imperatives.
- Many home owners may be unaware of the potential benefits and the ease retrofitting ceiling insulation.
- Around 1/3rd of the population live in rented homes, and landlords may not see any economic or amenity benefits to themselves in retrofitting ceiling insulation.

Introduction of a carbon charge or tax, to cover one of the environmental costs of energy production, would increase the price of energy from non renewable sources and by so doing create a stronger economic incentive for homeowners and occupiers to retrofit ceiling insulation in existing homes.

In doing so, there would also be an important role for government to communicate the necessity and rationale for the change, and the actions and choices available to home owners (including the retrofitting of ceiling insulation) that they can make to offset the increased costs of energy.

Government could also consider introducing star rating schemes to convey the efficiency of homes so as to build awareness about the benefits of ceiling insulation. The provision of such information might create additional demand for insulated homes, and result in the value of insulation being factored into house prices and rents.

There are also more targeted interventions that government can consider to reinforce the necessity for change. If we were to segment the target population into two groups – owner occupiers and landlords, then the following mix of interventions are worth considering:

Owner occupiers – suspensory loans or subsidies to create a sharper and short term incentive for home owners to retrofit ceiling insulation – and to enable low and medium income earners to adjust to increased energy costs; amend Section 112 of the Building Act to require retrofitting of ceiling insulation at the time renovations are carried out existing buildings to the performance standard of the current Building Code. This is a practical means of requiring the retrofitting of existing homes at a time when the costs of doing so are likely to be lowest. A similar approach is taken to the installation of disabled access and fire safety features in commercial buildings.

Landlords – government owns significant housing stock and so can undertake to retrofit ceiling insulation in all of the homes that it owns. In doing so, there are a number of benefits for government – investment value as it raises the value of its housing stock; reduces costs of living for low income people and this takes pressure off welfare as well as health.

For non government landlords, tax benefits are already present. Another option that could be considered is through introduction of minimum baseline standards through amendments to the Residential Tenancies Act 1986 (RTA).

Water metering

Because the infrastructure costs of water supply are mainly met by local and regional government, charges for water supply are predominantly also the concern of local and regional government.

While most local authorities include the costs of water supply as a component of rates, only some require or offer the option of water metering whereby homeowners pay for their water in proportion to the volume of water that they consume thereby creating an economic incentive for them to minimise their consumption.

From a national perspective, there is a case for central government intervention if:

- the broader environmental or economic costs of water consumption are not being factored into the fees charged by local authorities; or
- if there is the potential for scarcity of supply and the way that local authorities currently charge for the resource does not result in efficient allocation; or
- if the ways that local authorities currently charge for water does not result in adequate incentives for homeowners to appropriately manage their consumption of water.

If central government intervention were warranted, the most effective means of intervening are either:

- Under the Resource Management Act – by issuing a National Policy Statements under Section 45 of the RMA to state the objectives and policies to guide local authorities in the provision of water to home owners; or
- Under the Local Government Rating Act – by Amending Section 19 of the Local Government Rating Act to require local authorities to directly recover the variable costs of water supply directly from homeowners.

Alternatively, government could seek to facilitate a comprehensive approach across all local authorities to water charging. Through its leadership role, government could encourage adoption of more efficient approach to water charging in support of central and regional environmental objectives.

Space Heating

Although heat pumps and pellet burners offer economic benefits to home owners over the long term when compared to alternative means of space heating, the up front costs of conversion may outweigh the longer term benefits. It is also possible that some home owners are not aware of the benefits of converting to these more efficient forms of space heating.

Exposing energy companies (and their customers) to the full environmental costs of their energy production and consumption, through implementation of carbon charges or similar market pricing mechanisms would result in increased costs of energy that would provide added incentive for home owners to switch to more efficient means of space heating.

In doing so, central government would need to communicate the case for change and provide information to homeowners on actions they can take to offset the impacts of change (such as installation of more efficient mean of heating). There would also potentially be a role for central government tin providing financial or other assistance for home owners, especially low to medium income earners to adjust to more efficient means of heating that might involve additional short term costs.

At more specific levels, central government could:

- Provide suspensory loans or subsidies (possibly on an income targeted basis) specifically for the purposes of helping meet or mange some of the short term costs of switching to more efficient forms of space heating;
- Install heat pumps and pellet burners in Housing New Zealand Corporation managed residential properties;
- Regulate minimum efficiency levels for space heaters.

Water Efficiency Measures

The three water efficiency measures (low flow shower heads, dual flush toilets and water efficiency washing machines) have very high benefits in that they yield both water savings and energy savings.

While the financial costs to home owners of implementing the initiatives are very low, it is likely that a number of other factors including amenity concerns, finding the time to make or arrange for the switch and incomplete information on choices and the potential benefits of installing these features in new and existing homes are all barriers to their wised spread take up.

Central government could intervene in a number of ways to encourage and provide incentives for homeowners to switch to these more efficient means of water heating:

Exposing homeowners to the full environmental costs of their water consumption through better pricing and the introduction of carbon charges and similar market mechanisms would also result in improved incentives for homeowners to switch to such measures.

As with ceiling insulation and space heating there is a role for government in disseminating information to all citizens highlighting the value, relevance and gains that can be made from converting to more efficient methods of water dispersion. The provision of specific product information can help in this as might more general information and education campaigns, possibly in collaboration with professional bodies, retailers, architects and building associations.

At more specific levels, each of the following would potential complement improved price signals through mechanisms such as water metering or carbon charges:

- Install water efficient measures in Housing New Zealand Corporation managed residential properties;
- Regulate for their use in all new houses through amendments to the performance measures in the Building Code and the compliance documents that underpin them;
- Regulate for them to be installed in existing homes at the time alterations are made by amending Section 112 of the Building Act to require retrofitting of shower heads and toilets.

Water Heating

Both instant gas water heating and heat pump systems are more efficient than alternative means of water heating.

While the financial costs to home owners of implementing these systems are lowest for new home owners, the relative upfront costs of investing these more expensive systems for relatively small long term gains may continue to be a deterrent to their wider uptake. The incentives are relatively weak for existing home owners to convert, unless their current means of water heating requires replacement.

Central government could intervene in a number of ways to encourage and provide incentives for homeowners to switch to these more efficient means of space heating.

As with other proposals exposing homeowners to the full environmental costs of their energy consumption through better pricing and the introduction of carbon charges and similar market mechanisms would also result in improved incentives for homeowners to switch to these more efficient forms of water heating.

Associated with this is the need for government to inform citizens of the reasons for change and to either directly or indirectly through partnerships with industry associations educate citizens on their options and benefits that can be made from converting to more efficient methods of water heating. This would build on the current provision of product specific energy rating information and would ideally involve government partnering with professional bodies, retailers, architects, builders and plumbers to provide this information to homeowners.

At more specific levels, central government should consider:

- Providing suspensory loans or subsidies (possibly on an income targeted basis) specifically for the purposes of helping meet or mange some of the short term costs of switching to more efficient forms of space heating;
- Installing energy efficient means of water heating in Housing New Zealand Corporation managed residential properties;
- Regulating for their use in all new houses through amendments to the performance measures in the Building Code and the compliance documents that underpin them;
- Regulating for them to be installed in existing homes at the time alterations are made by amending Section 112 of the Building Act.

Compact Fluorescent Lighting

Replacement of incandescent bulbs with Compact fluorescent lighting (CFL) results in large benefits for home owners and the nation in terms of resource use efficiency (more efficient light bulb), more sustainable consumption (fewer bulbs required over time), and less waste and pollution (less thermal generation). Further, the costs of changing are very low, if incandescent bulbs are replaced with CFL when they expire.

These bulbs are widely available and the benefits of switching to them are currently promoted to consumers by government and industry.

Exposing homeowners to the full environmental costs of their energy consumption through better pricing and the introduction of carbon charges and similar market mechanisms would result in additional incentives for homeowners to switch to this more efficient form of lighting.

Government could also:

- Install energy efficient lighting in Housing New Zealand Corporation managed residential properties.

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7 Appendix A: ESSAM General Equilibrium Model

The ESSAM (Energy Substitution, Social Accounting Matrix) model is a general equilibrium model of the New Zealand economy. It takes into account the main the inter-dependencies in the economy, such as flows of goods from one industry to another and the passing on of changes in costs in one industry into prices and thence the costs of other industries.

The ESSAM model has previously been used to analyse the economy-wide and industry specific effects of a wide range of issues. For example:

- Investment in energy generation and energy pricing (for a major power company).
- Investment in roading and funding regimes for roading (for a consortium of road users).
- Policies to reduce carbon dioxide emissions (for government departments and a private energy company).
- Release of genetically modified organisms (for a consortium of government departments and an industry group representing life science research).
- Changes in import tariffs (for a government department).
- Impacts of climate change (for a government department and a crown research institute).

Some of the model's features are:

- 49 industry groups (currently), as detailed in the table below.
- Substitution between inputs into production - labour, capital, materials, energy.
- 4 energy types: coal, oil, gas and electricity, between which substitution is also allowed.
- Substitution between goods and services used by households.
- Social accounting matrix (SAM) for complete tracking of financial flows between households, government, business and the rest of the world.

The model's output is extremely comprehensive, covering the standard collection of macroeconomic and industry variables:

- GDP, private consumption, exports and imports, employment, etc.
- Demand for goods and services by industry, government, households and the rest of the world.
- Industry data on output, employment, exports etc.
- Import-domestic shares.
- Fiscal effects.

Production Functions

These equations determine how much output can be produced with given amounts inputs. A two-level standard translog specification is used which distinguishes four factors of production – capital, labour, and materials and energy, with energy split into coal, oil, natural gas and electricity.

Intermediate Demand

A composite commodity is defined which is made up of imperfectly substitutable domestic and imported components - where relevant. The share of each of these components is determined by the elasticity of substitution between them and by relative prices.

Price Determination
The price of industry output is determined by the cost of factor inputs (labour and capital), domestic and imported intermediate inputs, and tax payments (including tariffs). World prices are not affected by New Zealand purchases or sales abroad.

Consumption Expenditure
This is divided into Government Consumption and Private Consumption. For the latter eight household commodity categories are identified, and spending on these is modelled using price and income elasticities in an AIDS framework. An industry by commodity conversion matrix translates the demand for commodities into industry output requirements and also allows import-domestic substitution.

Government Consumption is usually either a fixed proportion of GDP or is set exogenously. Where the budget balance is exogenous, either tax rates or transfer payments are assumed to be endogenous.

Stocks
Owing to a lack of information on stock change, this is exogenously set as a proportion of GDP, domestic absorption or some similar macroeconomic aggregate. The industry composition of stock change is set at the base year mix, although variation is permitted in the import-domestic composition.

Investment
Industry investment is related to the rate of capital accumulation over the model's projection period as revealed by demand for capital in the horizon year. Allowance is made for depreciation. Rental rates or the service price of capital (analogous to wage rates for labour) also affect capital formation. Investment by industry of demand is converted into investment by industry of supply using a capital input-output table. Again, import-domestic substitution is possible between sources of supply.

Exports
These are determined from overseas export demand functions in relation to world prices and domestic prices inclusive of possible export subsidies, adjusted by the exchange rate. It is also possible to set export quantities exogenously.

Supply-Demand Identities
Supply-demand balances are required to clear all product markets. Domestic output must equate to the demand stemming from consumption, investment, stocks, exports and intermediate requirements.

Balance of Payments
Receipts from exports plus net capital inflows (or borrowing) must be equal to payments for imports; each item being measured in domestic currency net of subsidies or tariffs.

Factor Market Balance
In cases where total employment of a factor is exogenous, factor price relativities (for wages and rental rates) are usually fixed so that all factor prices adjust equiproportionally to achieve the set target.

Income-Expenditure Identity
Total expenditure on domestically consumed final demand must be equal to the income generated by labour, capital, taxation, tariffs, and net capital inflows. Similarly, income and expenditure flows must balance between the five sectors identified in the model – business, household, government, foreign and capital.

Industry Classification
The 49 industries identified in the ESSAM model are defined below. Industries definitions are according to Australian and New Zealand Standard Industrial Classification (ANZSIC).

		Industry
1	HFRG	Horticulture and fruit growing
2	MLVC	Mixed livestock and cropping
3	SHBF	Sheep and beef cattle farming
4	DAIF	Dairy cattle farming
5	OAGR	Other farming and services to agr, hunting & trapping
6	LOGG	Forestry & logging
7	FISH	Commercial fishing
8	COAL	Coal mining
9	OILG	Oil & gas extraction and exploration
10	OMIN	Other mining & quarrying and services to mining
11	MEAT	Meat processing
12	DAIR	Dairy product manufacturing
13	OFOD	Other food processing & mfg
14	TCFL	Textiles, clothing, footwear & leather mfg
15	WOOD	Log sawmilling, timber dressing & oth wood product mfg
16	PAPR	Paper and paper product mfg
17	PPRM	Printing, publishing & recorded media
18	PETR	Petroleum
19	CHEM	Chemical and chemical product mfg

20	RBPL	Rubber and plastic product mfg
21	NMMP	Non-metallic mineral product mfg
22	BASM	Basic metal manufacturing
23	FABM	Structural, sheet and fab metal prod mfg
24	MACH	Machinery and equipment mfg
25	OMFG	Other manufacturing
26	EGEN	Electricity generation
27	EDIS	Electricity transmission & supply
28	GASS	Gas supply
29	WATS	Water supply
30	BLDG	Construction
31	TRDE	Wholesale & retail trade
32	ACCR	Accommodation, cafes & restaurants
33	ROAD	Road transport
34	WRAI	Water and rail transport
35	AIRS	Air transport, services to transport, storage
36	COMM	Communication services
37	FIIN	Finance and Insurance
38	OWND	Ownership of owner-occupied dwellings
39	OPRS	Other property services
40	SCIT	Scientific research & technical services
41	COMP	Computer services
42	LAOB	Legal, accounting & other business services
43	GOVD	Govt administration & defence
44	SCHL	Pre-school, primary, secondary & other education
45	OEDU	Post-school education
46	HOSP	Hospitals, nursing homes, aged accom & other comm care
47	OHLT	Medical, dental and other health services
48	MPRT	Cultural and recreational services
49	PERS	Personal and other services, waste disposal & sewerage svs

8 Appendix B: Low Flow Shower Heads

The following table shows the calculation of expected water savings from low flow shower heads. Total national estimated savings are 8.4%. The TE106 report estimates 37.5% per dwelling, but it is not clear how, or even if this should be adjusted for dwellings that already have low flow rates in order to derive national savings. Nor is there any allowance for take-back in the form of longer showers to compensate for less pressure,[25] nor is it clear whether the ‘typical’ shower (of 6 minutes) has been adjusted for frequency to yield an average shower time – and hence water use – per annum.

Instead of the assumptions of 10 l/min and 12 l/min in line 4, we have looked at the effect of assuming that shower flow rates are Normally distributed. This raises the estimated savings to 10-11%, but the figure is sensitive to assumptions about where the tails of the distributions should be truncated. In any case the effect of this on total water savings under the package of three measures (low flow shower heads, dual flush cisterns and water efficient AAA washing machines) is not significant.

	Low Pressure	High Pressure	Total	Comment
% households	72%	28%	100%	Source: Ecosense
% with flow >9 l/min	25%	60%		Source: Ecosense
% hh to use low flow shower head	18.0%	16.8%	34.8%	
Mean flow for those >9 l/min	10	12		Working assumptions
Assume reduction to (l/min)	9	9	.	Higher than TE106 to allow for take-back via longer showers
Implied flow reduction %	10.0%	25.0%		
Weighted reduction	1.8%	4.2%	**6.0%**	
Mean flow (l/min)	7.2	10.6	8.2	l/min
Mean flow for <9	6.3	8.5		l/min
New mean flows	7.0	8.8	7.5	l/min
Mean saving			**8.4%**	

[25] ***Even systems that give the impression of high pressure are subject to a take-back effect, as anyone with teenage daughters will be aware that a certain volume of water is required for hair washing!***

9 Appendix C: Water Heating

	Heat pump compared to standard electrical						
			0.2	**BAU**	**Heat pump**	**Diff**	**% diff**
	Material	**Labour**	**Operating**	**kWh**	**kWh**	**kWh**	
Auckland	$3,562	$350	$174	2665	871	1794	0.673
Wellington	$3,562	$392	$189	2665	943	1722	0.646
Christchurch	$3,562	$365	$196	2665	980	1685	0.632
Dunedin	$3,562	$392	$206	2665	1031	1634	0.613
Rotorua	$3,562	$335	$185	2665	925	1740	0.653
Gisborne	$3,562	$350	$176	2665	881	1784	0.669
Masterton	$3,562	$365	$186	2665	931	1734	0.651
Invercargill	$3,562	$332	$207	2665	1035	1630	0.612
Weighted mean	$3,562	$361	$183	2665	916	1749	0.656
							0.656
$ saving per hh						$350	
	Gas Instant compared to standard electrical						
			0.086	**BAU**	**Gas**	**Diff**	**% diff**
	Material	**Labour**	**Operating**	**kWh**	**kWh**	**kWh**	
Auckland	$237	$170	$194	2665	2261	404	0.152
Wellington	$237	$180	$194	2665	2261	404	0.152
Christchurch	$237	$225	$194	2665	2261	404	0.152
Dunedin	$237	$180	$194	2665	2261	404	0.152
Rotorua	$237	$275	$194	2665	2261	404	0.152
Gisborne	$237	$250	$192	2665	2228	437	0.164
Masterton	$237	$225	$194	2665	2261	404	0.152
Invercargill	$237	$280	$194	2665	2261	404	0.152
Weighted mean	$237	$188	$194	2665	2260	405	0.152
							0.152
$ saving per hh				$533	$194	$339	
	Solar compared to standard electrical						
			0.2	**BAU**	**Solar**	**Diff**	**% diff**
	Material	**Labour**	**Operating**	**kWh**	**kWh**	**kWh**	
Auckland	$3,625	$1,500	$62	2665	311	2354	0.883
Wellington	$3,625	$1,500	$109	2665	543	2122	0.796
Christchurch	$3,625	$1,500	$119	2665	595	2070	0.777

Dunedin	$3,625	$1,500	$160	2665	798	1867	0.701
Rotorua	$3,625	$1,500	$86	2665	432	2233	0.838
Gisborne	$3,625	$1,500	$70	2665	349	2316	0.869
Masterton	$3,625	$1,500	$99	2665	493	2172	0.815
Invercargill	$3,625	$1,500	$160	2665	798	1867	0.701
Weighted mean	$3,625	$1,500	$88	2665	440	2225	0.835
							0.835
$ saving per hh						$445	

10 Appendix D: High Standards of Sustainability

Energy

Ref PR109		Zone 1	Zone 2	Zone 3	Weighted mean	Scale to TE106
No. dwellings		462,636	527,739	377,535	1,367,910	
Base energy	*kWh/hh/yr*	11,800	13,000	13,800	12,815	13,524
	kWh/p/yr	4,370	4,815	5,111		
HSS energy	*kWh/hh/yr*	9,050	11,000	12,000	10,616	11,204
	kWh/p/yr	3,352	4,074	4,444		
	% reduction	23.3%	15.4%	13.0%		
HSS % reduction target		*23.0%*	*15.0%*	*13.0%*	**17.2%**	
Base case demand TE106						
Space heating						4,934
DHW[1]						3,716
Cooking						954
Lighting						1,198
Appliances						2,721
of which Fridge						*1,281*
Total						13,523

Innovations:

1a Space heating - heat pump

	% reduction	Base load savings, kWh	Insulation savings as % of total	Heat pump (COP 2.5), kWh	Heat pump savings as % of total	Combined savings as % of total
Ceiling insulation	12.70%	627	4.6%	1,723	21.9%	26.5%
Underfloor	10.20%	503	3.7%	1,772	21.9%	25.6%
Wall	9.90%	488	3.6%	1,778	21.9%	25.5%
Ceiling/Floor	21.60%	1066	7.9%	1,547	21.9%	29.8%
Ceiling/floor/wall	29.30%	1446	10.7%	1,395	21.9%	32.6%

1b Space heating - pellet burner

	% reduction	Base load savings, kWh	Insulation savings as % of total	Pellet fire (eff. 85%), kWh	Pellet fire savings as % of total[1]	Combined savings as % of total
Ceiling insulation	12.70%	627	4.6%	5,068	-6.4%	-1.8%
Underfloor	10.20%	503	3.7%	5,213	-6.4%	-2.7%
Wall	9.90%	488	3.6%	5,230	-6.4%	-2.8%
Ceiling/Floor	21.60%	1066	7.9%	4,551	-6.4%	1.4%
Ceiling/floor/wall	29.30%	1446	10.7%	4,104	-6.4%	4.3%

Note 1: Pellet fire displaces electricty but uses more end-use energy.

2a Hot water heating - cylinder wrap

	HEEP 9 p114	135 l	180 l
Cylinder wrap savings, B&C	kWh/day	1	0.6
Cylinder wrap savings, A&B	kWh/day	0.3	0.3

	National number	Base load saving kWh per hh	Wrap savings as % of total
135 l (C & D)	240,000	365	2.7%
180 l (C & D)	160,000	219	1.6%
A & B	600,000	110	0.8%
Weighted savings		188	*1.4%*
Adjust for 72% on electricity			*1.0%*

2b Hot water heating - heat pump, solar & instant gas

	% reduction	Base load savings, kWh/hh	Savings as % of total	Combined savings as % of total[2]
Heat pump	65.6%	2439	18.0%	19.4%
Solar	83.5%	3102	22.9%	24.3%
Instant gas	15.2%	564	4.2%	4.2%

Note 2: Assumes new cylinder has high quality insulation which increases saving.

3 Lighting

Incandescent bulbs still in use	30,006,000 (about 6M changed already)
Suitable for CFL	25% (EC have assumed 25% suitable for replacement with CFLs)
Mean incandescent W	100

	National total	Base load saving per hh	CFL savings as % of total
100 W	7,501,500	240	1.8%

4 Appliances

Energy efficient fridge/freezer	500	kWh/yr	
Sales weighted energy use	2000	640	EECA appliance stats
	2006	480	25%

National total	Base load saving per hh	Fridge savings as % of total
	320	2.4%

Water

				Revised BAU	
Ref TE109	l/hh/d	l/p/d	l/hh/yr		l/p/d
Base total water consumption	900	300	328,500	Laundry	50
Reworked base line	723	241	263,895	Kitchen	15
				Toilet	55
HSS total water consumption	540	180	**197,100**	Bath	12
HSS % reduction target			40.0%	Shower	49
				Outdoor	60
Number of dwellings	1,367,910				**241**
				Total/hh/yr	263,895.00

Innovations:

1 Water saving devices

	% reduction	Base load savings (per annum)	Savings as % of total
Washing machine	60%	32,850	12.4%
Toilet	54.5%	32,847	12.4%
Shower head	8.4%	4,507	1.7%
		70,204	**26.6%**

Eff. water use	193,691	l/hh/yr	Meets HSS target
or	177	l/pp/d	

2 Rain water substitution plus water efficiency measures

Eff. Shower, toilet, laundry	109,500	(TE106)	i.e. after efficiency measures installed
	98,426	using modified BAU shower consumption of 49 l/pp/day	

	% reduction	Base load savings (per annum)	Savings as % of total	
2000 l tank	85.0%	153866	58.3%	Meets HSS target
7500 l tank	96.5%	165185	62.6%	Meets HSS target