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Overseas programmes for improving the operational carbon emissions from existing residential buildings – lessons for Aotearoa New Zealand

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Overseas programmes for improving the operational carbon emissions from existing residential buildings – lessons for Aotearoa New Zealand

Building Research Association of New Zealand (BRANZ)

Making sense of the numbers

Poutū-te-rangi 2023

Authors: Hugh Parsons, Nick Robertson, and Konrad Hurren

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Executive summary

There is growing pressure on governments around the world to improve the energy efficiency of people's homes, and Aotearoa New Zealand is no exception. The purpose of this report is to gather the evidence of what programmes are being tried internationally to retrofit homes. Taking the investigation further, this report also forecasts how the economy might react if a large retrofit programme were to be implemented in Aotearoa New Zealand. The key things to know from this report are:

Many homes in Aotearoa New Zealand require retrofitting

There is staggering evidence that many homes in Aotearoa New Zealand are not meeting the heating and energy needs of their occupants. Data from the 2018 Census showed that this number could be upwards of 460,000 homes. This negatively impacts the incomes, health, and mental wellbeing of occupants. Data from the 2021 General Social Survey showed that just under half of all respondents felt that their house was too cold all or some of the time. This number was broken down further:

- People renting were more likely to be living in homes that were too cold most of the time, and people living in crowded homes were even more likely to be living in cold homes.
- One parent with children households were more likely than other family types to be living in homes that were too cold most of the time.
- People who identified as Pacific people were the most likely to be living in homes that were too cold most of the time, followed by Māori and Asian households.
- People who identified as disabled were much more likely to be living in homes that were too cold most of the time.

Evidence from Aotearoa New Zealand shows that transitioning from a cold home to a warm home prevents hospitalisations, and results in children spending more days in school. While an energy efficient home has the economic benefit of reducing the cost of heating, the impacts on health and mental wellbeing should not be understated.

Ambitious retrofit programmes are underway overseas

Solving the issue of cold homes is not impossible. Large and ambitious programmes, which aim to deep retrofit underperforming homes, have been implemented across Europe and North America. This report examines the retrofit policies instigated by the European Union, and programmes in:

- Ireland
- The United Kingdom
- France
- The Netherlands
- Canada
- The United States of America.

The lessons from these programmes can be applied here

Analysing these international examples provides inspiration for what could be achieved in Aotearoa New Zealand. The 10 key lessons are:

1) **Retrofits must be affordable and low risk for households, homeowners, and organisations**

People will not sign on to what they cannot afford. The first step is ensuring that the retrofit is affordable and low risk. This can be achieved through grants, loans, and project management assistance options.

2) **Retrofit programmes must involve a simple process for participants**

Complexity discourages people. Having a single point of contact, with clear expectations, will help attract participants and ensure retrofit project expectations are managed.

3) **A new heater is not enough**

To be worth it, a retrofit must meaningfully improve the condition of the home. For all measures to be effective they must work together which means improving the walls, windows, roof, and floor together. Heat pumps provided by Warmer Kiwi Homes have helped households, but a significant amount of heat is lost through gaps in the homes, limiting the benefits which the pumps provide.

4) **Homeowners have different financing needs**

Not every homeowner is able to take on more debt, even at low interest. In such cases, there should be an option where the government can provide additional financial assistance. There should also be an avenue for Māori providers to offer retrofit assistance for Māori homeowners.

5) **Energy savings are only a fraction of the total benefit**

The benefits of improved health and productivity from living in a comfortable and warm home outweigh any increase in energy use from improved heating systems. Therefore, a retrofit programme should not put too much weight on energy use reduction as a key success factor.

6) **Project management influences cost and uptake**

Retrofitting is not always a straightforward process, and complexity varies across homes. Including project managers as part of the retrofit programme reduces complexity.

7) **Behavioural mechanisms, such as Energy Performance Certificates, could be explored**

There needs to be clearer data on how many houses need retrofitting. In a similar fashion, there also needs to be an indicator for how many retrofits are completed and how effective they are. Energy Performance Certificates are a key metric used throughout Europe that could be used in Aotearoa New Zealand.

8) **Trust is key**

For people to get on board with a retrofit programme, they must trust that it will deliver. It must be clear who the approved contractors are, and retrofits must be delivered to a guaranteed standard.

9) **Programmes must be robust to changes in government and government policy**

Boom and bust cycles have defined the Aotearoa New Zealand building sector over the last few decades. If a programme is to be established, it must signal that it is here to stay so that homeowners, contractors, and investors commit to delivering retrofits long term. There should not be speculation that the programme could be easily rolled back through successive governments.

10) A pilot deep retrofit programme will add value

The best data comes from action. While forecasts and cost-benefit analyses are useful tools to estimate costs, the most valuable insight will be understanding what challenges, unique to Aotearoa New Zealand, may occur during a large retrofit programme. A pilot programme will test the waters and provide direction for a larger scale programme.

The numbers indicate that households' income, health, and wellbeing will be better off if a large scale retrofit programme is implemented in Aotearoa New Zealand

A large scale retrofit programme will shock the national economy, as it will inject billions of dollars into the residential construction industry. Evidence from overseas, and within Aotearoa New Zealand, is clear that a concentrated effort to improve homes across the country will deliver benefits to health, mental wellbeing, and productivity. The final phase of this research used BERL's Computable General Equilibrium (CGE) model to forecast how a large retrofit programme might impact the country's economy. The model showed that:

- The shock to the economy, to 2050, would be an investment between $26 and $58 billion into residential construction and related industries.
- Investment would move away from exporting industries, as residential construction is purely a domestic market. This movement away from exporting would result in a reduction in total Gross Domestic Product (GDP); however, household incomes would increase despite the drop in GDP.
- The rise in household incomes can be attributed to the increased demand for higher paid skilled jobs to deliver retrofits, and the reduced demand for semi-skilled jobs.

Cost-benefit ratios produced in Aotearoa New Zealand, for existing retrofit schemes, were applied to the cost scenarios to illustrate what the value of the benefits could be if the same results were achieved.

- Depending on the level of investment into retrofitting homes, benefits upwards of $50 billion would be observed in the domains of health and energy savings. In the domains of wider wellbeing, benefits would be upwards of $116 billion.

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1 Introduction

The Climate Change Response (Zero Carbon) Amendment Act 2019 set the target to reduce Aotearoa New Zealand's net emissions of all greenhouse gases (except biogenic methane) to zero by 2050. To meet this target, the Ministry for Business, Innovation and Employment (MBIE) released their Building for Climate Change programme (2020a) which indicated that significant carbon reductions are needed in buildings' operational energy use (2020b) and whole-of-life embodied emissions (2020c). It was identified in the Ministry for the Environment's national emissions plan (2022) that buildings contribute over 15 percent of Aotearoa New Zealand's national carbon emissions. These emissions come from how buildings use energy (operational emissions) and the quantity of emissions produced by the building over its life, including its build, maintenance, and deconstruction (embodied emissions).

When focusing on residential buildings, the impact of inefficient energy use goes beyond the domain of emissions. A home which inadequately provides and retains heat is damper, mouldier, and costlier, and is therefore harmful towards its occupants across many domains of wellbeing. To make matters worse, when a home is inefficient, its occupants may choose to not heat the home at all. Homes with children are more likely to be cold, mouldy, and damp. It is estimated that around 30,000 children are hospitalised each year from preventable conditions such as asthma and pneumonia which peak in winter (Child and Youth Wellbeing, 2020). Poor quality homes also pose a significant risk to the resilience of Aoteaora New Zealand's communities in the face of extreme weather events, such as storms, heat waves, and cold snaps. Upgrading a home from poor to good condition is not straightforward for many households, as barriers such as cost, knowledge, and skill and supply shortages can prevent homeowners from taking action. Renters are in an even more challenging position as they can do little to influence upgrades to their homes beyond the required standards.

This research focused on identifying international examples of initiatives that promote residential renovations and retrofitting, with the objective of reducing greenhouse gas emissions from existing homes. These examples were viewed through an Aotearoa New Zealand lens to present what lessons could be applied here. The focus of this research was on evaluating international policies, and specific measures such as insulation and heating efficiency. The Aotearoa New Zealand commercial built environment possesses significantly different drivers, motivations, and policy jurisdictions to the residential built environment, and so this research has only focused on interventions designed for residential building stock.

The most successful overseas programmes were ambitious, and aimed to meaningfully improve many dwellings at a building-system level. The next critical success factor of retrofit programmes was to ensure that the funding mechanisms were appropriate for the needs of targeted households and homeowners, and that the mechanisms were simple for these groups to navigate.

This research then estimated the impacts of three retrofit scenarios of varying ambitions, to identify how different parts of the Aotearoa New Zealand economy might react to a significantly large retrofit programme. BERL used a Computerised General Equilibrium (CGE) model to understand how the economy would react to significant investment in the construction industry for residential retrofits from 2020 to 2050. Then, the wellbeing and health benefits of the same retrofit programme scenarios were estimated using existing methodology that was used to quantify the benefits of Warmer Kiwi Homes and Healthy Homes Initiative, which are current Aotearoa New Zealand residential energy efficiency programmes.

The national retrofit scenarios were calculated to require between $27 and $58 billion of capital to target 426,255 homes potentially exhibiting poor energy wellbeing. This number is consistent with the capital requirements of a programme of similar ambition in Ireland, which targets a similar number of houses. From this capital requirement, the CGE analysis produced interesting results. The model forecast that high levels of investment into domestic construction would direct activity away from exporting activity, which would reduce Gross Domestic Product (GDP). However, despite a reduction in GDP, household incomes, most significantly at low and medium income levels, would increase due to a rise in demand for higher skilled jobs in residential construction.

1.1 Purpose

This report presents the results of a literature review that identified international examples of initiatives that promoted residential renovations and retrofitting which lead to, or are intended to result in, a reduction in greenhouse gas emissions through decreasing operational carbon, especially energy, use. The literature scan assessed the solutions used in the initiatives, and the expected and actual impacts, where this information was available.

Following the literature scan, initiatives were shortlisted for analysis. The relevant assessments, for example Cost-Benefit Analyses (CBA) conducted by organisations abroad to estimate the impact of such initiatives, were used to assess their suitability for Aotearoa New Zealand. This helped to build a picture of what worked and what did not work in the implementation of these programmes, and how they relate to the ecosystem of the Aotearoa New Zealand building and construction sector, the regulatory system, the strategic environment, the current building stock, and future climate change.

The Building Research Association of New Zealand (BRANZ) commissioned BERL to undertake this analysis of international retrofit examples, in partnership with the New Zealand Green Building Council (NZGBC). BRANZ is the key research institute on buildings in Aotearoa New Zealand and oversees the Building Research Levy. The New Zealand Green Building Council (NZGBC) represents Aotearoa New Zealand in the world's effort to decarbonise building stock and construction methods through advocating for energy efficient heating and green building methods.

BRANZ, through their Transition to a Zero Carbon Built Environment programme, funds research that will help Aotearoa New Zealand to achieve its climate commitments through reducing greenhouse gases emitted by the built environment. Aotearoa New Zealand has emission targets that must be met, under both the Paris Agreement (50 percent reduction of 2005 greenhouse gas emissions, and net-zero carbon emissions between 2050 and 2100), and the Climate Change Response Act 2002 (amended in 2019 to reduce emissions (except methane) to net-zero by 2050).

This report recognises that there is a crucial need to improve the carbon performance of Aotearoa New Zealand's residential building stock. The benefits of energy efficient homes have been well researched in Aotearoa and abroad. Energy efficient homes often reduce energy demand (which reduces emissions from generation), increase resilience to extreme hot and cold weather events, and provide significant health and wellbeing benefits for occupants. While energy efficiency improvements must happen, *making* them happen deserves its own focus. The best way of learning is by doing, which is why international examples of retrofit policies and programmes have been examined, with priority given to ambitious programmes that targeted a large number of homes and which therefore aimed to make a significant impact to wellbeing and energy savings at a national level.

This report is structured as follows:

- Section 1.2 reviews the context for retrofitting in Aotearoa New Zealand. The condition of the national housing stock, and the prevalence of energy poverty in Aotearoa is discussed. Past and present efforts to improve the residential building stock, such as past retrofit grants, are outlined. Finally, Section 1.4 introduces retrofit programme archetypes, and Section 1.5 summarises key observations.
- Section 2 establishes a vision for retrofits in Aotearoa New Zealand, which feeds into an evaluation matrix that provides a high-level perspective of the international programmes through summarising their costs, benefits, and targets. Section 2 then discusses past and present international retrofit examples in detail, with a focus on Ireland, the United Kingdom (U.K), Canada, the Netherlands, France, the United States of America (U.S), and European Union
- Section 3 summarises the key lessons learnt from international retrofit programmes.
- Section 4 constructs three national retrofit programme scenarios to estimate the total capital that would be needed to deliver an ambitious programme.
- Section 5 estimates the impact of the scenarios outlined in Section 4 to the Aotearoa New Zealand economy, through CGE analysis.
- Section 6 estimates the health and wellbeing benefits of the scenarios outlined in Section 4
- Section 7 concludes the report with final recommendations which encompass the Aotearoa New Zealand context, international examples, and economic analysis.

1.2 Aotearoa New Zealand context

1.2.1 The need to retrofit kiwi homes

Climate impact

New Zealand is committed to reducing its climate impact through the Climate Change Response (Zero Carbon) Amendment Act 2019, which defined the following targets:

- Net emissions of all greenhouse gases, excluding biogenic methane, to zero by 2050.
- Reduce biogenic methane emissions to 24-47 percent below 2017 levels by 2050, including to 10 percent below 2017 levels by 2030.

- Establish a system of five-year emissions budgets for Aotearoa New Zealand, which will track downwards towards 2050.
- Establish the Climate Change Commission to monitor Aotearoa New Zealand's emissions (MfE, 2021).

A key action in Aotearoa New Zealand's Emissions Reduction Plan (ERP) also recognised the need to address buildings' operational carbon emissions:

> "Improve building energy efficiency by amending the Building Code and measuring energy performance to ensure buildings are designed, and retrofitted, to use less energy for heating and cooling" (MfE, 2022a, p.227).

Building for Climate Change

MBIE oversees the Building for Climate Change (BfCC) programme. This is a long-term work programme which aims to reduce emissions from construction and to ensure buildings are prepared for the effects of climate change, such as sea level rise and increased extreme weather events (MBIE, 2020a). This work programme ties into the Government's National Adaptation plan (MFE, 2022b) and Emissions Reduction Plan (MfE, 2022a), which sets out the direction for Aotearoa New Zealand to mitigate and adapt to the effects of climate change. The BfCC approach focuses on the principle of the right buildings, in the right place. The areas of action will:

- Improve the efficiency of buildings to reduce energy and water use, and improve ventilation and building temperatures. The assumption is that improved efficiency will lead to lower emissions from building operation.
- Reduce the whole of life embodied carbon footprint of buildings from construction materials, process, waste disposal, and building disposal at the end of its life
- Improve the ability of buildings to withstand future climate change events (MBIE, 2020a).

The two major elements of the ongoing BFCC programme are to reduce the embodied and operational emissions of buildings. The key objectives of these elements are summarised below.

Whole of life embodied carbon emissions reduction

- Improve new building efficiency; buildings are resilient, built to last, and as big as they need to be but no bigger. Existing buildings are being put to their best use.
- Improve material efficiency; buildings are designed to require less materials for the same performance, and waste is minimised at construction and demolition stages of the building life cycle.
- Reduce the carbon intensity of construction materials and products; lower carbon materials are used, and emissions are reduced in the production of materials such as concrete and steel (MBIE, 2020c).

Transforming operational efficiency

- Improve the thermal performance of buildings and indoor environmental qualities; design and orientation of buildings maximise performance, and insulation and ventilation are appropriate.
- Improve the energy efficiency of building services; heating and cooling systems are efficient.

- Improve water efficiency.
- Reduce fossil fuel use; renewable energy sources are used for heating and cooking (MBIE, 2020b).

National Adaptation Plan

A primary focus of the Aotearoa New Zealand Government's National Adaptation Plan (NAP) is concerned with the managed retreat of coastal communities throughout Aotearoa New Zealand due to sea level rise caused by climate change and coastal erosion (Ministry for the Environment, 2022).

Among the many actions to adapt to climate change presented in the NAP a standout action is to reduce and manage the impact of climate hazards on homes and buildings, outlined as follows:

> "[to] investigate incentives that could help building owners to increase their buildings resilience [...] to ensure the built environment is designed and planned to cope with extreme events and the changing climate [...] also help to ensure rules about the quality of public and private housing and tenancies consider climate change and remain fit for purpose" (MfE, 2022b, p.123).

A key hazard from climate change will be the increased chances of extreme weather events; heat waves in summer, and cold snaps and storms in winter. Homes that have inadequate heat retention will be more vulnerable to these events and are a risk to the resilience of Aotearoa New Zealand in the face of climate change.

The efficiency shortfall

Housing and the environment have a close, but often overlooked, relationship. The Aotearoa New Zealand building and construction sector contributes a significant amount of greenhouse gas emissions to the country's total emissions, which was estimated by Statistics New Zealand (Stats NZ) to be 16 percent of total national emissions in 2018. Greenhouse gases emitted by buildings are high due to their long functional life; 90 years for houses built from 1860 to 1980, and 130 years for houses built from 2000 (Stats NZ, 2021).

Aotearoa New Zealand households' operational energy use contributes to emissions, although not as much as in other OECD countries such as the U.K. and Canada, due to most electricity in Aotearoa New Zealand being drawn from renewable sources. However, when electricity demand is high, coal-fired generation is used to meet shortfalls. In addition, electricity demand spikes during cold snaps increase the chances of power gird blackouts, which places risk on households and electricity-reliant critical infrastructure. Research into dwellings' contribution to energy demand mismatches, by Jack , Mirfin, and Anderson (2021), concluded that rapid uptake of energy efficient dwellings would reduce the winter-summer energy demand variation by 75 percent by 2050.

Inadequate house conditions mean households require more energy to maintain a comfortable temperature level, which is often higher for people such as the elderly, those living with disabilities, and children. Operational energy use is the highest contributor to the lifetime emissions of a building, and includes the energy used for:

- Heating
- Cooling

- Heating water
- Plug-in appliances
- Interior lighting

Chandrakumar, McLaren, Dowdell, and Jacques (2020) analysed current and forecast building stock to determine if Aotearoa New Zealand's new-built detached houses aligned to the warming limit of 2°C defined by the Paris Agreement. To estimate this, the study modelled the emissions contribution of houses which existed at the end of 2017. The authors stated that the climate impact of the Aotearoa New Zealand detached housing sector from 2018 to 2050 was estimated to 128,130 CO_2 equivalent kilotons, of which 66 percent was attributed to the existing housing stock. The largest contribution to emissions over this period was operational energy use (62 percent).

Chandrakumar et al (2020) predicted that the climate impact of operational energy use of pre-existing houses will contribute 67,030 kilotons of CO_2 equivalent emissions over the 2018-2050 period. The carbon budget for energy operation of pre-existing buildings over the same period was 13,074 kilotons. The data indicated that the existing housing stock emissions (67,030 kt) are predicted to already be exceeding the carbon budget (13,974 kt) by a factor of five or more. Chandrakumar et al (2020) argued that new buildings needed to be far more energy efficient than current building standards required. To meet the identified carbon budget, the performance of new buildings must be raised (which may not always be possible), and the performance of existing buildings must be lifted. The following studies examined why Aotearoa New Zealand houses exhibit poor energy efficiency.

Housing conditions

White, Ferguson, Goodyear, and Saville-Smith (2021) analysed the condition of owner-occupied and rented houses in Aotearoa New Zealand by linking a Pilot Housing Survey (PHS) with the 2018 Census, and the 2018 General Social Survey (also known as the Wellbeing survey or GSS). Their analysis came to the following conclusions[1]:

- Just 7.2 percent of houses had roofs in excellent or good condition, and houses that were occupied by owners were more likely to be in better condition than rented houses.
- Owner occupied houses were more likely to have better condition cladding than rented houses.
- Rented houses were more likely to have defects with windows, with 58.1 percent of rentals indicating at least one defect compared to 42.1 percent of owner-occupied houses.
- Blocked guttering was present in 17.5 percent of rented houses and 9.3 percent of owner-occupied houses.
- 49.2 percent of houses had less than adequate levels of insulation in the roof space, and there was no difference between rented or owner-occupied houses on this measure.

[1] This data was collected before Healthy Homes Standards came into effect for rentals (2019). Therefore, the data may vary from current condition proportions.

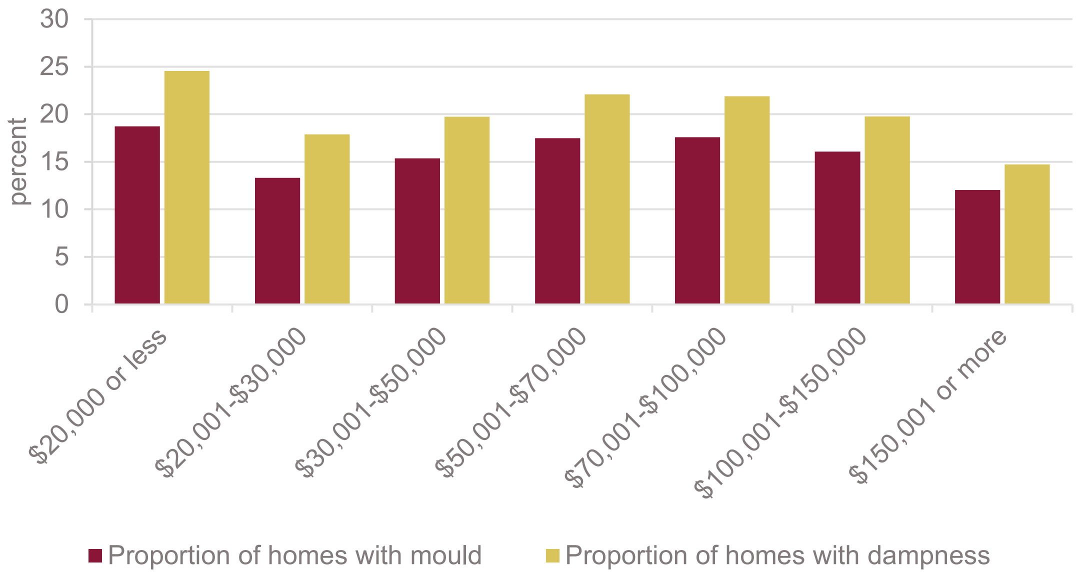
- 75.7 percent of Aotearoa New Zealand houses were entirely single-glazed. Owner-occupied houses were twice as likely to be double glazed than rented houses.
- 72.5 percent of houses lacked any kind of ground moisture barrier.
- Rented houses were more likely to have no heating measures, portable electric heaters, or fixed electric heaters (not to be confused with heat pumps).

The responses to the PHS were also used by Stats NZ in their report, *Housing in Aotearoa: 2020* (2021), which highlighted the largely inadequate characteristics of Aotearoa New Zealand's housing stock. The 2018 census asked respondents if their home was mouldy and/or damp, and if this was all the time or some of the time. The presence of mould and/or dampness indicates if a home requires improvement to its heating and heat retention systems. Overall, the Census showed that 21.5 percent of homes (319,000) were affected by dampness, and 16.9 percent of homes (252,855) had visible mould larger than A4 size at least some of the time (Stats NZ, 2021). The report also concluded that people living in cold, damp, and/or mouldy houses had more frequent colds and flu, and were more likely to report suffering from asthma and poor mental wellbeing, compared to people living in homes that did not have these problems (Stats NZ, 2021)

Indicators across the PHS, GSS, and the Census around housing habitability were largely consistent with each other: rented homes tended to be in worse condition than owner-occupied homes, low-income households were most likely to be living in damp and/or mouldy houses, and cities tended to have higher rates of mould and/or dampness than rural areas (Stats NZ, 2021 & White et al, 2021).

Most current residential heating interventions in Aotearoa New Zealand are aimed at households that classify as low income, or who live in high deprivation neighbourhoods. However, Figure 1.1 shows that the sub-standard housing issue is not one purely based on income.

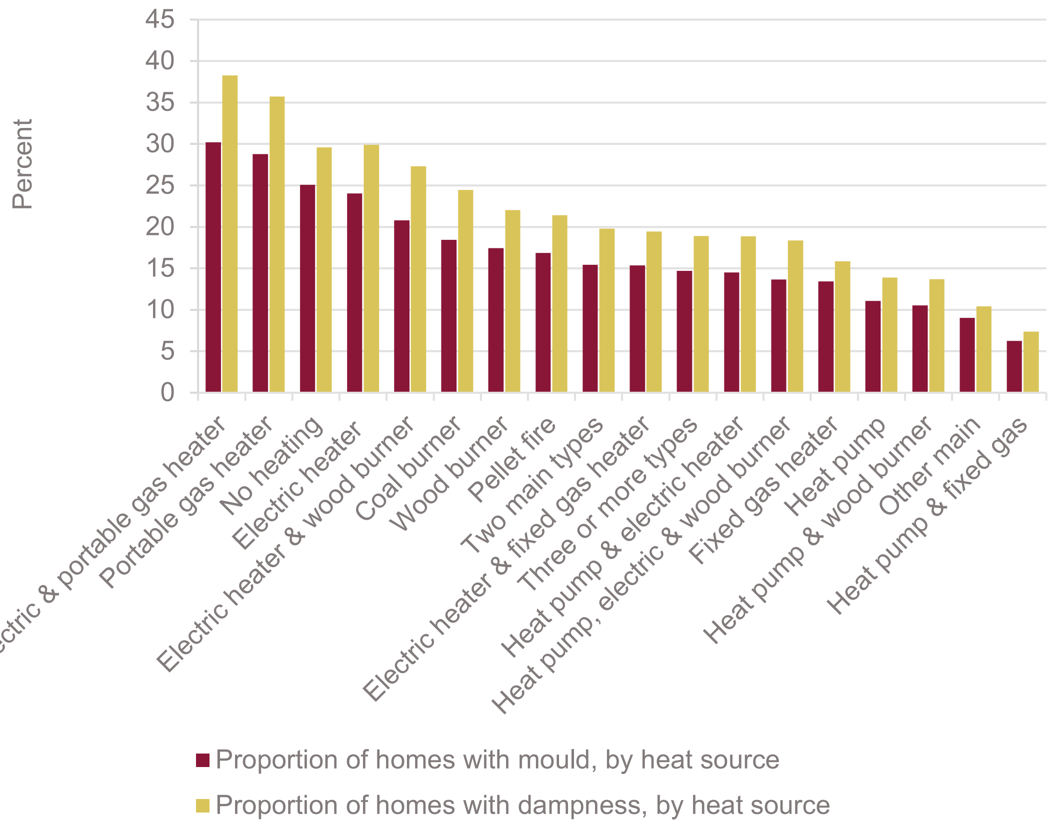
Figure 1.1 Proportion of households with mould and/or dampness (all or some of the time), by income group, 2018



Source: Stats NZ

Figure 1.2 arranges households reporting mould and/or dampness by heating method. This figure indicates a clear relationship between heating method and mould and/or dampness.

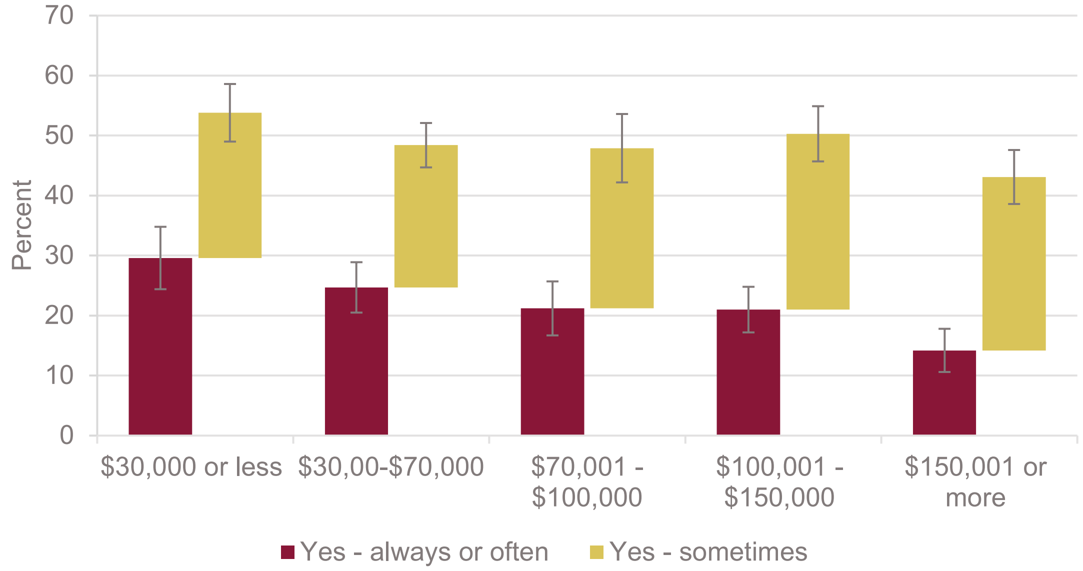
Figure 1.2 Proportion of households with mould and/or dampness, by heat source, 2018



Source: Stats NZ

The results from the 2021 GSS showed that conditions have not improved significantly since 2018. The GSS asked respondents if their home is colder than they would like during winter, either some of the time, or all the time. Again, the presence of high rates of heating inadequacy is not only focused on low-income groups. Figure 1.3 demonstrates this observation. The results of the 2021 GSS were limited by COVID-19 containment measures, which resulted in a reduced sample size compared to previous years. Error bars have been included in figures from the 2021 GSS to account for the increased margin of error.

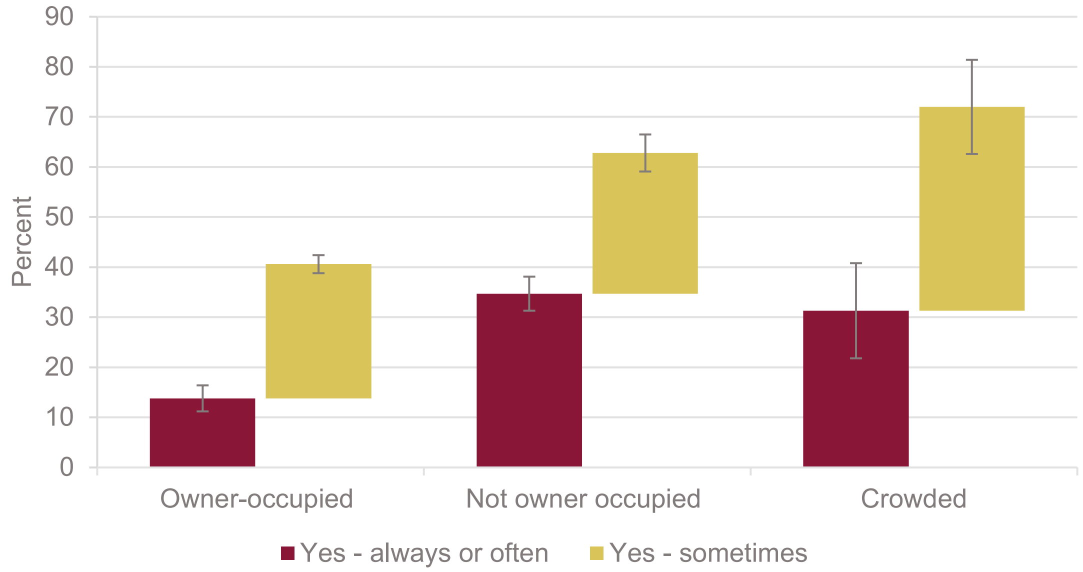
Figure 1.3 House or flat is colder than would like, by household income group, 2021



Source: Stats NZ

Figure 1.4 outlines that households who were renting were most likely to always or often be living in cold homes. Crowded households were the most likely to be sometimes living in cold homes.

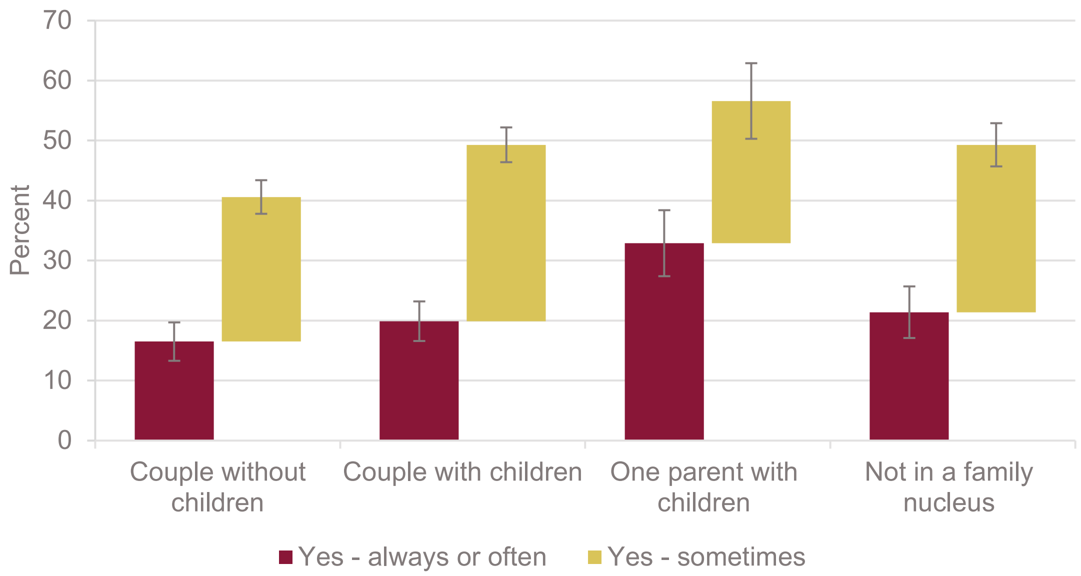
Figure 1.4 Home is colder than would like, by housing tenure, 2021



Source: Stats NZ

The 2021 GSS also showed that children with one parent were at the most risk of being always or often cold during winter, as displayed in figure 1.5.

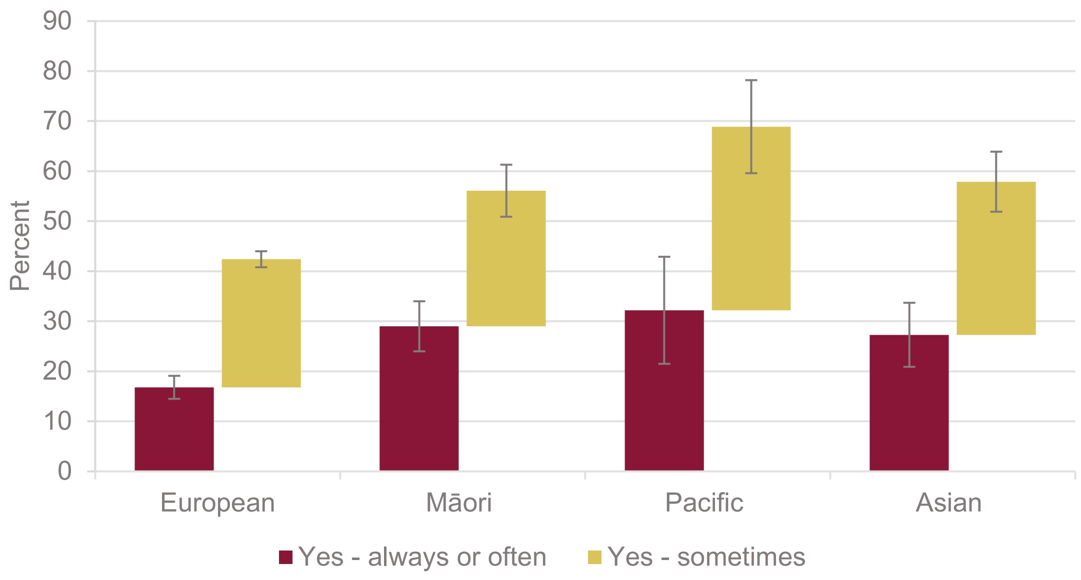
Figure 1.5 Home is colder than would like, by family type, 2021



Source: Stats NZ

Figure 1.6 shows that Māori households were more likely to be living in cold homes than European households, with Pacific households being the most likely, albeit with a higher margin of error.

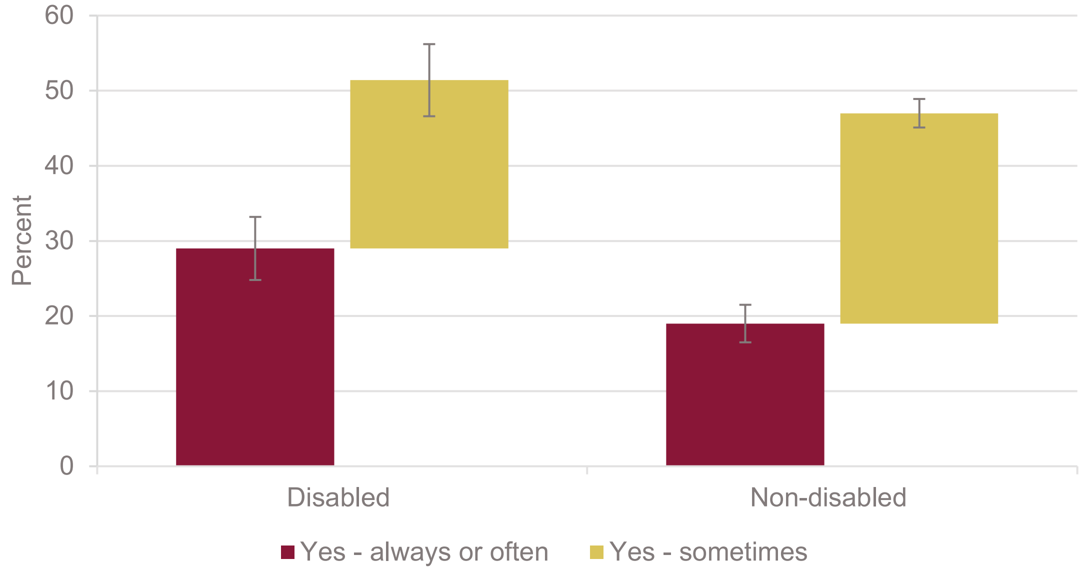
Figure 1.6 Home is colder than would like, by ethnicity, 2021



Source: Stats NZ

The GSS also identified that respondents who were disabled were more likely than non-disabled to report living in a home that was always or often too cold, as shown in Figure 1.7.

Figure 1.7 Home is colder than would like, by disability status (Washington Enhanced Set), 2021



Source: Stats NZ

The above figures and statistics point towards a clear picture; Aotearoa New Zealand's residential housing stock is not adequately meeting the heating and energy efficiency needs of households. These issues contribute towards poor health and wellbeing outcomes, and increase the risk of Aotearoa New Zealand not meeting its emissions targets, which will increase the likelihood of climate change. The following section examines the programmes which have aimed to address these issues.

1.2.2 Previous Aotearoa New Zealand programmes

Warm Up New Zealand: Heat Smart (WUNZ) was a programme, open to kiwi households from 2009 to 2013, that partially funded home insulation and heating retrofits and was mostly aimed at roof and floor insulation and heat pump installation. The WUNZ programme was developed from an earlier retrofit programme known as Energywise Homes, which had been in effect since 2003. The average WUNZ service provider retrofitted 780 homes per year over the programme, equalling approximately 234,000 insulation and space heating retrofits completed over the course of the programme. The programme funded:

- 33 percent of the cost of roof and floor insulation, draught proofing, moisture barriers, and remediation, up to a maximum of $1,300 for most homeowners. For low-income homeowners and landlords of low-income households, 60 percent of the cost could be funded, and there was no maximum cost limit.
- $500 to $1,200 towards a clean heater, which was eventually phased out of the programme.

WUNZ required homeowners to arrange and pay service providers to deliver the retrofit, then the service provider obtained the rebate via a claim to the Energy Efficiency and Conservation Authority

(EECA). Consumers could pay for the retrofit via mortgage extensions, interest-free loans, or repayments through their council rates bill.

A Cost-Benefit Analysis (CBA) was completed in 2012 by Grimes, Denne, Howden-Chapman, Arnold, Telfar-Barnard, Preval, and Young. The CBA concluded that the present value of costs associated with the programme was $339 million, and the present value of benefits was $1.56 billion. An important note was that the energy benefits only equalled $21 million, while the benefits associated with health equalled $1.54 billion (Grimes et al, 2012). While energy savings were identified, they were not as large as expected due to the observation that households would increase their energy use after receiving an upgraded heating system. This observation is known as a “take-back effect” which is a key characteristic of energy upgrades both internationally and in Aotearoa New Zealand.

1.2.3 Current Aotearoa New Zealand initiatives

The current programmes designed to address energy hardship in Aotearoa New Zealand (one of the outcomes of poor energy efficient homes), is the Warmer Kiwi Homes (WKH) programme, which is administered by the EECA. As of 2022, WKH comprised two grants. The first grant covers 80 percent of the total cost of ceiling and underfloor insulation for homeowners who live in their home, built before 2008, and have a community services card or live in an area identified as low-income. The second grant covers 80 percent of the cost of an approved heater, with the same requirements as the first grant, plus the house must have ceiling and underfloor insulation that meets EECA standards.

Another measure in force is the Healthy Homes Standards (HHS), which was established into law mid-2019. The standards require rental properties to have heating, insulation, ventilation, moisture ingress prevention, and draught stopping measures above a level of adequacy. While the HHS has resulted in an improvement to many households’ energy efficiency and heat retention levels, the standards have probably not gone deep enough to make houses as energy efficient as they could be. For example, the 2021 General Social Survey (GSS) indicated that just under half (49.1 percent) of households felt that their home was warm enough during winter. In a similar fashion, the most recent HHS monitoring report (Ministry of Housing and Development, 2021) uncovered that 55 percent of renters felt their home had a problem with heating and/or keeping warm in winter, and 57 percent of renters said their home had a problem with dampness or mould. The response to the same questions were largely the same in the 2020 monitoring report. Most landlords cited costs (40 percent) and impracticability (32%) as the key barriers for implementing HHS measures into their properties (HUD, 2021).

The impact of heat pumps from the WKH heating grant

An impact evaluation of the WKH programme was delivered in 2022 by Motu Economic Policy and Research for EECA (Fyfe, Grimes, Minehan, & Taptiklis, 2022b & 2022a). The evaluation examined the impact of heat pump provision on 127 households’ living areas.

The evaluation concluded:

- Applicants for the WKH were motivated primarily by improvements to comfort levels, such as having more effective heating (74.6 percent), and improving comfort in winter (70.6 percent). The motivation ranked second was to save on costs, either from the subsidy on the heat pump (54 percent), or on the energy bill (51.6 percent).
- Before installing heat pumps, 31.9 percent of households reported limiting heating in the living area due to cost. After installation, this number reduced to 7.7 percent of households.
- More than half (59.4 percent) of households reported always or often having condensation on their windows. After heat pump installation, this number reduced to 2.2 percent.
- Households reporting dampness in their living or bedroom reduced from 20.9 percent to 2.2 percent after having their heat pump installed.
- Most participants (81.6 percent) reported that their home was much more comfortable, or more comfortable, because of installing a heat pump, and 91.3 percent of households reported they were very happy, or happy, with their experience with the WKH programme.
- Heat pumps were less effective at raising indoor temperatures when the house was draughty. The final evaluation will examine other aspects of house condition that might affect the heating capability of heat pumps.
- Electricity use increased as external temperatures fell. When controlled for an interaction effect, the evaluation models hourly electricity savings of 0.056 kW per household at mean outdoor temperature. At zero degrees Celsius, hourly electricity savings were 0.149 kW per household. At high outdoor temperatures, electricity usage increased after heat pump installation, due to their use as air conditioners.

WKH costs and benefits

Grimes and Preval (2020) examined the costs and benefits of the WKH programme from administration, health and wellbeing data. They also summarised the locally based research that informed their approach to quantifying the benefits of warmer homes across wellbeing dimensions.

This evaluation stated that the total costs from 2018 to March 2020 were $73,253,869, which was comprises of the following:

- Number of households that received an insulation grant: 20,296
- Total value of insulation grants: $55,562,305
- Number of households that received a heater grant: 3,870
- Total value of heater grants: $9,984,440
- Incentive payments and administration costs: $2,751,217
- EECA operating expenses: $4,955,908.

Grimes and Preval (2020) quantified the benefits accrued by the programme noting that, as in the WUNZ programme, improvements to heating systems resulted in take-back effects, where households used their new heating systems significantly more than their old systems, thus increasing their energy use. Despite take-back effects, the benefits to health and mortality rates resulted in a high primary benefit-cost ratio (BCR) of $4.66 of benefit for every $1 spent on the programme. Section 6.2.2 of this report looks at this BCR in closer detail.

Healthy Homes Initiative

The Healthy Homes Initiative (HHI, not to be confused with the HHS) is a programme funded by the Ministry of Health to improve the living conditions of low-income families, with children at risk of rheumatic fever, living in crowded households. The target of the programme was expanded in 2016 to focus more broadly on providing warm and dry housing for low-income families with children up to five years old and pregnant people. The programme is provided by mostly Māori and Pacific organisations to deliver a "by community, for community" approach. Such organisations include Māori health providers, housing providers, sustainability providers, and public health providers. Families receive a referral through a hospital visit, where a provider helps the family access services that might improve their living conditions. The HHI focuses on delivering four key interventions:

- Access to insulation, curtains, beds, bedding, carpet, draught proofing, heating, and child safety devices
- Ability to apply for critical and/or minor repairs
- Education and advice to support behaviour changes to keep applicants' houses warm and dry
- Advocacy with landlords for improvements, and to the Ministry for Social Development for social housing.

A three-year evaluation was completed in 2022 by Pierse, Johnson, Riggs, and Watson for Te Whatu Ora, Health New Zealand. The evaluation used data in the Integrated Data Infrastructure (IDI) to link a child referred to the HHI to data held on the IDI to construct a household dataset. The information used to evaluate the effectiveness of the HHI was hospitalisation records, education attendance records, Inland revenue (IRD) taxable income, and benefits received from the Minsitry of Social Development (MSD).

The evaluation concluded:

- Costs to 2021 equalled $55.7 million, mostly comprising staffing costs.
- The cohort analysed was 75,858 individuals across 14,625 households
- 9,745 hospitalisations were prevented per year across the programme, equalling 29,234 hospitalisations prevented over three years
- 1,870 extra days spent in education
- Average benefit amount reduced by approximately $200 per year per person
- Four percent increased likelihood of being employed
- Total benefits were equivalent to $200.5 million over three years (Pierse et al, 2022).

This evaluation was limited due to the fact that the HHI interventions referred clients to other services provided by external organisations, programmes, or initiatives. The evaluation did not analyse which of these interventions were most effective at delivering the above benefits. The evaluation of HHI displays the importance of guiding families towards interventions through trusted processes.

Kāinga Ora Retrofit Programme

Kāinga Ora is the agency responsible for providing social housing in Aotearoa New Zealand. A large portion of their housing stock, 40,000 homes, will need upgrading over the next 20 years. Currently, Kāinga Ora is investing $500 million to retrofit 1,500 homes throughout Aotearoa New Zealand over two years. The retrofits include full insulation of the walls, ceilings, and floors, double glazing, improved airtightness, ventilation, and new heating (Kāinga Ora, 2021).

Retrofitting was estimated to take four to five months, and the tenants were moved into temporary housing with the support of the Kāinga Ora Tenancy Liaison team to ensure the tenant was confident and trusted the retrofit process.

Kāinga Ora managers commented that every house had to be retrofitted with a bespoke approach, even though the targeted state houses were built at the same time. This was because works required for retrofits varied significantly across homes. Crucial to the ongoing success of the programme was the careful and mana-enhancing management of Kāinga Ora clients, some of whom were in vulnerable living situations. Keeping occupants in the loop, and granting them control over some aspects of the retrofit, meant disruption was mitigated as much as possible. Clients were made aware of the benefits that would result from the retrofits and project timelines were communicated early. Most disruption to timelines came from material supply issues, such as those described in Section 1.2.5 of this report.

Green financing

There has been growing pressure on financial institutions to finance activities which align with the climate goals of Aotearoa New Zealand. Many large banks, for example ANZ and Westpac, offer green finance products to their corporate customers to improve business sustainability. However, there is little on offer for personal customers to improve the sustainability of their homes. Mid-2022, ANZ was the first institution to announce their Good Energy Home Loan, which can provide up to $80,000 at a fixed rate of one percent over three years, to fund measures which improve the energy efficiency of a home. Once the three-year term is up, the loan takes on the customer's mortgage rate. Westpac followed not long after ANZ's announcement with their own similar short-term, low-interest sustainability loan aimed at households. More products have since been announced, although these products may change rapidly as financial market conditions change.

1.2.4 Demand constraints – exceeding the minimum

In 2019 BRANZ completed a study into the attitudes of homeowners to exceeding minimum standards for refurbishments and retrofits (MacGregor, Magan, & Brunsdon, 2019). The study contained several significant insights. Firstly, the study was undertaken because it was highlighted by previous research (MacGregor & Donovan, 2018) that consumers were likely to see the New Zealand Building Code (NZBC) as a quality assurance mechanism instead of as a legally allowed building standard. In practice, this meant that consumers would misinterpret a retrofit or building being ‘to code’ as a proxy for quality, while in reality it meant that the project was achieving the bare minimum of quality. Therefore, it was important that research was undertaken to understand what motivates homeowners to retrofit their homes beyond the NZBC standards.

First, it was already known by BRANZ that homeowners had difficulties accessing information on how to exceed minimum building standards, and how to do so in a way which was technically and economically efficient (MacGregor et al, 2019). However, it was identified that as costs increased, along with potential electricity savings, returns on investment were difficult to achieve, most notably due to the lack of recognition of high-performing retrofits in house prices, which meant that homeowners did not recoup enough of the investment when they sold.

The 2019 attitudes study analysed 245 survey responses from homeowners who were planning or undertaking a residential retrofit. The study concluded that homeowners were most likely to obtain retrofitting information from local councils, and the information most likely to be sought was regulations and the building code. Information around costs and feasibility was the second most likely to be sought (MacGregor et al, 2019).

1.2.5 Supply constraints – pressure and low productivity

There are two significant projects underway that aim to improve Aotearoa New Zealand’s building and construction sector. In 2022 the Commerce Commission began investigating supply chain pressures which have become pronounced due to integral building materials, for example plasterboard and insulation, only being available from a limited number of producers and suppliers. The second project is being led by the Ministry of Business, Innovation and Employment (MBIE), which aims to reform the sector through changes to the consenting system and other policy interventions.

The Commerce Commission outlined the key players and characteristics of the residential building sector:

Regulatory bodies:

The following organisations oversee and influence quality in buildings and construction in Aotearoa New Zealand. The issues noted in this section may influence the costs and timeline of a large scale retrofit programme.

MBIE Building Performance Branch – sets performance requirements under the Building Code.

Building Consent Authorities (BCAs) – registered authorities that issue building consents, conduct inspections, and issue compliance certificates.

Standards NZ – independently sits within MBIE, and is responsible for managing standards in Aotearoa New Zealand. Usually compliance with standards is voluntary, unless required through regulation or cited in Acts. Standards NZ specifies the performance standards needed from building supplies.

CodeMark – product certification programme that provides a pathway for compliance with the building code. Of the four bodies accredited to issue CodeMark, BRANZ is the only one that resides in Aotearoa New Zealand while the rest are based in Australia.

BRANZ – independent research and testing organisation, that as well as issuing CodeMark certification, conducts building product testing, consultancy, and other functions associated with the building and construction industry.

Characteristics

- Aotearoa New Zealand's building sector is a small isolated market distanced from other countries. This makes it challenging to achieve efficient scale for domestic manufacturing. It is unattractive to import products manufactured overseas
- Aotearoa New Zealand's construction sector goes through boom-bust cycles, which influences appetites to invest in capacity in manufacturing and supply
- The 'leaky homes' crisis of the early 2000s, and the Christchurch earthquakes in 2010 and 2011, influenced the shaping of the regulatory and standards systems. There was a focus on ensuring weathertightness and durability of homes, with a theme of conservatism in design and consenting
- There has been limited growth in large-scale builders over the last decade
- The New Zealand Building Code sets performance criteria that work must meet, but does not specify how work should be done. Qualitative phrases such as "adequate", "low probability" and "sufficient" are used to set performance levels. The Code also does not set standards for building products outside of specified uses of that product (Commerce Commission, 2022).

Pressures

- Increases in demand for key building supplies, along with pressure on supply chains, led to shortages in structural timber, plasterboard, and insulation.
- Significant increases in the number of consents for new homes were observed across 2020 and 2021. Consents for alterations also increased during this period. This number has fallen over 2022.
- Global and domestic supply chains have been disrupted due to COVID-19. Lockdown periods resulted in production outages and loss of production.
- Surveys in 2021 concluded that key issues faced by the sector were increases in the prices of materials and supplies, of which worldwide shipping was identified as being the primary cause of the issues.
- Supply shortages cause impacts to the entire construction process, as well as to the workers. This is because payments to builders are often conditional on achieving key milestones of building projects. As a result, shortages cause flow-on disruptions for other industry participants.

- In some cases, when builders fail financially during a project, the cost is borne fully by the homeowner
- Government policy to address climate change will require residential building to be environmentally sustainable and to limit building emissions (Commerce Commission, 2022).

Building consents

According to MBIE (2022c), Aotearoa New Zealand's building and construction sector is undergoing a period of strong growth. However, this is causing several pressures on the government's consenting systems. MBIE is investigating updates to the country's building consent process, and this will be part of a wider reform to change the housing market in Aotearoa New Zealand.

The reform aims to unlock productivity growth, stimulate urban development, and make houses more affordable. The building consent system will be evaluated through the elements of:

- Institutions
- Practice
- System management.

MBIE heard from industry stakeholders that where assurance and accountability is weak, trust and confidence in the consenting system is seriously diminished. The whole-of-system approach to fixing issues relating to risk in the building sector aims to bring together the many elements of the building control system with the aim of getting building work right the first time (MBIE, 2022c). This aim links directly with retrofit programme potential in Aotearoa New Zealand. Firstly, if a building was not built right the first time, it will require a retrofit in the future. Also, if a retrofit is not done right the first time, another will be required. Because retrofits are generally "sold" as being paid back over their useful lifetime, a defective retrofit loses this benefit, and harms overall trust in retrofits. A question that will arise from homeowners, developers, builders, and manufacturers will be - who bears the risk in a retrofit programme?

MAIHI Ka Ora – National Māori Housing Strategy

MAIHI Ka Ora was introduced in 2022 alongside the Government Policy Statement on Housing and Urban Development (HUD). MAIHI Ka Ora sets the vision where "all whānau have safe, healthy, affordable homes with secure tenure, across the Māori continuum" (HUD, 2022). As the data indicated in Section 1.2.1, Māori households are at higher risk of living with poor energy wellbeing, and therefore any potential retrofit programme will be of importance to Māori interests. The goals of MAIHI Ka Ora are outlined as follows:

- Work in partnership where the Crown and Māori achieve balance through a collaborative work programme that strengthens housing solutions for whānau.
- Māori leading and providing local housing solutions to whānau.
- The number of Māori, iwi and hapū owned houses can meet the housing needs of all Māori.

- Whānau have better access to effective support that is fit for purpose and enables them to attain and maintain their preferred housing option.
- The system supports Māori to accelerate Māori-led housing solutions.
- Whānau are supported to achieve mana-enhancing housing solutions on their whenua. Māori are able to sustain a connection to their own land through housing, and their housing is innovative and responsive to the effects of climate change (HUD, 2022).

The Ministry of Housing and Urban Development primarily focuses on housing supply issues, for example combatting homelessness and supporting whānau to transition from renting to home ownership. Retrofits will play a crucial part in ensuring homes are adequate for their new occupants. The Māori Housing Strategy also outlined a target of 700 whānau-owned homes to be repaired by June 2024.

When considering an international programme for Aotearoa New Zealand, the role of iwi, hapū, and whānau should not be overlooked. The MAIHI Ka Ora Strategy was clear that Māori homes require Māori solutions, and one size should not be assumed to fit everyone.

1.2 Programmes considered

A long list of policies and programmes were identified before six countries were investigated in more detail. These were: Ireland, the United Kingdom, the Netherlands, France, the United States, and Canada. A programme that was conducted across the European Union was also investigated. Retrofit programmes are diverse, but they can be classified into broad models to be examined as archetypes. Section 1.4 discusses retrofit archetypes.

1.3 Archetypes

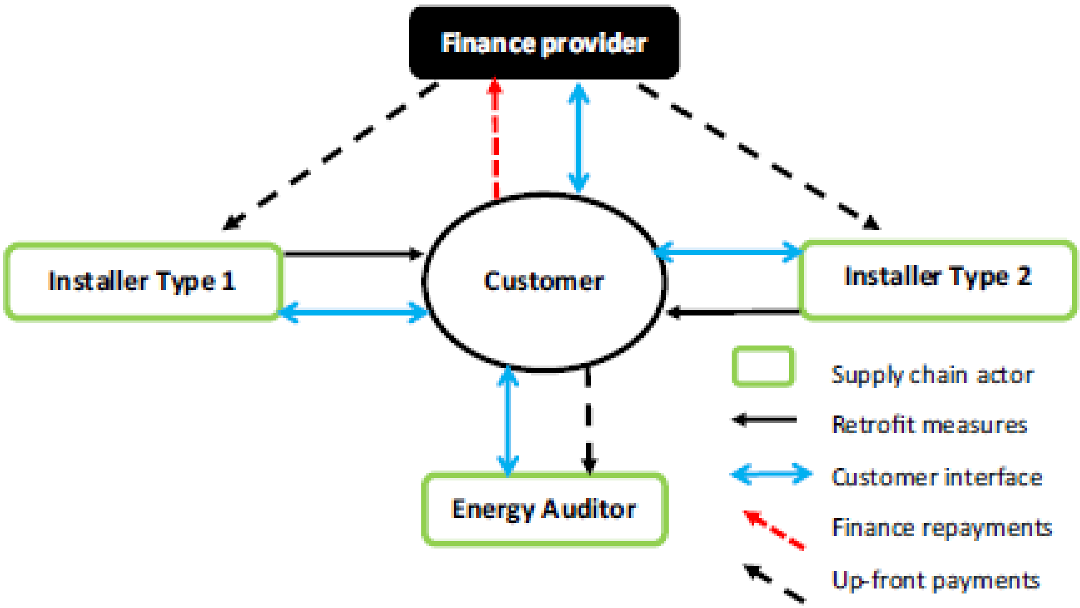
Brown (2018) identified five archetypes of residential retrofit business models, which were assessed for suitability to the United Kingdom. The archetypes identified were the Atomised market model, the Market intermediation model, the One-stop shop, Energy services agreement model, and the Managed energy services agreement model. This section will outline the key details of each of the archetypes to provide an understanding of the various approaches to retrofit programmes by authorities and businesses around the world.

Atomized market model

Atomized market models, displayed in Figure 1.8, are the primary model used in the U.K., and are provided on estimated energy cost and carbon savings. Technologies and installations are sourced from different contractors. The homeowner is responsible for sourcing the retrofit measures, the finance, energy audits, and installers. The 'atom' comes from the shape of the model, where the homeowner is the nucleus:

- The Atomized model can also be thought of as a 'siloed' approach to retrofits, because each of the parts (finance, supply, contractors, and energy auditors) are engaged separately and do not formally interact with each other.

Figure 1.8 Atomized market model

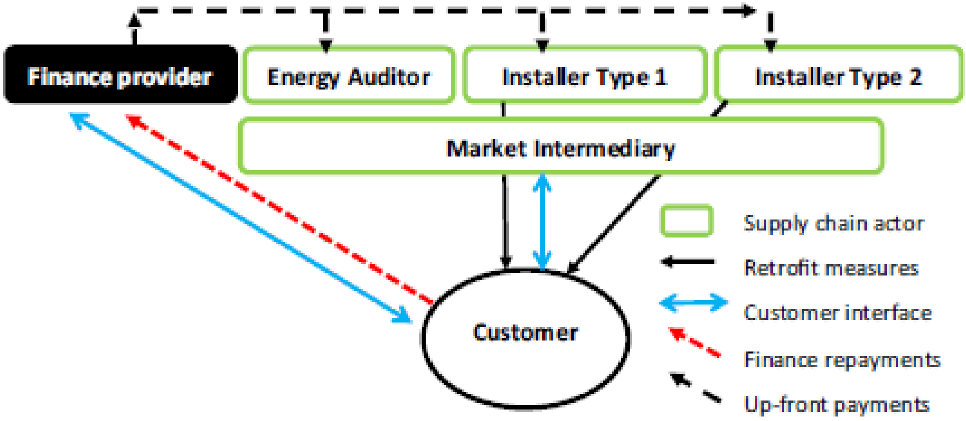


Source: Brown (2018)

Market intermediation model

- Displayed in Figure 1.9, Market intermediation models usually involve the use of a government subsidy programme.
- An intermediation organisation coordinates the supply chain and provides a customer interface to the homeowner. The homeowner is responsible for arranging the retrofit through the intermediary, and arrange upfront payment through a finance provider.
- The programme continues for as long as there is an intermediary organisation to facilitate the interaction between homeowners with suppliers and installers.

Figure 1.9 Market intermediation model

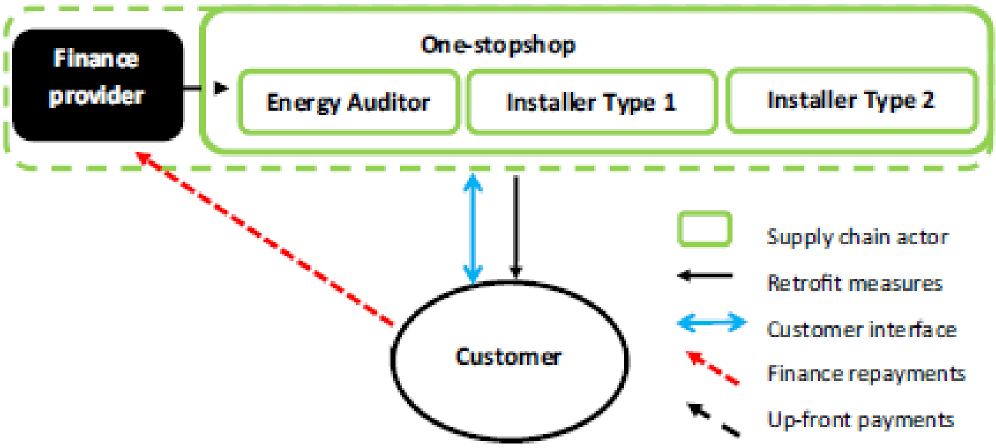


Source: Brown (2018)

One-stop shop

- Displayed in Figure 1.10, the One-stop shop model is an integrated supply chain and interface that functions as a single point of contact for the homeowner. This model usually offers a whole-house approach which can be provided by single supplier-installers, or a network of supplier-installers. The interface arranges finance application and the energy assessment of the house for the homeowner.

Figure 1.10 One-stop shop model



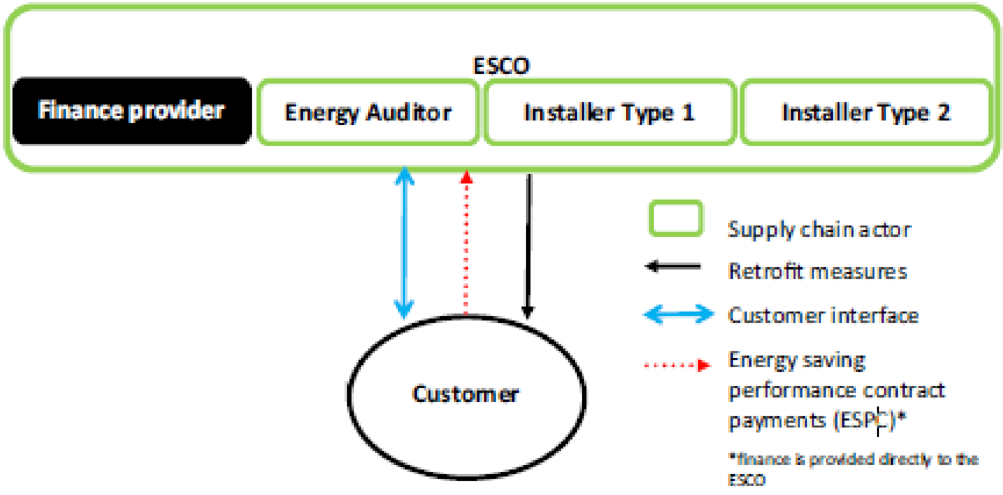
Source: Brown (2018)

Energy Services Agreement (ESA)

- In the ESA model, displayed in Figure 1.11, the homeowner interacts with a single interface, as with the one-stop-shop model. Where the models differ is in how the retrofit finance is repaid. The model guarantees a level of energy saving through an Energy Saving Performance Contract (ESPC).

- The money saved from making the building energy efficient is used to repay the loan from the finance provider. This model is used primarily by organisations which own social housing, as usually for this model, the tenant is not responsible for repayments.

Figure 1.11 Energy services agreement model

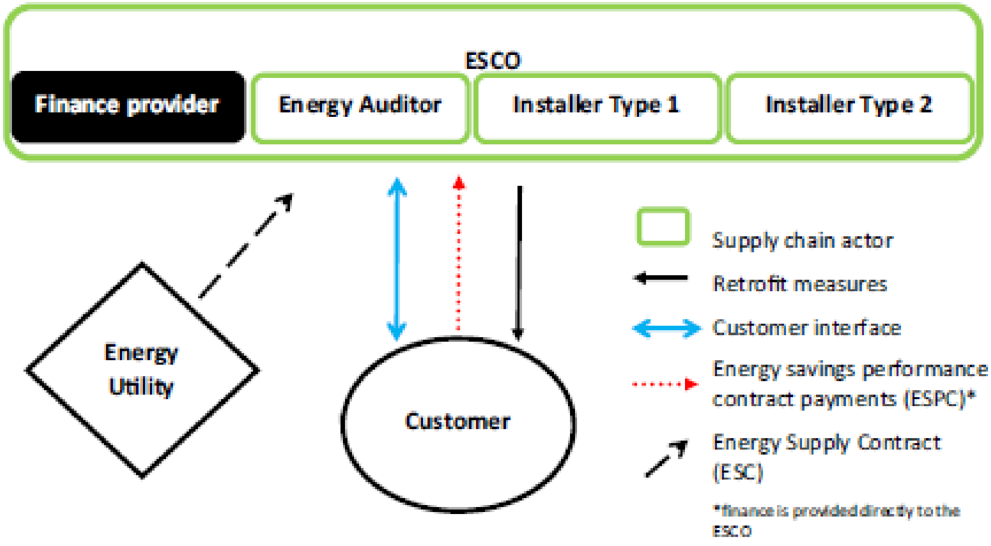


Source: Brown (2018)

Managed energy services agreement (MESA)

- The MESA approach, displayed in Figure 1.12, is like the ESA, where repayments are modelled to be equal to the amount of energy saved post-retrofit (the 'guarantee'). The difference with MESA is that the guaranteed repayments are managed with the home's energy service provider, so that the repayments are delivered through an energy bill. Through this method, tenants can repay the loan, with the understanding that they will receive a constant energy bill along with improvements to their comfort.
- If the occupant's energy use exceeds the guarantee, they are required to pay for the extra energy used.
- According to Brown (2018) A comprehensive retrofit which includes microgeneration (such as solar panels), is a precondition for the MESA model.

Figure 1.12 Managed energy services agreement model



Source: Brown (2018)

Model observations

Brown (2018) offered the following recommendations from their review of retrofit business models:

- The value proposition of a programme should focus on comfort, health benefits, aesthetics, building longevity, and improvement of capital value for the homeowner. Emphasis on carbon and energy savings are less likely to encourage owners to engage with the programme.
- ESAs can be attractive to customers, but they transfer the risk and costs to contractors.
- Supply chain integration can improve product quality and reduce supply risks. However, bringing together siloed disciplines requires a large investment of skill and time.
- A single and trusted point of contact is important for family-focused programmes.
- Capital that is low-cost is essential for the viability of long-term comprehensive approaches.
- Energy Performance Guarantees can reduce perceived risk for investors.
- Integrated financing packages provided with retrofits is likely to encourage demand.
- Networked approaches like the ‘atomized’ model are only suitable for single measure retrofits, not comprehensive ones.
- Intermediary organisations, and their competency, is crucial for the success of a retrofit programme, particularly if it is a new programme with no track record.

2 International examples of deep retrofit programmes

2.2 Retrofit programme matrix

This section captures the key information from international retrofit programmes. The information summarised in the matrix is concerned with:

- the programme models
- costs
- benefits (how much, and what kind)
- applicability to Aotearoa New Zealand in terms of housing typology, climate, and existing policy
- strengths
- limitations

In some cases, not all the information was available for certain programmes. The information presented here is from a high-level, and explained in deeper detail in Section 3 of this report. All dollar values have been converted into New Zealand dollars (NZD).

Programme	Business model	Costs	Benefits	Comparability with New Zealand	Strengths	Limitations
Ireland						
Deep retrofit pilot programme (2017-2020)	One-stop-shop. Retrofits were organised by the Government's energy sustainability authority.	Fully funded by the Government. Average cost from poor energy efficiency to excellent efficiency: $98,611.	Average improvement from poor to excellent: 365 kWh saved per annum. $270 per kWh saved.	Detached dwellings built after 1978; villa bungalows, ex-state houses. Ireland has a similar climate and population size (five million) to New Zealand. Ireland is part of the European Union. The EU determined the target of retrofits to be delivered by 2030 by the Irish Government (500,00).	Provided data for each house typology to help the Irish Government estimate the total funding needed to provide retrofits to their total housing stock. The sample of the pilot reflected the proportion of the total Irish housing stock.	Actual data from the retrofit pilot programme was unavailable. Actual energy use post-retrofit might be different on a large scale. Take-back effects may result in smaller national energy savings than estimated from the pilot. Key assumption was that significant movement from low- to high-energy efficiency will result in decreased energy demand.
National Retrofit Programme (2020-present)	Combination of multiple models: One-stop-shop; Atomised; Energy company obligation (ECO)	Paid for in part Government, EU, and private funds. Total cost was estimated to be $49 billion.	Unquantified as of the time of writing. Estimates drawn from the pilot programme.	Typologies same as above. Target is 500,000 homes to very good energy efficiency (BER B2) or better.	The plan is specific and brings together all of the actions in place and to be implemented. Monitoring has been set up at the start to allow for changes as the programmes progress.	All of the elements of the plan may not work together as planned, such as with the Green Deal and ECO in the U.K. Assumes some finance packages will reduce risk and will encourage private firms to provide retrofit finance.

United Kingdom (U.K.)						
Carbon Emissions Reduction Target (CERT) (2008-2012) and Community Energy Saving Programme (CESP) (2009-2012)	Energy Company Obligation (ECO); where interventions were provided by energy companies, and costs were dispersed through energy bills to customers. The CESP targeted homes in energy poverty.	$66 per tonne of CO_2 saved.	CERT: 296.2 metric tonnes (mt) of CO_2 savings.CESP: 16.31 mt of CO2 savings; 20.2 mt savings after compensation.	U.K. homes targeted were generally attached or semi-detached townhouses. ECOs are not a familiar retrofit vehicle in New Zealand.	Energy company provided measures were able to be provided to many households to deliver substantial CO_2 savings.	Companies targeted 'easy to treat' homes to maximise CO_2 savings. However, this meant 'hard to treat' homes were paying for benefits they did not receive, due to energy bills increasing to pay for interventions.
Green Deal and Energy Company Obligation (ECO) (2013-2015)	Managed Energy Services Agreement	$178 to $184 per tonne of CO_2 saved.	ECO provided 525,000 energy saving measures which were mostly improved hot water systems. Green deal delivered 14,000 retrofit loans in total.	As above.	ECO targeted 'hard to treat' homes, which did not save as much CO_2 as the CERT and CESP. However, the outcomes were more equitable. The National Audit Office evaluation (2016) provided substantial lessons.	Green Deal failed to spur homeowners to invest in retrofitting their houses. ECO delivered interventions to hard-to-treat homes that were successful, but fewer in number than CERT.
RE:NEW (2009-2017)	Market intermediation model	$5.8 million invested by European Investment Bank (EIB) and Greater London Authority (GLA)	BCR: every $1 invested resulted in $1.7 worth of tonnes of CO_2 emissions saved	Model is similar to the Healthy Homes Initiative that acts an intermediary between communities and existing programmes.	Highlighted the effectiveness of community-based initiatives to deliver interventions.	Targets between the funders were vastly different, and not proportional to how much the funders were investing. The EIB's targets were much smaller despite investing substantially more to the programme than the GLA.

Kirklees Warm Zone (2007-2010)	One-stop-shop	$45 million	Loft insulation in 43,000 homes.New heater systems in 602 homes. Wall insulation in 21,000 homes. Fire safety checks in many other homes.	See above regarding U.K, house typologies.	Zip-up method to deliver measures to neighbourhoods was novel. Provided insight into delivering measures to communities at a large scale.	Issues with contractors associated with the programme that attempted to deceive homeowners. Programme was fully funded, so no financing vehicle was necessary.
France						
I Renovate Low Consumption Buildings (2010)	One-stop-shop	Average price was $92,000 per household Average price per square metre: $679	83 kWh/m^2 reduction of energy used per annum, per household (41 percent savings).	France has a continental climate, larger population, and housing stock is typically terraced houses.	Displays the value of project managers to oversee retrofits.	Inclusion of project manager increases the cost of retrofit delivery. Environmentally friendly materials. Very small sample size used in cost and benefit estimates.
Low-energy Renovation (2011)	Market intermediation model	Average price was $54,000 per household Average price per square metre: $474	63 kWh/m^2 reduction of energy used per annum, per household (29 percent savings).	See above.	Standard retrofit programme.	Very small sample size used in cost and benefit estimates.

Netherlands						
Energiesprong (2010-present)	Managed energy services agreement	From Nottingham: $21.3 million for 155 retrofits. Small numbers of retrofits estimated to be $139,000 per home Reduces to $94,500 per home when more homes were targeted	70 percent reduction to thermal energy use. 15 percent reduction to electricity demand.	Designed for attached townhouses common in the U.K. and Netherlands. Netherlands exhibits similar climate to New Zealand, but possesses a much larger population.	Has potential to be hassle-free for homeowners and occupants.	There is little evidence to suggest Energiesprong is successful on a large scale. Requires scalable products that can be produced offsite and applied to homes with uniform characteristics. If energy use does not decrease post retrofit, the occupants pay more for their power.
Canada						
Greener Homes Initiative (2021-present)	Market intermediation model	$6,000 in grants per household for retrofits. Up to $50,000 per household in loans per household for retrofits. Total capital that can be accessed: $56,000. $3.4 billion available for grants.	Grants allocated for up to 700,000 homes. 10,300 homeowners had accessed the grants so far.	The state of Nova Scotia has the most comparable housing stock, climate, and population to New Zealand. Canada is home to First Nations peoples, of which there are provisions in their retrofit programmes to fast-track funding for retrofits.	Combination of grants and loans allow for a substantial amount of capital to be accessed. Special provisions for First Nations peoples.	No data on loan uptake as of the time of writing.
Property Assessed Clean Energy (PACE) Atlantic (2010-present)	Energy Service Agreement	$13 million invested into energy efficiency retrofits, paid by homeowners	2,242 tons of emissions savings.	See above regarding Nova Scotia.	Capital is sourced privately, and PACE can leverage with local and national programmes.	Loans are secured against properties, which can expose households to risk if they default on the loan. Refer to section 3.6.3 for more analysis on the PACE model.

United States of America (U.S.)						
Weatherisation Assistance Program (1976-present)	Market intermediation model	$7,700 per household. Department of Energy invested $455 million per year. Energy companies and utilities contributed an additional $1.4 billion.	$609 energy savings per household per year (18 percent heating savings and 7 percent electricity savings). BCR: $1.72 of energy benefits for every $1 spent on the programme. $2.78 of non-energy benefits for every $1 spent.	Varied climate and housing environment. Some states have climates similar to New Zealand, and consist of detached and semi-detached homes.	Extra investment from energy companies had allowed the programme's scope to expand.	Amount granted per household very low in comparison to other measures in other countries.
Whole-house rebate program (2021 and re-designed in 2022)	Atomised model	$14.7 billion available as announced in 2022. $369 million of this pool available Native American Tribal Authorities. Up to $6,500 available for households and $655,000 available for multi-unit buildings.	Modelled to reduce energy savings by up to 35 percent.	See above. Allocation for Native Americans.	Substantial amount of funding available for buildings across the US.	If rebates move towards actual energy savings, the expected rebates for households may become very uncertain, particularly for households with pent-up demand for energy.

2.3 International examples of deep retrofit programmes

International examples were selected based on similarity to Aotearoa New Zealand's climate and building conditions. Countries in the western part of Europe, such as the Netherlands and the United Kingdom, are temperate with warm summers.

All dollar values referenced in this section have been converted into New Zealand dollars (NZD), to aid with comparability across programmes. However, each country is subject to its own supply and demand pressures that influenced costs associated with retrofits. Prices should therefore be interpreted as indicators of the scale, or depth, of retrofit projects.

Each part of this section outlines programmes of note from each country, and discusses useful research which has originated from the programme.

2.3.1 European Union

The European Union (EU) has a long history of encouraging the improvement of energy efficiency in buildings. The Energy Performance of Buildings Directive and Energy Efficiency Directive were established in 2010 and 2012, respectively, to create a legislative framework to help achieve an energy efficient and decarbonised building stock, a sustainable environment for investment, and to enable consumers and businesses to make informed choices to save energy and money (European Commission, 2021). Buildings were responsible for 40 percent of EU energy consumption and 36 percent of energy-related emissions in 2021.

The Directives were updated in 2018, 2019, and 2021. A notable change was to require all new buildings in the EU to be at least nearly zero energy buildings, and Energy Performance Certificates to be issued when buildings are sold and rented. The Renovation Wave Strategy aimed to at least double the annual energy renovation rate of EU countries by 2030, and to foster deep renovation (European Commission, 2021).

More recently, the European Commission has proposed further revisions to recognise the need to increase the momentum of energy efficiency improvements in both new and old buildings. The measures the Commission is considering are:

- Minimum energy performance standards to trigger renovation of poorly performing buildings.
- New standards for new buildings (near-zero emissions), and a more ambitious vision for buildings to be emitting zero emissions.
- Enhanced national Building Renovation Plans.
- Increased reliability, quality, and digital availability of Energy Performance Certificates (EPCs).
- Defining deep renovation, and introducing renovation passports.
- Modernisation of buildings and their systems, by improving their integration into energy systems of heating, cooling, ventilation, electric vehicle charging, and renewable energy (European Commission, 2021).

Turnkey Retrofit project

The focus of Turnkey was to assess the replicability of retrofit programmes within the EU. A key element of the project was to expand successful one-stop-shop models from France into Spain and Ireland to meet the EU's target of 35 million renovations to building units by 2030. The project concluded that expanding existing models across countries was possible, but that it also contained several challenges. This section examines the key insights from the project.

The Turnkey report, 'Underpinning the Role of one-stop-shops in the EU Renovation Wave' (2021), looked at the opportunities presented by one-stop-shops in EU countries, and what elements of one-stop-shops could be replicated across countries. The easiest elements to replicate were ones which were based online, such as digital marketing, websites, and online help tools. The most difficult to replicate were on-site visits from professionals, project planning, and upholding quality assurance post-retrofit.

The report argued that one-stop-shops should be just one part of a wider policy package. There should also be regulatory measures, such as mandatory minimum energy performance standards, training for professionals, and support campaigns. Another crucial aspect was, of course, an easily accessible and affordable funding mechanism that could drive one-stop-shops.

The 12 key recommendations from the report were:

1) Require most building owners to have access to reliable renovation advice.
2) Streamline technical assistance and funding requirements.
3) Set up a standardised one-stop-shop project template.
4) Set up certification for highly qualified experts.
5) Build capacity at the local level to enable the implementation of one-stop-shops.
6) Encourage local authorities and financial institutions to get involved.
7) Create a toolbox of replicable one-stop-shop elements for local implementers.
8) Set up standardised contract templates and use one-stop-shops to aggregate renovation opportunities.
9) Explore how one-stop-shops can be used to aggregate renovations.
10) Provide a toolbox with guidelines and good practice examples for local installers.
11) Provide guidelines on stakeholder engagement in one-stop-shop implementation.
12) Explore how one-stop-shops can be used to market deep renovations.

2.3.2 Ireland

Pilot retrofit programme

The Sustainable Energy Authority of Ireland (SEAI) launched a deep retrofit pilot programme to address the concern that one million homes in Ireland had poor insulation and inefficient heating systems (SEAI, 2021a). Like most other European countries, Ireland used Energy Performance Certificates (EPCs, here referred to as BERs) to communicate the energy efficiency of homes to homeowners, renters, and local authorities. A Building Energy Rating Certificate (BER) of A1 was the most energy efficient, while G was the least energy efficient. An overview of BER ratings is included in Figure B1 and Figure B2 in Appendix B of this report.

Most houses in Ireland are detached and semi-detached homes, which is similar to the housing stock in Aotearoa New Zealand. The pilot was targeted at a sample which closely resembled Ireland’s housing database, so insights could be applied to the whole country.

The technologies implemented by the retrofit programme, in addition to insulation, included heat pumps in all homes, mechanical ventilation in 83 percent of homes, Mechanical Ventilation with Heat Recovery (MVHR) in 17 percent of homes, and solar power in 69 percent of homes. The inclusion of mechanical ventilation (with or without heat recovery) was required by SEAI due to the vast improvements in airtightness of deeply retrofitted homes. MVHR produced an additional benefit of improved air quality for occupants as well as reducing carbon emissions and household costs (SEAI, 2021b).

The deep retrofit pilot was successful; in 2017 before intervention, the 526 homes which participated in the pilot programme averaged a BER rating of F (417 kWh/m^2/yr.). By 2021, all participating homes had achieved a BER rating of at least A3 (52 kWh/m^2/yr.). The average total capital cost to bring an F rated home up to an A rating was $98,611. Generally, the wider the gap was for improvement, the higher the costs were (SEAI, 2021a). The BER rating concerns the primary energy use of a home, not just the energy service use.

Warmer Homes Scheme and Communities Scheme

Rohan (2020) conducted a Social Impact Assessment of SEAI programmes targeting energy poverty. Over the same period, the Irish Warmer Homes Scheme and Communities Scheme were also in effect. The Warmer Homes Scheme, which closely resembled Aotearoa New Zealand's Warmer Kiwi Homes programme, ran from 2009 to 2019 and delivered energy efficiency works to 124,345 homes. The Communities Schemes ran from 2012 to 2019 and delivered interventions to 12,940 homes at a higher risk of experiencing energy poverty.

Interventions per household were typically valued at $3,400 for most of the Warmer Homes scheme period, as interventions focused on delivering shallow measures such as attic insulation. However, the value of interventions increased significantly in 2018 when the programme was expanded to include internal and external wall insulation. After this change, the average cost per household was $21,500 (Rohan, 2020). In 2019, spending on Warmer Homes was $67 million, and spending on the Communities Scheme was $35 million. Most homes (62 percent) that received works under the Warmer Homes Scheme obtained a BER rating between C1 and D2, while a significant proportion (35 percent) obtained a rating of G to E1 which was only a slight movement along the BER rating scale (Rohan, 2020). The pilot retrofit programme showed that movements from the bottom end of energy efficiency to the top end were possible, but a new approach to that which was familiar under the Warmer Homes and Communities Schemes was required as homes targeted by these interventions were still exhibiting poor energy performance.

SEAI also produced valuable behavioural analysis from the pilot, programmes, and other surveys which is summarised in Section 3.1.2. Section 3.1.3 examines Ireland's National Retrofit Plan, which followed the success of the pilot retrofit programme.

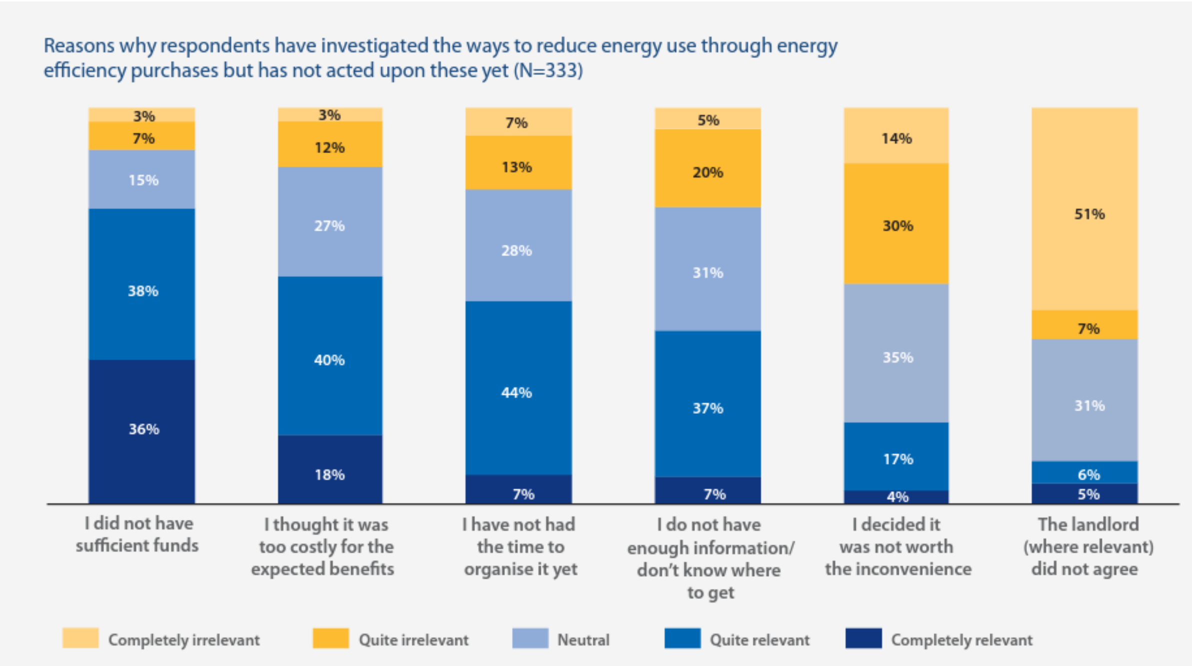
Behavioural insights

The crucial stage of a retrofit programme is to convince homeowners to apply for, and follow through with, retrofits to create a tangible impact on national energy use and health. SEAI (2020) identified key trigger points for homeowners that could result in the decision to improve the home's energy efficiency. The frequency of deep retrofit decisions was estimated to occur every 15 years, while shallow retrofit decisions were estimated to occur every six years. The trigger points were broadly identified as:

- Anticipated home improvement
- Buying a new house
- Retirement
- Extending family, or illness
- A new community initiative (SEAI, 2020)

The key to ensuring these trigger points resulted in a retrofit decision was to ensure that the homeowner received the right information from the right people, and that they were confident they could afford the retrofit that would result in the outcome that best addressed their needs (SEAI, 2020). The barriers to acting upon retrofits were graphed by SEAI and are shown in Figure 8.

Figure 2.1 Reasons why respondents have investigated ways to reduce energy but not acted, by relevance, 2020



Source: SEAI (2020)

SEAI recommended low-interest rate energy loans, combined with grants, as an attractive and feasible option for Ireland because loans can complement existing national or local programmes. If loans are long term, then lifetime benefits outweigh the costs. More consumers were likely to participate if they already trusted the finance provider. Another insight is that homeowners did not make decisions based purely off costs and benefits – they considered the impact of retrofitting on their own comfort level. This conclusion was shared by Aotearoa New Zealand consumers according to the map of the home consumer landscape undertaken by BRANZ (Hindley & Brooks, 2020), but with a caveat: Aotearoa New Zealand consumers cared about their comfort, but did not know how to navigate getting a home to above the building code to achieve this comfort.

National Retrofit Plan

The success of the 2017-2019 retrofit pilot programme led to the announcement by SEAI of Ireland's National Retrofit Grant programme at the start of 2022, which formed the backbone of the Government of Ireland's ambitious National Retrofit Plan (2022). The National Retrofit Plan aims to achieve the equivalent of 500,000 residential homes retrofitted to a B2 Building Energy Rating (or cost optimal or carbon equivalent). The secondary target aims to install 400,000 heat pumps in existing homes to replace less-efficient heating systems. Both targets aim to achieve these numbers by the end of 2030.

To achieve 500,000 homes to B2 BER, significantly more homes will need to be targeted by the programme, as not every home will be able to achieve this rating. The Government of Ireland (2022) estimated that between 2019 and 2025, 185,000 homes will have received energy upgrades, with over 83,000 of those homes upgraded to a B2 or above level.

The retrofits will be organised and monitored by teams from the Department of Energy, SEAI, and the newly formed National Retrofit Steering Group. The monitoring teams will develop annual residential retrofit plans to ensure the programme stays on track, and will include additional measures, such as regulation and taxation policy levers, if needed.

Currently, the programme consists of three grant packages:

- **Individual energy upgrade grant package:** Up to 80 percent of the retrofit cost paid for by SEAI, where the retrofit project is self-managed by the homeowner. The homeowner pays for the retrofit work first, then claims the grant afterwards. Homes built before 2011 are eligible for insulation and heating upgrades.
- **One-stop-shop (OSS) service package:** A complete home retrofit service, provided by a registered company approved by SEAI. Up to half (45 to 50 percent) of the cost is covered by SEAI. All work, including the grant application, is managed by the service. The service is for homes built before 2011 and ensures a minimum rating of B2 for all homes.
- **Fully funded upgrade package:** All costs are covered by SEAI. This package is for homeowners who receive welfare support from the government, for example the Job Seekers Allowance and the Carers Allowance. Homes built before 2006 are eligible. This arm of the programme previously existed as the SEAI Warmer Homes Scheme which received $170 million of funding in 2021. The Warmer Homes Scheme previously delivered 143,000 upgrades to homes, with an average value of $30,000.

The grants are only one dimension of the plan. The other products of the plan include:

- **Upgrading the BER into the BER Advisory Report:** The scope of the BER is expanded to provide more to homeowners than just an energy efficiency rating. Similar to work which proposed the idea of energy passports (Irish Green Building Council & Limerick Institute of Technology, 2020), the BER will be upgraded to include an advisory report which details the steps required to get the house to at least a B2 rating. The Advisory report functions as a guide for the homeowner to understand what works will be necessary, and the best routes to seek funding to ensure the works are affordable and feasible. The BER Advisory report is attached to the house (not the owner), which means the information will pass on to new owners if the house is sold

- **A network of one-stop-shops will be established:** To simplify the homeowner journey, one-stop-shops (OSSs) will be linked with the help of SEAI. The SEAI will register all OSSs to ensure they meet performance indicators, and that project pipelines progress at the expected rate.
- **Increased support for Sustainable Energy Communities (SECs):** SECs were set up in 2015 to support communities with energy-saving awareness activities and local energy saving measures. The target is to grow the number of SECs in Ireland from 530 to 1,500 by 2030. Increased funding will support small-scale community programmes that deliver energy-saving products and services to households.
- **Requirements for rental properties:** Because the incentive to improve the energy efficiency of a house is misaligned between landlords and tenants, the National Retrofit Plan will introduce a minimum BER rating requirement for all private rentals from 2025.
- **Expansion of the Local Authority Retrofit Programme:** 36,500 homes will be targeted to be brought up to a B2 standard through the Local Authority Retrofit Programme by 2030. $148 million has been allocated to local authorities in 2022 to deliver these retrofits to their communities.
- **The Energy Company Obligation programme will be expanded:** There has been an energy company obligation (ECO) programme in place in Ireland since 2014. ECOs and how they function are discussed in greater detail in the following section. Energy companies are required to deliver energy saving interventions to households, either through their own programmes, or through partnership with SEAI one-stop-shop providers.
- **Residential Retrofit low-cost loan guarantee scheme:** The Government of Ireland is working with the Strategic Banking Corporation of Ireland to develop a scheme where the Government, through EU funding and Exchequer funds, will provide risk protection to retail credit institutions to deliver loans for low-energy upgrades. Because of the Government backed guarantee, the National Retrofit plan expects the result to produce commercially available low-interest long term loans for efficient residential retrofits.
- **Focused training:** The Government of Ireland will invest in Near-Zero Energy Building training in specialist centres, and further invest into building and construction apprenticeship support. Building capacity within local authorities and central agencies will be prioritised to ensure adequate support is available for retrofit projects. Importantly, a prime focus will be on increasing the number of BER assessors in Ireland to ensure retrofit projects are not bottlenecked at the beginning of their journey.

Funding model

The National Retrofit Plan estimated that the cost to retrofit the fabric of a house and install a heat pump (to achieve a B2 rating) will be between $24,000 and $115,000 per house in 2022 prices. When this cost is multiplied by the number of targeted buildings, a lump sum of $49 billion would be required to deliver all the required retrofits in 2022 (Government of Ireland, 2022). Of course, it was not feasible to provide these funds from government coffers alone.

The budget of the National Retrofit Plan draws from allocations provided under the Government of Ireland's National Development Plan, which earmarked $14 billion of funding to residential retrofits, of which $8.71 billion is to be drawn from carbon tax revenue. The total amount is sizeable, but will not be enough on its own to deliver 500,000 B2 retrofits by 2030. The National Retrofit Plan expects homes that fall outside of central loan and grant packages to be upgraded partly through the Low-Cost Loan Guarantee scheme, which would put less immediate pressure on Government funds (as funds are only needed if debtors' default on their guaranteed loan). The other element to meet shortfalls will be interventions directly or indirectly delivered by energy companies through their ECO obligations. The plan envisions that those unable to afford retrofits will receive them through appropriate grant packages, and those who can afford retrofits can access cheap and low-risk capital to deliver the retrofits.

The National Retrofit Plan exemplifies that there is no silver bullet to solve residential energy efficiency. Rather, the plan proposes an ambitious mix of policies that can act together and separately to deliver interventions to households across demographics and housing types. At the time of writing, there was limited data on programme uptake rates and retrofits delivered so far.

2.3.3 United Kingdom

Kirklees Warm Zone

An effective retrofit project was the Kirklees Warm Zone, which took place in the Metropolitan Borough of Kirklees, a district of West Yorkshire in the United Kingdom. This project offered insight into a retrofit programme which was place-oriented; where implementation was targeted at specific wards and neighbourhoods in Kirklees. The following lessons were drawn from an analysis provided by the University of Ulster, Northern Ireland (Liddell, Morris, & Lagdon, 2011). The lessons from this programme were limited to implementation because homeowners did not have to pay for the upgrades they received.

The Warm Zone project started out small in scope, with only $6.21 million allocated for retrofitting homes in energy poverty. After setting up the project, the Kirklees Council and Scottish Power committed an additional $38.8 million, which meant that the scope of the project could be expanded to all homes regardless of whether they met the criterion of energy poverty.

Crucially, the timeframe for the project was not expanded with the scope. This situation led to an innovative method being implemented by the project team to meet their targets quickly and effectively. This method was called the Zip-Up Method:

- Residents were divided by ward
- Wards were classified according to deprivation level, and homes already insulated
- Wards were targeted for project implementation, ensuring that they were completed before moving on. The project would alternate between least and most deprived, until all wards were completed

- Wards were divided into patches, so single streets or neighbourhoods were saturated with retrofits at a time. This meant recipients were satisfied at the same time for each area, and wards with higher needs did not overwhelm the project too early.

The results speak for themselves: loft insulation was installed in 42,999 households, wall insulation in 21,473 households, fire safety checks in 5,838 households, smoke alarms in 9,896 homes, carbon monoxide detectors in 129,986 homes, and new heating systems in 602 households (from 2,033 referrals). A notable aspect of this project was that fire safety was also rolled into energy saving interventions. This meant that houses that did not need retrofits still benefitted in some way (Liddell, Morris, & Lagdon, 2011).

The Warm Zone team coordinated multiple stakeholders in tandem with ward-targeted marketing campaigns. Initially, contractors who were not approved by the team attempted to 'gate-crash' the project by offering their own retrofit service. This identified the need to make households aware of approved contractors, and what to expect from the Warm Zone project. Ultimately success came down to the buy-in from homeowners, and so it was key that the project was trusted. Construction and contractor shortages had to be communicated well in advance, and project representatives had to be easily identifiable (they wore bright red jackets when canvassing the community).

Three waves of uptake were identified by Liddel, Morris, and Lagdon (2011): the early adopters, those persuaded by word of mouth, and the last chance adopters informed of the cut-off date. The power of saturating each neighbourhood before moving on was that neighbours would see works underway, and feel comfortable jumping on board. SEAI noted in their behavioural insights research (2020) that energy-saving initiatives were significantly more effective if they were shared through community networks.

The U.K. Technology Strategy Board (2014) identified characteristics of successful retrofit programmes, which were also identified in the Warm Zone project:

- **Planning:** Clear, achievable, and ambitious performance targets were key to ensuring the project team stayed on track. Retrofits should be able to be tailored to suit the varied conditions of houses, and contingencies should be in place in case of shortages, or scope creep (for instance, works could reveal faulty pipes). Careful planning should account for residents who may have difficulties moving off-site, and the disruption that is caused by works happening in the home.

- **Fabric first:** Heat retention is the priority when retrofitting a home. Having prescriptive solutions might result in homes not being made as warm as they could be, for example installing a compliant heat pump but nothing else. Expensive materials which are thinner should be saved for when they are most needed, and exploring daylight designs can aid in offsetting natural light loss from thicker walls.

- **Engaging residents:** Once on board, residents (whether they own the home or not) should be continuously engaged throughout the project, and if there are changes or delays, they should be notified as soon as possible. When the property is handed over, care should be taken to explain what has changed, and how to use new heating systems. A risk was that if the residents thought the system was too complex, they would not use it and would revert to old habits. It should also be clear about who is responsible for repayments. Some programmes require occupants to pay, while others require the homeowner to pay (The U.K. Technology Strategy Board, 2014).

Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP)

The CERT and CESP were precursors to the Energy Company Obligation and later the Green Deal, which are discussed in Section 3.2.3. The CERT was the legislative driver to improve residential energy efficiency by requiring energy companies to provide energy-saving interventions to households. The energy companies could then pass the costs of the interventions onto all their customers through their energy bills. The CERT ran from April 2008 to December 2012 and was aimed at all households in the U.K. The CESP was a policy designed to run alongside the CERT to provide energy efficiency measures to households in the most deprived areas of the U.K. The CESP ran from October 2009 to December 2012 (Department of Energy and Climate Change (DECC), 2014).

CERT

There were six participating energy companies in CERT, which achieved 296.2 mega tonnes (Mt) of CO_2 savings by the end of 2012, which met the overall target of 293 Mt CO_2 savings. However, two companies did not meet their targets. The measures energy companies provided were insulation, lighting, heating, micro-generation, combined heat and power, behavioural measures, demonstration, and appliances. Of the measures, insulation provided the largest proportion of carbon savings over the CERT term. Approximately one-in-five of all residential properties in the U.K. received a CERT measure (DECC, 2014).

CESP

By the end of 2012, the six energy companies and four energy generators which participated in the programme achieved 16.31 Mt CO_2 savings, equivalent to 85 percent of the 19.25 Mt CO_2 savings target (DECC, 2014). Despite coming close to meeting the target, the performance of participating companies and generators varied. Post-programme evaluation revealed that three out of the six energy companies, and three out of four generators, failed to meet their obligations. As a result, these participants were required to deliver return savings as compensation. After returns were accounted for, 4 Mt CO_2 savings were delivered as mitigation, which led to a total of 20.2 Mt CO_2 savings at the programme's end.

Across 491 individual programmes tied to the CESP, companies and generators provided insulation measures (49 percent) and heating measures (39 percent) to households, which were delivered through social housing providers working in partnership with the households.

Green Deal and Energy Company Obligation

The Green Deal and Energy Company Obligation (ECO) programmes followed the CERT and CESP in 2013, but they did not see similar success. In 2016, the U.K.'s National Audit Office examined the Green Deal and ECO to evaluate what went wrong, and what could be learned to apply to future retrofit programmes.

ECO

The ECO required the largest energy suppliers to install measures, usually efficient appliances or easy to install insulation, in homes that would reduce national CO_2 emissions by a set amount. The suppliers would be penalised if they did not meet these targets, similar to how the CERT and CESP were enforced. The suppliers could install measures or contact installers directly, and through public auctions. After improvements to a house's energy efficiency, the suppliers would pass their costs on to all their customers through increased energy bills. Programmes like the ECO had been in place for approximately 20 years prior, so this model was the familiar vehicle for reducing household emissions in the U.K. The ECO was launched with the Green Deal in 2013 as the replacements to the CERT and CESP.

The CERT was previously effective at addressing "easier to treat" homes, because "hard to treat" homes required much more investment. This brought a regressive quality to energy company facilitated interventions because hard-to-treat households, who were most likely to be at risk of energy hardship, were paying for the improvement of easy-to-treat homes through increased energy bills (National Audit Office, 2016). Therefore, because one of the objectives of the ECO was to alleviate energy poverty, changes in 2013 required energy companies to target hard-to-treat homes, while the Green Deal would target easier-to-treat homes.

The Green Deal

The Green Deal was a financing programme which allowed homeowners access to easy capital to improve their home's energy efficiency. The finance would then be repaid through the house's energy bill. A framework of advice, accreditation and assurance accompanied the finance package to ensure trust in the supply chain to deliver the home improvements.

Outcomes

The 2016 audit concluded that the main target, to provide energy-saving measures to one million homes by the end of 2014, was met earlier than expected. However, this did not reduce emissions, because the measures varied significantly across homes.

The Green Deal did not state what proportion of the cost of the measures should be paid for by households, and it did not quantify how much CO_2 the Green Deal should save in addition to the ECO's targets. This meant there was nothing in place to detect if the Green Deal was off-track early.

The change to ECO to focus on harder-to-treat homes, alongside reduced CO_2-saving obligations, resulted in the programmes saving far less CO_2 than previous programmes. The new conditions for the ECO meant that the projects energy companies focused on were more expensive for less CO_2 saved. Green Deal finance was intended to fill the gap by incentivising homeowners to pay, which did not happen, as only one percent (14,000) of the total number of homes which engaged with the programmes had taken up Green Deal loans. The ECO was initially expected to improve 100,000 hard-to-treat homes per year, but the target was reduced to 23,500 per year in 2014.

The ECO provided 525,000 measures to households, most of which were improved boilers. Despite this achievement, the programmes were less cost-effective in terms of saving CO_2 than previous programmes, costing $178 to $184 per tonne of CO_2 saved, excluding suppliers' administration costs. The CERT and CESP together cost $66 per tonne of CO_2 saved (National Audit Office, 2016).

The National Audit Office (2016) identified the following elements which contributed to the programmes' ineffectiveness at meeting their goals.

Lack of information sharing

Two of the programmes' objectives were focused on costs, one of which was to increase households' contributions towards paying for efficiency measures, and the other was to reduce the cost to improve hard-to-treat homes. However, there were no indicators being used to measure the progress to meet these objectives. The Department of Energy and Climate Change was unable to test how much households were contributing to costs, and there was no information on how much the ECO was costing suppliers. There was also no data on what impact the programmes were making, if any, on energy poverty due to the lack of income data of participating households.

Design ballooned costs

Because the ECO was designed to improve hard-to treat homes, along with blended finance from the Green Deal, delivery costs were significantly increased for retrofit suppliers as the projects were more complex than before, and required detailed carbon savings assessments. This led to difficulties monitoring and identifying eligible homes for the programme. What was initially intended to reduce costs, in the long-term ultimately increased costs for suppliers by the end of the programme.

Finance model was untested

The Green Deal was a cold sell to consumers. While the ECO was established and familiar, the challenge of the Green Deal was to generate the demand for self-funded retrofits to ensure consistently high uptake of the loans. Ultimately, homeowners were reluctant to pay for retrofits themselves, and the process to apply for the loans was complex and discouraging in the early phases of the Deal.

The programmes did not work together

The programmes were designed to target different parts of the equation, in theory to address demand and supply with approaches that aimed to alter consumer behaviour, and to encourage innovation in the industry to address harder projects. Because one of the programmes did not work as planned, the other programme was unable to function on its own. Unceremoniously, the Green Deal programme was shut down in 2015 without a replacement, which might have dampened confidence in homeowners and suppliers that there was a consistent vision, or commitment, from the government to decarbonise the U.K.'s building stock (National Audit Office, 2016).

RE:NEW

RE:NEW was a technical assistance programme first implemented in 2009 by the Greater London Authority (GLA) to reduce carbon emissions in homes. The programme worked with London's boroughs, housing associations, and universities to provide end-to-end support surrounding residential retrofits. Phase three of the programme began in 2014, and set out ambitious goals to boost the retrofit rate in the Greater London area.

The context for the programme was significantly affected by the changes to the ECO over its operating period, and the cessation of the Green Deal in 2015. The RE:NEW project was funded by GLA and the European Investment Bank (EIB) which had different targets. The GLA targets were significantly more ambitious than the EIB targets. The achievements were evaluated by Regeneris Consulting in 2016, when the programme had spent 75 percent of its budget.

EIB (funded $5.3 million to the programme) targets:

- 25,000 retrofitted homes (107 percent achieved)
- 13,283 tonnes of carbon savings per year (181 percent achieved)
- 63 million kWh saved (113 percent achieved)

GLA (funded $542,000 to the programme) targets:

- 175,000 retrofitted homes (15 percent achieved)
- 93,000 tonnes of carbon savings per year (31 percent achieved)
- 440 million kWh saved (16 percent achieved) (Regeneris Consulting, 2016)

RE:NEW exceeded its EIB targets, but did not come close to achieving its GLA targets. The GLA targets were designed to ambitious and substantial to meet the London housing carbon reduction targets. The EIB did not have to meet the same objectives as the GLA, so they were able to set goals which were more easily achievable.

The targets did not match the level of funding provided by the organisations; despite expecting more from the programme, the GLB contributed far less capital than the EIB. The targets set out by GLA relied on RE:NEW facilitating the Green Deal and ECO in the London area (Regeneris Consulting, 2016). The failures of the programmes meant the RE:NEW programme was limited in what it could achieve. However, although the number of homes retrofitted was not as high as expected, the level of retrofits and investments was higher than expected per house, which meant the amount of carbon savings per home was greater than planned. The evaluation estimated that, despite the challenges, the programme generated $1.70 of value in carbon emission savings for every $1 invested (Regeneris Consulting, 2016).

2.3.4 France

STUNNING Project

The STUNNING project report, completed in 2019, was led by DOWEL Management for the European Union’s Horizon 2020 research and innovation programme. This project sought to provide a comprehensive review of home retrofit programmes, to construct appropriate benchmarks, to understand barriers to success, and to map replicable business models. The STUNNING project compiled a database of 400 retrofit projects, 80 percent of which were in France. In the database, retrofit solutions consisted of four key approaches:

- Envelope insulation
- Heating system replacement
- Ventilation
- Renewable energy system installation

Sixty different combinations of these approaches were identified. To conduct a Cost-Benefit Analysis, the authors drew out from the database six types of packages from retrofit combinations that were the most used:

- Glazing, façade, and roof insulation
- Glazing, roof, floor, and façade insulation
- Heating system, glazing, ventilation, and façade insulation
- Heating system, glazing, ventilation, and roof and façade insulation
- Heating system, glazing, ventilation, roof and floor and façade insulation
- Heating system, glazing, ventilation, roof and floor and façade insulation, and installation of solar panels.

Fifty five percent of the database implemented one of the above retrofit packages. The remainder of the database implemented only one measure, such as roof insulation. The authors believed that an approach that used just one measure constituted a shallow energy renovation with slight or marginal benefits. For a retrofit to be impactful, a package should provide several measures that work in tandem to achieve a much warmer and energy-efficient home. Unfortunately, the database was no longer accessible at the time of writing this report.

Cost-Benefit Analysis of regional programmes

Electricité de France (EDF) published a CBA of two regional deep retrofit programmes in France (Raynaud, Osso, & Marteau, 2018). The analysis also informed the STUNNING project report. To set the scene, at the time of publication France had set itself the target of energy retrofitting 500,000 homes per year, retrofitting all private residential buildings with yearly energy consumption above 330 kWh/m^2/yr by 2025, and having a fully retrofitted building stock to low-consumption standards by 2050. EDF stated that the most effective renovations cost $40,932 (in 2018 prices); however, most retrofits occurring at the time hovered around the price tag of $16,372. This signalled that most retrofits did not go far enough to meet France's home energy reduction targets. EDF conducted their analysis to test what indicated an efficient and well used retrofit programme.

The two projects which EDF assessed took place in the same region in eastern France, in separate territories. One territory was urban, and used for the 'I Renovate Low Consumption Buildings' programme (Project 1). The other territory was rural, and used for the 'Low-Consumption Renovation' programme (Project 2). Households in both territories could also receive financial incentives for home retrofits, such as interest-free loans and tax credits.

Project 1: I Renovate Low Consumption Buildings. Sample size: 25 pre-retrofits and 37 post-retrofits. 14 households belonged to both samples. The following measures were included:

- Onsite visit for retrofit recommendations.
- At least two or three measures relating to the thermal envelope: roof (93 percent of houses); walls (93 percent of houses); floors (83 percent of houses); glazing (81 percent of houses).
- Installation of Controlled Mechanical Ventilation (CMV) system.
- Change of heating system (63 percent of homes).
- Air leak test for 84 percent of operations.
- Financial incentives including 50 percent of project management costs capped at $4,912, 70 percent of work costs capped at $16,372, and stipend of $2,500 for an air tightness test. The incentives were provided by the regional government and EDF (Raynaud, Osso, & Marteau, 2018).

Project 2: Low-Consumption Renovation. Sample size: 31 pre-retrofit and 46 post-retrofits. 31 houses belonged to both samples. The following measures were included:

- Thermal diagnosis of the property.
- Qualified craftsmen and contractors were clustered to deliver retrofit project.
- Most projects were focused on the insulation of walls, attics, and sometimes the floor; installation of glazed windows, installation of CMV, and change of the heating system of 45 percent of homes.
- Site handover with air-tightness test.
- Support from a business manager throughout the project.
- Cumulative financial assistance from $330 to $7000 from EDF, depending on measures (Raynaud, Osso, & Marteau, 2018).

The limits to EDF's CBA were that due to variability of prices at the time, benefits were estimated on energy used, not actual money saved from energy used. Another limit was the relatively small sample size, particularly for houses which were assessed pre- and post-retrofit. The following differences between the projects were noted:

- Works in Project 1 were carried out systematically, but in smaller numbers than Project 2.
- Works in Project 1 had 17 percent higher insulation levels than Project 2
- Project 1 had more expensive roof insulation than Project 2
- There was slightly more efficient glazing in Project 1 than Project 2 (Raynaud, Osso, & Marteau, 2018).

Analysis:

Project 1 saw an average total consumption of 216 kWh/(m^2/year) before retrofit, and 127 kWh/(m^2/year) after works, a 41 percent reduction of energy used, or 89 kWh/m^2 per year. Average savings per surveyed households were 83 kWh/m^2, which suggested there was minimal bias on the sampled households. The average price of this project's retrofits was $91,687, with a minimum price of $27,833 and maximum price of $148,992. The average price per square metre was $679 (median $672).

Project 2 saw average total consumption of 218 kWh/(m^2/year) before retrofits reduce to an average of 155 kWh/(m^2/year) after the retrofit. This was a 29 percent reduction of energy used, or 63 kWh/m^2 per year. Surveyed households reported saving 72 kWh/(m^2/year) which was also close enough to the average amount of energy saved to assume minimal bias. The average price of retrofits, disregarding tax and financial aid, was $54,000, with a minimum price of $9,823 and a maximum of $121,158. The average price per square metre was $474 (median $442).

While Project 2 exhibited lower upfront costs, Project 1 resulted in a higher net energy saving than Project 2. Project 1 also used more environmentally sustainable materials, and the inclusion of an on-site project manager helped to improve acceptability and quality of retrofit implementation. An important thing to note is that participants in Project 1 had higher incomes than those in Project 2. Higher incomes meant they could afford higher-quality materials, and this drove the cost of the project (Raynaud, Osso, & Marteau, 2018).

2.3.5 Netherlands

Energiesprong model

The Netherlands was the birthplace of quite a popular programme in building circles, Energiesprong ("Energy Leap" in English). The programme has been replicated in the U.K, France, Germany, and parts of the United States. Energiesprong began as a programme called Stroomversnelling, which was a deal between building contractors and housing associations to retrofit 111,000 homes to "Net Zero" energy requirements.

Energiesprong was structured to use money that would usually be spent on energy bills and maintenance to pay for a retrofit project, so that the occupants were no worse off financially and they would still receive the comfort benefits of a warmer home. Retrofits were paid for by housing associations, and then households repaid this cost over the next 30 years through their energy bills. Typically, legislation must be changed in the host country in order to change the monthly energy bill of a home into a monthly service fee to accommodate a repayment plan. Any energy use that went above old levels was billed as normal (Energiesprong, 2019).

The key factor for Energiesprong's success was scale. The selling point was that retrofits could be supplied and completed quickly and cheaply. Demand for retrofits must be generated, then policy and regulation, banks, contractors, and suppliers must be coordinated to create a viable path to scale. Funding from other sources, such as local councils and sustainability trusts, was also useful in making the programme affordable (Energiesprong, 2019).

The Energiesprong style of retrofit involved a full-house upgrade including a thermally efficient façade (usually constructed in bulk off-site) and a solar roof system.

Nottingham Energiesprong

The Nottingham City Council was the first authority in the U.K. to trial an Energiesprong approach to retrofits. The Energiesprong approach was used under the Deep Energy Retrofit Energy Model as a scalable demonstration project with an end target of 400 homes retrofitted by the end of the pilot. 155 homes across Nottingham were granted approval for the project in 2017. The total cost of the 155 retrofits was estimated to have been $21.3 million (Energy Hub, 2020). The average price per house was $139,000, when the scale was small (around 100 homes). For 4,000 homes, the average price was forecast to be $94,500 per home.

Expected energy demand savings were estimated to be around 70 percent reduction of thermal energy use through insulation and heat recovery, and 15 percent reduction of electricity demand in lighting and appliances changes (Energiesprong, 2017).

There is very little information on post Energiesprong project evaluation, and therefore whether the actual results of large scale Energiesprong retrofits matched projected savings. The Nottingham Energiesprong project received some negative press when occupants complained that they were paying significantly more for their energy post-retrofit (Hennessy, 2021).

2.3.6 Canada

Greener Homes Initiative

Canada offers a retrofit grant and loan programme, the Canada Greener Homes Initiative. The grant has been available since May 2021, and the loan programme was launched in June 2022. The states of Nova Scotia and Quebec have their own provincial programmes which are partnered with the Greener Homes Initiative. The grant ranges from $155 to $6,234 for retrofits, and offers up to $750 for a home energy evaluation. The unsecured loan ranges from $6,234 to $49,878, over a 10-year interest-free term. The loan finances eligible low emission retrofit products, and the homeowner must have completed a pre-retrofit evaluation from an energy adviser to be approved.

Combined, the programme allows homeowners to access $56,113 of capital to retrofit their home. There are special provisions for Indigenous groups which allow them to register multiple homes, while for non-Indigenous homeowners, their house must be their primary residence.

The total value of the grant programme was valued at $3.4 billion, which equates to approximately 700,000 grants on offer for Canadian households (Government of Canada, 2022).

As of June 2022, there were over 171 applications to the programme. $49.3 million of grants have been awarded to 10,300 homeowners, which represented 75 percent of all homeowners who had completed their retrofits. The most popular intervention has been the installation of heat pumps, followed by energy efficient windows and doors, attic insulation, and solar panels.

The Greater Toronto Area leads with the most applicants (31,063), followed by Calgary (13,470) and Ottawa (8,891).

As was the case for Ireland, this programme has limited data on the success of its loan programme due to its recent implementation.

Local programmes – Property Assessed Clean Energy (PACE) Atlantic Programme

A product on offer for Canadians in select states and municipalities is the Portfolio Administrators of Property Assessed Clean Energy (PACE) Programme. The PACE Atlantic Community Interest Corporation, based in Halifax, Nova Scotia, has seen sizeable success.

PACE programmes lend homeowners capital for energy-efficiency upgrades through low-interest, long-term loans secured against the property, and paid back through the municipalities' property tax system (i.e. rates bill) (Saxe, 2021). PACE expects the utility savings from higher efficiency to make the loan cost neutral for the homeowner. Because the loan is tied to the property, when the house is sold the loan is paid back, or the loan stays attached to the property for the next owners to pay off.

PACE Atlantic works as a third-party administrator to handle energy-saving upgrades for households, which can channel funding from private and public sources. PACE programmes require changes to legislature to enable their funding model, which requires the securitisation of the homeowner's house against the loan, usually with priority to the mortgage if there is one (DBRS Morningstar, 2022).

According to their website, PACE Atlantic has provided $13 million in capital investments, and reduced 2,242 tons of greenhouse gas emissions (PACE Atlantic, 2022). However, the PACE model is not without its issues. Section 3.6.3 discusses the problems which arose with PACE programmes in the US.

2.3.7 United States of America

Weatherisation Assistance Program and Whole-House Rebate (HOMES) program

The Weatherisation Assistance Program (WAP) is delivered by the U.S. Department of Energy (DoE) to support low-income households with improving the energy efficiency of their homes. The programme uses state-based teams utilising computer-based energy assessments. Data is sourced from initial analysis which uses blower doors, manometers, and infrared cameras to create an energy analysis and forecast of a home. The analysis determines the most cost-effective methods to improve energy efficiency. The team creates a customised work order to supply the measures, for example insulation and window upgrades, through trained crews. After installation, the final product is inspected for quality control (U.S. Department of Energy, 2022b).

According to figures provided by the DoE in 2022, the programme supplied the following values:

- Annual households targeted: 35,000
- Average weatherisation cost per household unit $7,700, consisting of:
  - 10 percent administration costs
  - 15 percent health and safety costs
  - 55 percent operations costs
  - 20 percent training costs
- Jobs supported: 8,500
- Annual energy costs savings per household: $609 p.a., consisting of:

- 18 percent heating consumption savings
- 7 percent electric consumption savings

- For every $1 invested in the programme, $1.72 energy benefits were generated, and $2.78 non-energy benefits, such as health, were generated (U.S. Department of Energy, 2022b).

In 2019, utility companies and states supplemented DoE funding by an additional $1.38 billion which more than tripled the total invested by DoE (approx. $455 million for that year).

Whole-House Rebate (HOMES) program

Households can currently receive a tax credit to cover up to 10 percent of the cost of insulation materials and other energy efficiency improvements, and an additional $491 credit for purchasing efficient heating equipment such as a heat pump. Rebates are supplied by the DoE, which calculates the potential energy savings from the retrofits.

Inflation Reduction Act

The Inflation Reduction Act was announced by the Biden administration in 2022. The Act announced nearly $14.7 billion to be available for states and Native American Tribal Authorities for consumer home energy rebate programmes (U.S. Department of Energy, 2022a). The intention of the rebate programme is to allow low-income households to afford efficient appliances and energy efficient retrofits. The amounts will include:

- Rebates for energy performance-based retrofits ranging from $3,300 to $6,500 for individual households, and up to $655,000 for multifamily buildings, such as apartment blocks.
- Grants for state authorities to provide rebates for retrofits:
  - Up to $3,300 for retrofits that will reduce modelled energy use by 20 percent or more
  - Up to $6,500 for retrofits that will reduce modelled energy use by 35 percent or more
- $369 million allocated for Native American Tribal Authorities to deliver energy-saving measures to areas with a low median income.

A significant risk to the programme's expected scope is the intention to investigate basing rebates on actual energy savings (Wojick, 2022). As has been observed in Aotearoa New Zealand and overseas (Grimes and Preval, 2020), the take-back effect of retrofits and energy appliances can result in minimal actual energy savings due to behaviour changes post retrofit. As a result, households may face uncertainty as to how much rebate they may receive. As a result, trust in the HOMES rebate programme may reduce if households do not receive as much rebate as they expected (Wojick, 2022).

R-PACE US

R-PACE US is the residential arm of the PACE programme in the U.S. As in Canada, the programme functions by supplying cheap and easy capital, secured to the property, to homeowners to deliver energy-efficiency measures (Federal Housing Finance Agency, 2010). The loan is paid back incrementally through the house's tax (rates) bill. Rather than focus on benefits and costs associated with this programme, R-PACE offers more valuable insight into how loan-funded programmes may result in exposing low-income households to significant financial risk.

In 2010, the Federal Housing Finance Authority (FHFA) released a statement on “Certain Energy Retrofit Loan Programs” which identified that PACE loans posed risks to lenders and secondary market entities, as PACE loans were granted on a collateral basis, not on an ability to pay basis. PACE loans were attached to the debtor’s property, often as first lien, which meant that if the debtor defaulted on the loan, their mortgagee would not receive the full value of the property back. This would put the homeowner at risk of bankruptcy. The FHFA was particularly sensitive to such situations in the wake of the 2008-2009 financial crisis only a year before they issued the statement.

The FHFA opened feedback in 2020 on their proposal to reduce loan-to-value (LTV) ratios in states or communities where PACE is available. The feedback from community advocacy organisations indicates that risk posed by PACE to low-income households is still a concern, and even though reduced LTV ratios would reduce risk somewhat on PACE loan takers, a reduced LTV ratio would harm other households that did not take PACE loans (National Consumer Law Center, 2020).

Another aspect of PACE that was causing an issue was the delay in reflecting loan repayments on tax bills. Because of administration delays to load the repayments onto the bills, households would not see the repayment on their bill for several months. By the time the repayment appeared it reflected months’ of arrears, which low-income households were often not prepared for, and would result in a rapid default (National Consumer Law Center, 2020). The National Consumer Law Center (2020) also identified further issues such as loan stacking to avoid LTV ratios by PACE contractors, and misleading sales tactics incorrectly setting expectations about how much repayments would be.

3 Lessons

This section outlines the key lessons that can be drawn from the common themes across the international retrofit programme examples.

3.2.1 Retrofits must be affordable and low risk for households, homeowners, and organisations

The most significant barrier to homeowners improving their home's energy use is cost. A retrofit programme must make clear economic sense (i.e. close to cost-neutral) for homeowners to sign up for the programme, whether the funding vehicle is a grant, low-interest loan, or energy service repayment fee. However, securitisation of houses to retrofit loans must be treated with caution.

Vulnerable households are often not able to take on more debt, and if they are unable to make repayments, defaults can spiral into bankruptcy, as observed with R-PACE in the US. Low-income households should be prioritised for grants rather than loans, and if they do receive loans, the capital should not be securitised against their house. A government guarantee on retrofit loans might help to make lenders more comfortable providing unsecured low-interest loans.

Landlords and organisations that own multiple homes will likely have their own needs when considering retrofits. Programme information channels should be clear and open with these stakeholders to ensure the final product is usable and feasible for portfolios with many dwellings.

3.2.2 Retrofit programmes must involve a simple process for participants

Knowledge has been identified in both Ireland and Aotearoa New Zealand as a barrier to homeowners retrofitting. If an owner has the perception that a retrofit is complex, time consuming, and expensive, they are unlikely to engage with the programme even if it addresses these problems for them. Eligibility should be clear, and timeframes well-communicated. One-stop shops provide the most effective solution for simplifying the process, out of all the archetypes, as homeowners only have to interact with a single point of contact.

3.2.3 A new heater is not enough

A critical aspect of making a home warm is heat retention. If only a new heating system is installed in a draught-prone and uninsulated home, the residents will still be wasting heat no matter where it is coming from. If a house can contain heat, it will require less use of a heater. Energy saving is important, but what impacts people the most is the improvement to comfort and wellbeing from living in a warm home. Installation of insulation and improving airtightness should be a priority.

3.2.4 Households have different financing needs

Not all households are in the same situation. Aotearoa New Zealand has a significant population of renters and owner-occupiers who live in energy poverty. Landlords might not have the capital or the capability to meaningfully improve their properties. A programme which only targets homeowners who reside in their homes (such as Canada's programme) would exclude renters from the benefits of a warm home and would therefore be inequitable. Regardless of if a resident owns the home or not, there should be a way for their house to be retrofitted.

It is not realistic for the government to cover the full costs of retrofits for all homeowners. International examples have shown that funding full or most of the costs should be prioritised for homeowners who are unable to pay for works. For those with a higher ability to pay, a low interest loan can help encourage work to get over the line. Including project management into the grant and finance service will probably increase the uptake of the programme, but will increase the cost to government and loan-takers.

There should be a vehicle available for Māori to access retrofits, provided by Māori. As a key recommendation from the MAIHI Ka Ora project, it will be of utmost importance that Māori are able to access a retrofit programme through organisations and processes which recognise their values and needs.

3.2.5 Energy savings are only a fraction of the total benefit

Evidence from Aotearoa New Zealand and overseas indicates that actual energy savings vary after a retrofit, and take-back effects apply additional uncertainty as to whether net national energy savings will be produced by a retrofit programme. This does not mean retrofit programmes are unsuccessful. There is ample evidence that retrofits improve wellbeing and health outcomes for occupants and therefore provide value not just to individuals but the country as a whole through total health savings and productivity gains. However, these outcomes are less visible to policy makers and evaluators than electricity use.

Caution must be taken if success indicators for a retrofit programme only consider energy savings and CO_2 emissions. A programme's worth comes from its impact on households' total wellbeing, not just their expenditure on electricity.

3.2.6 Project management influences cost and uptake

Arranging and managing a retrofit is costly in time, skill, and risk. Homeowners may be tempted to save costs by managing a retrofit themselves but if they lack the necessary skills and knowledge the retrofit may not be fit for purpose, or it may balloon in costs due to rework. Including an experienced intermediary reduces the risk of a retrofit failing, but this contributes significantly to the cost of a retrofit project. Homeowners may be reluctant to participate in a programme if it requires too much management on their part, or they might not engage if the intermediary is not trusted.

A significant aspect of the Ireland National Retrofit Plan and PACE schemes is ensuring the steady supply of energy advisors to aid in the delivery of retrofit projects. In a similar fashion, a programme in Aotearoa New Zealand should ensure that there is an adequate training pipeline for project managers and construction workers/builders to deliver the scale and quality of retrofits needed. A bonus of an ongoing retrofit programme is the signal to workers and investors that the construction demand will be constant, rather than an up-and-down cycle of activity.

3.2.7 Behavioural and monitoring mechanisms, for example Energy Performance Certificates, could be explored.

Ireland's National Retrofit Plan is the most ambitious, and comprehensive, of all the programmes that were analysed. What has determined the targeting of the plan, and what will measure its success, is the number of homes below a BER rating of B2, and how many move from low ratings (F and G) to high (B2 and above). The BER allowed projects completed through the pilot retrofit programme to be compared to projects completed through existing programmes, which justified the ambition of the National Retrofit Plan. The BER also provides clear information to central and local authorities as to where the highest concentration of houses in poor condition are, and crucially, if a programme is not meeting its targets. As was observed with the Green Deal, implementing a retrofit programme with few or inadequate measures to monitor success can be a driver of policy failure.

The introduction of Energy Performance Certificates across Aotearoa New Zealand's entire residential building stock would be time-consuming and costly to implement, although the government has signalled EPCs are on the cards as a policy tool (MfE, 2022a). There is evidence that EPCs have not reflected the actual energy use of households in Ireland (Coyne & Denny, 2021). EPCs reflect the energy condition of a house, but the behavioural drivers behind energy use mean, that due to take-back effects and suppressed demand, an efficient EPC rating might not equal a household that uses energy efficiently (Coyne and Denny, 2021). EPCs should therefore be considered as one of many indicators for retrofit programme success. For instance, tracking how many homes move from a low to a high EPC rating after the introduction of a programme, by neighbourhood or region.

3.2.8 Trust is key

Uptake will make or break the programme. The Kirklees Warm Zone showed that large-scale retrofits can be done, and approaching implementation on a targeted neighbourhood basis helps build trust because the neighbours can see results for themselves. However, such large-scale programmes can have unintended consequences on the building market, and can create a divide between approved and unapproved contractors. Unapproved contractors taking advantage of a retrofit programme by pretending to be official was an issue on the Kirklees project, and warnings on the Canadian Green Building Portal indicated that such incidents have occurred during their programme as well. Clear targets and visible branding can help build recognition and momentum in trust.

3.2.9 Programmes must be robust to changes in government and government policy

A retrofit programme's scope is across decades, not years. Elected officials tend to view things in a shorter time-frame, typically in Aotearoa New Zealand's three-year election cycles. Part of the failure of the Green Deal was that it was vulnerable to changes in government, so suppliers were not confident the programme would be reliable for long term plans. In order for homeowners, financers, and suppliers to engage with the programme, there must be certainty that the programme will deliver on its goals over a defined number of years. This will require a commitment from organisations to set targets and meet them, and make changes if targets are not met. Expectations must be clear and consistent to avoid feast or famine cycles in retrofit deliveries.

3.2.10 A pilot deep retrofit programme will add value

The following section describes what a retrofit package might cost and mean for Aotearoa New Zealand's economy. However, the numbers were based on estimates and cannot account for the unforeseen realities of delivering large scale retrofits en-masse. What gave the Ireland National Retrofit Plan traction and promise was the lessons learned from the pilot retrofit programme delivered by SEAI from 2017 to 2019. Given the lack of comprehensive retrofit programmes in Aotearoa New Zealand, a pilot programme would provide lessons specific to the country, and would familiarise the idea of a retrofit plan with the public and politicians.

4 Estimating scope and cost of retrofit programme scenarios

The previous sections have outlined the context for improving Aotearoa New Zealand's building stock, common retrofit typologies, and examples of overseas schemes and programmes which have attempted to deliver retrofits to many households.

The next piece of the puzzle was to identify what impact a retrofit programme would have in Aotearoa New Zealand. Framing impact required identifying how many houses would need to be targeted, and how deeply they should be retrofitted in each region of Aotearoa New Zealand. Rather than estimating the future health or energy benefits from retrofits on an aggregated household level, on which work has already been completed, this section forecasts what impacts could be expected across Aotearoa New Zealand's economy if an ambitious retrofit programme was introduced and implemented up until 2050. The scenarios outlined in this section do not detail if the funding is derived from public or private funds, and whether there are other policies alongside the programme. The intention of these scenarios is to discern what the potential impact would be if the Aotearoa New Zealand economy was shocked by a retrofit wave, of varying magnitudes.

High prices were used in these scenarios to reflect potential maximum prices, and to cover unforeseen material cost increases, and unexpected complexity. Retrofit projects could be delivered at lower cost than the "medium" scenarios outlined in this section. In saying this, the "deep" costs outlined in this section are close to prices observed in the Ireland retrofit examples (averaging around $98,000 for poor to excellent).

From this approach, BERL estimated how the construction and related industries across Aotearoa New Zealand would be affected by a large retrofit programme. To estimate the effects of large national shocks to the economy a CGE model was used. A CGE model predicts how different sectors across an economy would adjust their spending and production when spending changes significantly in one or more sectors (i.e. the shock). Before the CGE model could be shocked, the magnitude of the shock had to be estimated. In other words, it was necessary to calculate the total investment of a retrofit programme.

4.2.1 Scope of potential retrofit programmes

The international examples described in Section 3 targeted a significant proportion of local housing stock. To analyse an ambitious programme in New Zealand BERL estimated the number, location, and typology of poor-quality houses that would need to be targeted. Then, using 2022 construction cost data provided by eCubed[2], the costs of retrofits at a deep and medium level were estimated for each housing type, in each region of New Zealand. This methodology allowed the overall national cost of deep and medium level retrofits to be estimated as a lump sum in 2022 prices.

Estimating the number of homes to be targeted

Because there is no granular data source that measures the individual energy performance or quality of New Zealand homes, such as an EPC or BER, the number of homes that reported the existence of mould and/or damp in the 2018 Census was used as a qualifier of a home exhibiting poor energy performance, and therefore likely to be in need of a retrofit. The number of homes exhibiting mould and/or damp was then arranged by deprivation area to identify homes which were

[2] Courtesy of NZGBC, from an upcoming report to be released in 2023 in collaboration with Concept consulting and Dr. Michael Jack, University of Otago. The report conducts a CBA into finding the cost optimal retrofit package for the four housing typologies. eCubed's website can be found here: https://www.e3bw.co.nz/

likely to operating in energy poverty conditions. The proportion of home typologies, namely bungalow, State house, pre-1970s house, and post-1978 house, was applied to the number of homes in each region. These typology estimates were drawn from Ryan, Burgess, and Easton (2008) to be consistent with eCubed's costing methodology.

Estimating the costs for deep and medium retrofits

This methodology allowed the number of homes in need of a retrofit, and those in need of a retrofit in places of high deprivation, to be estimated for each district in New Zealand. Understanding where these homes were located helped to estimate where costs were likely to be concentrated.

The two retrofit packages were defined as deep and medium, and were based on eCubed cost estimations from 2022 prices observed in the Aotearoa New Zealand building and construction market.

The deep retrofit package involved choosing the most expensive option for each housing typology and included roof, floor, and wall improvements, and draught stopping. Total annual energy savings per specific measure were not known at the time of analysis, so it was assumed that the most expensive option would provide above-code results, and that the medium cost option would provide at least to-code results. The intention of these estimates was to provide a high-price and medium price estimates for total investment from retrofitting a large number of houses across Aotearoa New Zealand.

Bungalow

Deep option

- Wall: insulated wall lining, $33,080
- Floor: slab edge insulation and skirt, $11,960
- Windows: full window replacement (double glazed, low-e, thermally broken), $17,865
- Roof: insulated ceiling lining/insulated plaster board, $22,330
- Draught stopping: weather stripping doors and windows, $897
- Total: $86,132.

Medium option

- Wall: drill and fill wall insulation, installed from outside or inside, $13,710
- Floor: underfloor insulation sections / friction fit semi-rigid insulation, $3,190
- Windows: double glazing retrofit into existing frames, $12,600
- Roof: warm roof, $17,420
- Draught stopping: caulking of visible gaps and services penetrations, $616
- Total: $47,536.

State house

Deep option

- Wall: exterior wall insulation (exterior cladding boards), $31,500

- Floor: slab edge insulation and skirt, $11,700
- Windows: full window replacement (double glazed, low-e, thermally broken), $10,893
- Roof: insulated ceiling lining/insulated plaster board: $19,058
- Draught stopping: caulking of visible gaps and services penetrations, $616
- Total: $73,767.

Medium option

- Wall: drill and fill wall insulation, installed from outside or inside, $13,450
- Floor: underfloor insulation sections / friction fit semi-rigid insulation, $2,723
- Windows: double glazing retrofit into existing frames, $7,700
- Roof: warm roof, $14,820
- Draught stopping: weather stripping doors and windows, $598
- Total: $39,291.

Pre-1970s house

Deep option

- Wall: insulated wall lining, $31,717
- Floor: slab edge insulation and skirt, $11,440
- Windows: full window replacement (double glazed, low-e, thermally broken), $25,735
- Roof: insulated ceiling lining/insulated plaster board, $16,583
- Draught stopping: weather stripping doors and windows, $897
- Total: $86,372.

Medium option

- Wall: drill and fill wall insulation, installed from outside or inside, $12,070
- Floor: underfloor insulation sections / friction fit semi-rigid insulation, $2,450
- Windows: double glazing retrofit into existing frames, $18,200
- Roof: warm roof, $12,870
- Draught stopping: caulking of visible gaps and services penetrations, $616
- Total: $46,206.

Post-1978 house

Deep option

- Wall: insulated wall lining, $33,175
- Floor: slab edge insulation and skirt, $15,600
- Windows: full window replacement (double glazed, low-e, thermally broken), $33,548

- Roof: insulated ceiling lining, $30,800
- Draught stopping: weather stripping doors and windows, $1,859
- Total: $114,982.

Medium option

- Wall: drill and fill wall insulation, installed from outside or inside, $14,260
- Floor: underfloor insulation sections / friction fit semi-rigid insulation, $4,400
- Windows: double glazing retrofit into existing frames, $23,100
- Roof: warm roof, $4,480
- Draught stopping: caulking of visible gaps and services penetrations, $932
- Total: $47,172.

Most pricings assumed an R-value of 2.4 for wall insulation, and 3.2 for roof insulation. Usually, the most optimal R-value for walls is 2.8 from glass-wool insulation installed into cavities behind wall plaster board. The report to be released by eCubed and Concept Consulting later in 2023 aims to provide cost-optimal pricing packages for different energy efficiency ratings in Aotearoa New Zealand.

The numbers imply that the medium retrofit options were not shallow measures. Both deep and medium retrofit packages would deliver a whole-house approach to improving heat retention. Heating systems, for example heat pumps, are not included in these retrofit packages.

From these costs, BERL was able to estimate the amount that would be needed to address the number of each housing type in each region of Aotearoa New Zealand. In addition to the above costs, preliminary costs (12 percent), contingency costs (10 percent), and margins (10 percent) were added. These costs are consistent with pricing practice outlined in Deloitte's (2018) report[3] on the cost of building materials for Fletcher Building Limited:

- Margins: added cost of contractor or manager on top of works
- Contingency: added costs allowing for unforeseen circumstances
- Preliminary: costs for consents, levies, development contributions, insurance, temporary services, and some site preparation (Deloitte, 2018).

Finally, an administration cost of 4.2 percent, drawn from the administration costs of Warmer Kiwi Homes as a proportion of total insulation and heater grants delivered, was added to produce a grand total for each region. EECA operating costs would also be likely to increase. However, this amount could not be estimated as it was unknown how resources within EECA would be reallocated if a new retrofit programme were to replace Warmer Kiwi Homes.

Costs were applied to the number of houses in three scenarios:

- The first scenario provided deep retrofits to all houses that exhibited mould and/or damp in 2018
- The second scenario provided medium retrofits to the same number of houses

[3] The Deloitte report was predominantly focused on the cost of materials for new buildings.

- The third scenario provided deep retrofits to houses in deprivation areas ranked seven to ten, while the remaining houses in one to six deprivation areas would be provided with medium retrofits.

The total national costs for the scenarios are produced in Table 4.1. The following sections examined the totals by region. The scenarios produced a maximum deep retrofit total cost of approximately $58 billion, and a medium retrofit total cost of $27 billion. A mixture of deep and medium produced a total cost of approximately $42 billion. The total number of houses that would be targeted in all scenarios was 426,255, approximately 24 percent of Aotearoa New Zealand's housing stock. For comparison, Ireland's National Retrofit plan targets 500,000 homes, which is also 24 percent of Ireland's housing stock (approximately 2.1 million homes), at an estimated cost of $49 billion. Therefore, these total costs were not unreasonably small or large, given the additional allowances (approximately 36 percent) made for contingencies, preliminaries, margins, and administration costs.

Table 4.1 - Retrofit scenarios, total costs

Total all regions	Dep Index 7 to 10: Total households	Dep Index 7 to 10: Households with mould and/or dampness	Rest of Dep Index: Total households	Rest of Dep Index: Households with mould and/or dampness	All: Households with mould and/or dampness	Retrofit scenarios ($m): Deep retrofit all houses with mould and/or dampness	Retrofit scenarios ($m): Medium retrofit all houses with mould and/or dampness	Retrofit scenarios ($m): Deep retrofit Dep 7 to 10 with mould /dampness; medium retrofit rest with mould/dampness
Bungalow	56,384	17,732	89,247	18,953	36,684	3,160	1,744	2,428
State House	147,664	47,622	222,114	47,984	95,607	7,053	3,756	5,398
1970s house	96,511	31,086	146,619	31,364	62,452	5,394	2,886	4,134
Post 1978	354,336	115,625	540,629	115,886	231,512	26,620	10,921	18,761
Total	654,895	212,065	998,609	214,187	426,255	42,226	19,307	30,722
Total plus preliminary, contingencies, and margin costs						55,738	25,485	40,553
Admin costs						2,340	1,070	1,702
Grand total						58,078	26,555	42,255

5 Economic impact of retrofit scenarios

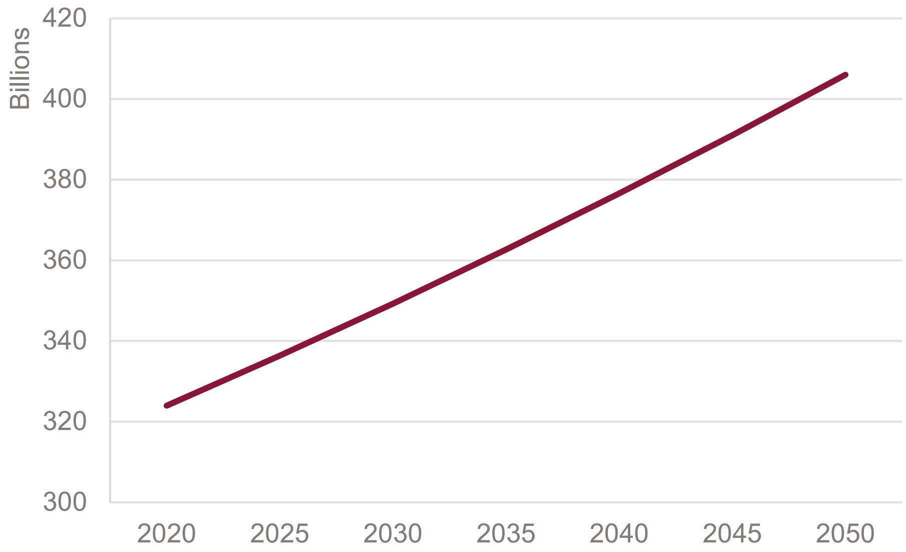
5.2 Scenario summary

5.2.1 Base case (business as usual)

5.2.1.1 A gently growing economy out to 2050

BERL designed a base case for the Aotearoa New Zealand economy to describe what could happen between 2020 (the model's starting point) and 2050 (the end point of the scenarios). For this exercise, BERL predicted a gently growing economy that would experience 25.3 percent total growth (0.75 percent per annum). While not explicit, this overall gentle growth is consistent with periods of rapid growth followed by periods of shrinking (recessions).

Figure 5.1 Real GDP business as usual, 2020 – 2050



5.2.1.2 Demographic changes create the slowing

Assumptions about demographics in the base case created most of the slowing in the scenario. The labour supply grows by about 26 percent over the 30 years modelled, while the aged population (those receiving Superannuation) grows by 33.6 percent. The number of households grows by a modest 15.3 percent. Labour demand follows GDP and grows by 25.7 percent in total. The unemployment rate grows by 0.077 percent in total, which will change the reported unemployment rate from 3 percent to 4.1 percent.

Table 5.1 Demographic variable changes, base case, 2020 - 2050

	% Change between 2020 and 2050
Labour supply	26.0
NZ Superannuation population	33.6
Number of households	15.3
Labour demand	25.7
Unemployment rate	0.077 (from 3% to 4.1%)

5.2.2 A shift in consumption

Retrofitting houses makes them more energy efficient which lowers the average spend on electricity. BERL calculated that average household spending on electricity will be around 2.9 percent lower than in the base scenario, which implies a decrease in total household consumption of about 0.03 percent. This calculation is summarised in Table 5.2

Table 5.2 Calculating the decrease in electricity spend

Measure	Source	Unit	Value
Number households	Statistics New Zealand	Number	1,794,800
Number retrofit	BERL	Number	426,253
% Retrofit	Calculated	%	23.749
Total kWh New Zealand	EECA	kWh	8,492
Total kWh saved	Ireland Deep retrofit Pilot Programme	kWh	365
% Energy savings	Calculated	%	4.298
Household spend	Statistics New Zealand	$	1,261
Electricity spend	Statistics New Zealand	$	36.9
Electricity % of household spend	Calculated	%	2.926
% Total consumption lower	Calculated	%	0.030

5.2.3 Scenario 1 - Deep retro all mould and/or damp

This scenario is described by the third to last column in Table 4.1 which is reproduced below. In this scenario, the total cost of the retrofit programme is $55.7 billion over the 30 years of the programme, with the administration cost added the grand total cost is $58.1 billion.

Table 5.3 Total retrofit cost - Scenario 1

Total all regions	$m
Bungalow	3,160
State House	7,053
1970s house	5,394
Post 1978	26,620
Total	42,226
Total plus preliminary, contingencies, and margin costs	**55,738**
Admin costs	2,340
Grand total	**58,078**

5.2.4 Scenario 2 - Medium retro all mould and/or damp

This scenario is also described in Table 4.1 and reproduced below. In this scenario, the total cost of the retrofit programme is $25.5 billion over the 30-year timeframe, with the administration cost added the grand total cost is $27.6 billion.

Table 5.4 Total retrofit cost - Scenario 2

Total all regions	$m
Bungalow	1,744
State House	3,756
1970s house	2,886
Post 1978	10,921
Total	19,307
Total plus preliminary, contingencies, and margin costs	**25,485**
Admin costs	1,070
Grand total	**26,555**

5.2.5 Scenario 3 - Deep retro high dep mould and/or damp, medium retro rest mould and/or damp

Similarly, this scenario is described Table 4.1 and reproduced below. In this scenario, the total cost of the retrofit programme is $40.6 billion over 30 years, with the administration cost added the grand total cost is $42.3 billion.

Table 5.5 Total retrofit cost - Scenario 3

Total all regions	$m
Bungalow	2,428
State House	5,398
1970s house	4,134
Post 1978	18,761
Total	30,722
Total plus preliminary, contingencies, and margin costs	**40,553**
Admin costs	1,702
Grand total	**42,255**

5.3 High level results

5.3.1 Gross Domestic Product (GDP)

CGE modelling is complex. A crucial concept of CGE modelling is the idea of a *general equilibrium.* In economics it is often reasoned through a change in the economy in terms of a partial equilibrium. A retrofit programme can be assumed to cause an increase in spending in the construction industry. If only construction is allowed to respond to the retrofit programme, then it is correct to say that GDP, employment, and the economy in general will increase. However, through a new *general equilibrium,* all sectors are allowed to respond to the change, and to respond to each other. This is explained further in Section 5.4 and Appendix A.

In the case of this retrofit programme, BERL modelled an increase in the size of the construction industry from the new spend. This is combined with a decrease in overall consumer spending because retrofitted houses use less electricity, as estimated from the Ireland retrofit pilot study.[4]

When the demand for residential construction was shifted upwards by the retrofit programme, it caused the following flow on effects in the CGE model (in no order):

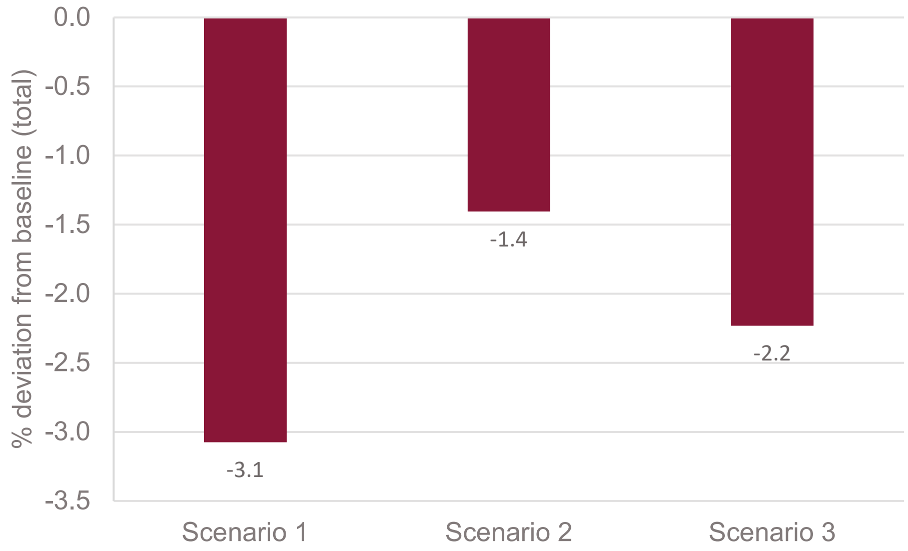
- All other industries reduce output domestically
- Exporting industries reduce exports (note that construction cannot be exported by assumption)
- Prices of all goods increase (except housing)
- Investment in all industries (other than those who supply to construction) falls
- Export prices rise.

The combination of all these shifts causes the measure of GDP to be lower than what might otherwise be expected. It is complex to say definitively but it is likely that the shift downwards in exports is the primary driving force behind the overall decrease in GDP.

The CGE modelling shows that in Scenario 1, GDP in 2050 will be around 3.1 percent lower than it would be in the base case. In Scenario 2, GDP will be 1.4 percent lower.

It should be emphasised that although the effect on GDP from the retrofit programme appears to be negative, the programme will have positive impacts on health and wellbeing. Additionally, the economic impact on household incomes is positive, as we detail below.

Figure 5.2 Real GDP deviation from baseline (total)



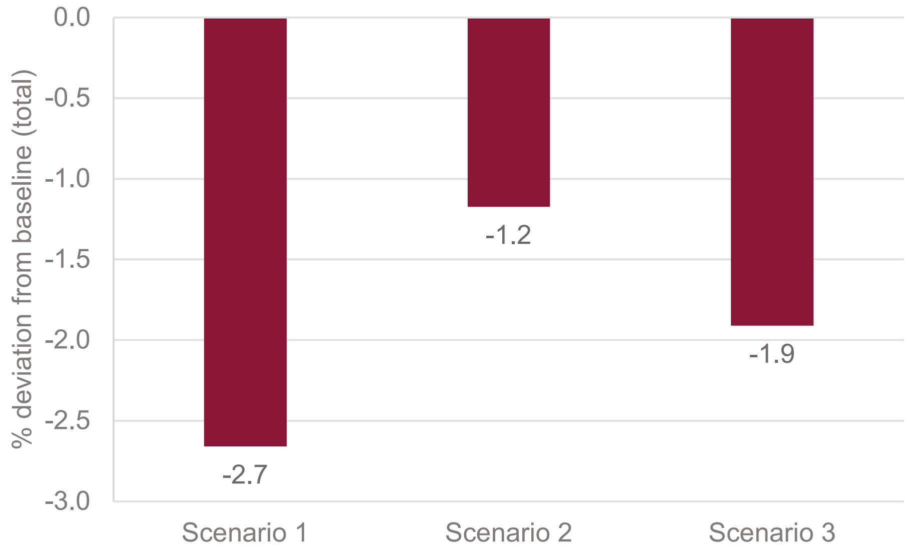
5.3.2 Export volumes

As explained above, when the demand for residential construction is shifted upwards (to simulate the retrofit programme), the investment in, and output of all, exporting industries decreases.

[4] BERL assumed households would only minimally compensate for cheaper electricity by using more electricity. Although take-back effects were observed most strongly in retrofits involving heater upgrades, the retrofit scenarios in this report do not include heater upgrades so take-back effects were assumed to be slight.

In Scenario 1, the change in exports is roughly 2.7 percent below the baseline. In Scenario 2, it is 1.2 percent lower, and in Scenario 3 exports will be 1.9 percent lower in 2050 than in the base case.

Figure 5.3 Export volumes deviation from baseline (total)

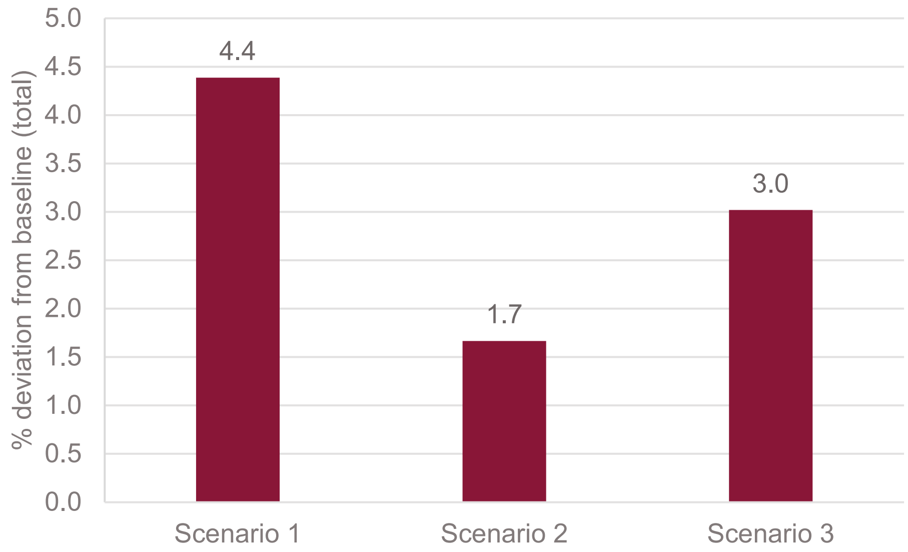


5.3.3 CPI price inflation

When the demand for residential construction is shifted upwards to simulate the retrofit programme in the CGE model, an increase in all prices is observed. This increase flows through to consumers in the Consumer Price Index (CPI). This measure is commonly reported as *inflation*.

In Scenario 1 the CPI will be 4.4 percent greater in 2050 than it would be in the base case. In Scenario 2 it will be 1.7 percent greater, while in Scenario 3 it will be 3 percent greater in 2050 than in the base case.

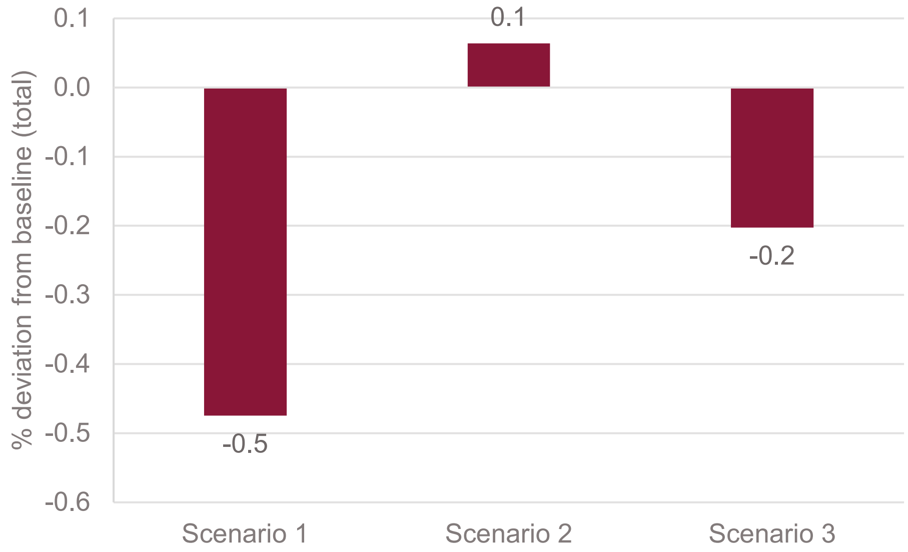
Figure 5.4 Consumer Price Index deviation from baseline (total)



5.3.4 House prices

The CGE model can calculate the percentage change in spend on housing (house prices and rent) for households as a result of a change in the economy. In Scenario 1 this measure will decrease by 0.5 percent. In Scenario 2 it will increase by 0.1 percent. And in Scenario 3, the spend on housing for households will decrease by 0.2 percent. This shift results from the increased investment in construction created by the retrofit programme.

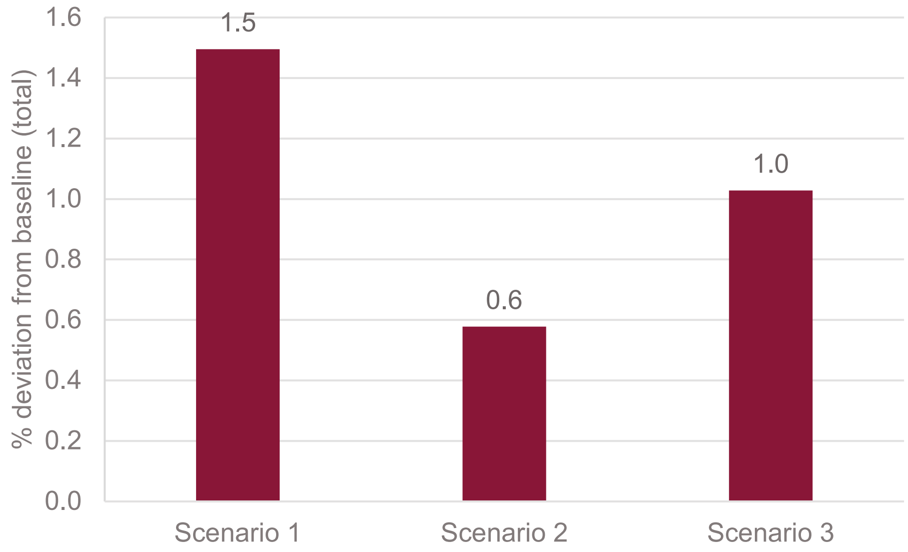
Figure 5.5 House prices deviation from baseline (total)



5.3.5 Government income

The increased output of the construction industry created by the retrofit programme shifts government income upwards in the CGE model. In Scenario 1, this increase is about 1.5 percent in total by 2050, and in Scenario 2 it is roughly 0.6 percent. In Scenario 3, government revenue will be one percent greater in 2050 than it would be in the baseline.

Figure 5.6 Government income deviation from baseline (total)



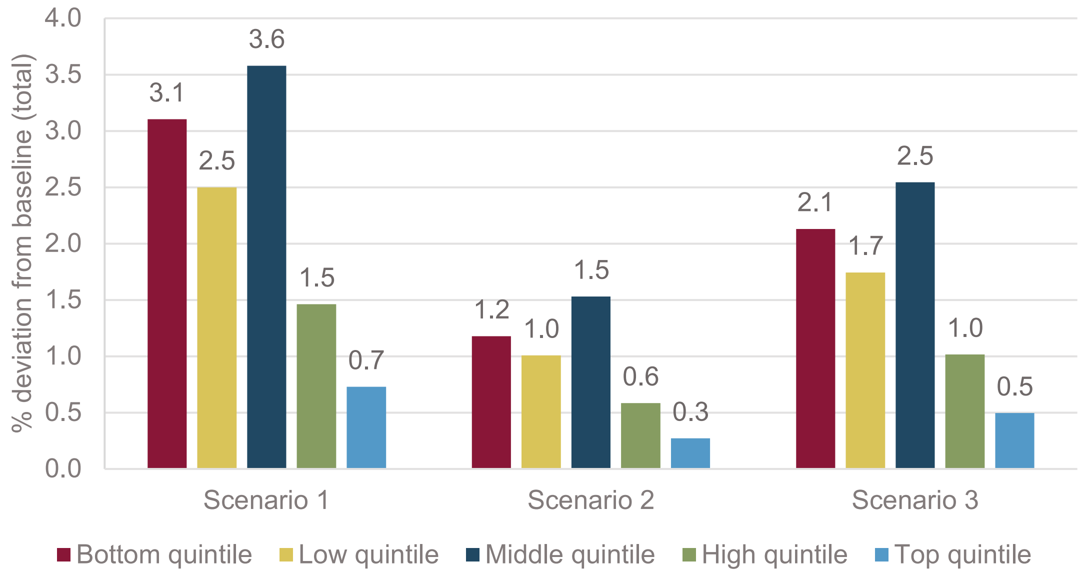
5.3.6 Household income

Against the fall in GDP, the result showing an increase in household income deserves attention.

Household income increases from two sources: the first is an increase in government income. In the CGE model the government's balance is held fixed. If government income increases (which the results show), the government is assumed to increase transfers to households (primarily unemployment benefits and superannuation). This is a direct increase to household income.

The second source of the increase in household income is from a change in the structure of the labour market. In each scenario high skilled and skilled labour demand increases, while semi-skilled labour demand decreases slightly. The model shows that this investment in residential construction will shift workers from semi-skilled occupations to skilled and high skilled occupations. These latter occupations are better compensated which creates an upward shift in wages for the economy, and this drives the bulk of household income. The increase in household income, by income quintile, is shown in Figure 5.7, where households in the bottom and middle quintiles receive the highest increases in income across the scenarios.

Figure 5.7 Household income deviation from baseline



5.4 Approach taken

Appendix A describes the idea behind CGE modelling in full. However, before introducing the results in detail it is valuable to consider what *general equilibrium* means.

Most economic modelling builds a static view of the economy, makes a change, and observes the results. There are two options when it comes to allowing the model to output results. The first option is to assume all the sectors in the model continue to make the same decisions except those which are explicitly modelled to change. This is known as a *partial equilibrium* because one sector of the model is forced to adapt to a change (find a new equilibrium), while all other sectors remain static.

The second option is that the proposed change to the economy should affect all sectors, and all sectors should be able to change their decisions. Additionally, all sectors should be able to change their behaviour not just in direct response to the explicit change in the model, but also to the changes in decisions of all other sectors. In technical words, a new *general equilibrium* is allowed to occur in the model. This is the approach taken in the modelling in this section.

What is CGE modelling?

CGE modelling is a comparative static methodology that can be used to show the change over time based on different scenarios.

It requires a base case of the economy (business as usual), which is then 'shocked', in this case by the spending from a large retrofit programme. This sees the scenarios take the form of the base case plus the change.

Because the base case is consistent across scenarios, the difference can be attributed to the 'shock'.

When reading through our results it is useful to keep this distinction in mind. This section summarises the result of thousands of iterations of all the sectors making new decisions. These decisions are made in response to the changes made explicitly (the shock), and made in response to the changes in decisions made by all other sectors. In this instance, the shock (investment from the retrofit scenarios) was focused on the residential construction industry and industries related to residential construction.

5.5 Detailed results

The main results of the CGE modelling are presented in detail below.

5.5.1 Scenario 1

Table 5.6 provides a detailed summary of the results of our CGE modelling for Scenario 1. The left column of the table displays the business-as-usual (BAU) Scenario results. Total annual real GDP will increase by $82.1 billion over the 30-year timeframe (25.3 percent in total). Government income will increase by $22 billion (23.5 percent). Export volumes will grow by $77.3 billion (87.3 percent total). CPI price inflation will grow 5.7 percent. House prices fall 17.3 percent in total by 2050.

Household incomes will increase over all quintiles; the bottom quintile will experience an increase in income of 14.6 percent, low quintile will be 21 percent, middle quintile will be 25.5 percent, high 26.9 percent, and the top quintile will experience income growth of 32.1 percent.

Labour demand will also grow in the BAU Scenario matching a steadily growing economy. For elementary skill workers labour demand will grow a total of 29.9 percent, and for semi-skilled it will grow 25.4 percent. For skilled workers labour demand will grow 27.2 percent and for high skilled workers it will grow 23.3 percent by 2050.

The next column shows the results of the CGE modelling as at 2050, which is read the same way as the BAU column.

The final column shows the difference between Scenario 1 and the BAU. This column represents the difference that the retrofit programme makes to the Aotearoa New Zealand economy.

The Scenario 1 retrofit programme will result in a lower GDP figure by about $2.5 billion by 2050, this is a decrease of about 3.1 percent total growth.

Government income will increase by about $300 million ($0.3 billion) which represents about 1.5 percent greater growth.

Export volumes will be lower with the retrofit programme. This is likely to be the largest contributor to the lower GDP result. Export volumes will be $2.1 billion lower than BAU export volumes (2.7 percent lower total growth).

CPI inflation will be 4.4 percent higher in Scenario 1 than in the BAU. While house prices will be a further 0.5 percent lower.

Household incomes in the bottom, low, middle, high, and top quintiles will grow by 3.1, 2.5, 3.6, 1.5, and 0.7 percent, respectively.

Labour demand for elementary skill, skilled, and high skill labour will increase by 0.2, 0.2, and 0.3 percent, respectively. Demand for semi-skilled labour will fall 1.3 percent.

Table 5.6 Detailed economic impacts - Scenario 1

		Cumulative change from 2020 to 2050		Difference
Measure	Units	BAU	Scenario 1	Scenario 1 versus BAU
Real GDP	$ billion	82.1	79.5	-2.5
Real GDP	% growth	25.3	24.5	-3.1
Government income	$ billion	22.0	22.3	0.3
Government income	% growth	23.5	23.9	1.5

Export volumes	$ billion	77.3	75.2	-2.1
Export volumes	% growth	87.3	85.0	-2.7
CPI price inflation	% growth	5.7	5.9	4.4
House prices	% growth	-17.3	-17.2	-0.5
Household income				
Bottom quintile	% growth	14.6	15.0	3.1
Low quintile	% growth	21.0	21.6	2.5
Middle quintile	% growth	25.5	26.4	3.6
High quintile	% growth	26.9	27.3	1.5
Top quintile	% growth	32.1	32.3	0.7
Labour demand by skill level				
Elementary	% growth	29.9	29.9	0.2
Semi skilled	% growth	25.4	25.1	-1.3
Skilled	% growth	27.2	27.3	0.2
High skilled	% growth	23.3	23.4	0.3

5.5.2 Scenario 2

Table 5.7 provides a detailed summary of the results of CGE modelling for Scenario 2. In the left column ("BAU"), the table displays the business-as-usual Scenario results. The BAU results were described above.

The final column shows the difference between Scenario 2 and the BAU. This column represents the difference that the retrofit programme could make to the Aotearoa New Zealand economy.

The CGE model shows that the retrofit programme will result in a lower GDP figure by about $1.2 billion by 2050, which is a decrease of about 1.4 percent total growth.

Government income will increase by about $100 million ($0.1 billion) which represents about 0.6 percent greater growth.

Export volumes will be lower with the retrofit programme. This is likely to be the largest contributor to the lower GDP result. We calculate that export volumes will be $0.9 billion lower than BAU export volumes (1.2 percent lower total growth).

CPI inflation will be 1.7 percent higher in Scenario 2 than in the BAU, while house prices will be a greater by 0.1 percent.

Household incomes in the bottom, low, middle, high, and top quintiles will grow by 1.2, 1, 1.5, 0.6, and 0.3 percent, respectively.

Labour demand for elementary skill, skilled, and high skill labour will increase by 0.1, 0.1, and 0.2 percent, respectively. Demand for semi-skilled labour will fall 0.6 percent.

Table 5.7 Detailed economic impacts - Scenario 2

		Cumulative change from 2020 to 2050		Difference
Measure	Units	BAU	Scenario 2	Scenario 2 versus BAU
Real GDP	$ billion	82.1	80.9	-1.2
Real GDP	% growth	25.3	25.0	-1.4
Government income	$ billion	22.0	22.1	0.1
Government income	% growth	23.5	23.7	0.6
Export volumes	$ billion	77.3	76.4	-0.9
Export volumes	% growth	87.3	86.3	-1.2
CPI price inflation	% growth	5.7	5.8	1.7
House prices	% growth	-17.3	-17.3	0.1
Household income				
Bottom quintile	% growth	14.6	14.8	1.2
Low quintile	% growth	21.0	21.2	1.0
Middle quintile	% growth	25.5	25.9	1.5
High quintile	% growth	26.9	27.0	0.6
Top quintile	% growth	32.1	32.2	0.3
Labour demand by skill level				
Elementary	% growth	29.9	29.9	0.1
Semi skilled	% growth	25.4	25.3	-0.6
Skilled	% growth	27.2	27.3	0.1
High skilled	% growth	23.3	23.3	0.2

5.5.3 Scenario 3

Table 5.8 provides a detailed summary of the results of CGE modelling for Scenario 3. In the left column ("BAU") the table displays the business-as-usual Scenario results. The BAU results were described above.

The final column is the difference between Scenario 3 and the BAU. This column represents the difference that the retrofit programme makes to the Aotearoa New Zealand economy.

The CGE model shows that the retrofit programme will result in a lower GDP figure by about $1.8 billion by 2050, which is a decrease of about 2.2 percent total growth.

Government income will increase by about $200 million ($0.2 billion) which represents about one percent greater growth.

Export volumes will be lower with the retrofit programme. This is likely to be the largest contributor to the lower GDP result. We calculate that export volumes will be $1.5 billion lower than BAU export volumes (1.9 percent lower total growth).

CPI inflation will be three percent higher in Scenario 3 than in the BAU, while house prices will be a lower by 0.2 percent.

Household incomes in the bottom, low, middle, high, and top quintiles will grow by 2.1, 1.7, 2.5, 1, and 0.5 percent, respectively.

Labour demand for elementary skill, skilled, and high skill labour will increase by 0.1, 0.1, and 0.2 percent, respectively. Demand for semi-skilled labour will fall 0.9 percent.

Table 5.8 Detailed economic impacts - Scenario 3

		Cumulative change from 2020 to 2050		Difference
Measure	Units	BAU	Scenario 3	Scenario 3 versus BAU
Real GDP	$ billion	82.1	80.2	-1.8
Real GDP	% growth	25.3	24.8	-2.2
Government income	$ billion	22.0	22.2	0.2
Government income	% growth	23.5	23.8	1.0
Export volumes	$ billion	77.3	75.8	-1.5
Export volumes	% growth	87.3	85.6	-1.9
CPI price inflation	% growth	5.7	5.9	3.0
House prices	% growth	-17.3	-17.3	-0.2
Household income				
Bottom quintile	% growth	14.6	14.9	2.1
Low quintile	% growth	21.0	21.4	1.7
Middle quintile	% growth	25.5	26.1	2.5
High quintile	% growth	26.9	27.1	1.0
Top quintile	% growth	32.1	32.3	0.5
Labour demand by skill level				
Elementary	% growth	29.9	29.9	0.1
Semi skilled	% growth	25.4	25.2	-0.9
Skilled	% growth	27.2	27.3	0.1
High skilled	% growth	23.3	23.3	0.2

5.6 CGE model observations

The CGE model delivered an unexpected result; that introducing large retrofit programmes would reduce total GDP growth in Aotearoa New Zealand over 30 years. This is explained by the fact that in the model, exporting sectors respond to the extra output of the residential construction industry by reducing investment in their own industries. This results in lower export volumes. The initial hypothesis was that the reduced electricity spend contributed to this lower GDP effect. Subsequent calculations showed the effect of lower electricity spend is not material to overall GDP.

The negative effect on GDP is outweighed by the positive effect on household incomes, for all household income quintiles. This means that households will be unambiguously better off, even if the economy “shrinks” in terms of total GDP.

The effect of the retrofit programmes on labour demand is intriguing. The model shows that labour demand for all skill levels except semi-skilled workers increases. Labour demand for semi-skilled workers decreases as a result of the retrofit programme.

The effect of the retrofit programme on government income is also positive. The retrofit programme creates an increase in government income from all sources.

This section detailed the purely economic impacts of a proposed retrofit programme under three scenarios. BERL maintains that the health benefits of the retrofit programme will be large, even if not captured by this purely economic model. The evidence discussed in section 1 and 2 of this report points to the fact that retrofits improve health and wellbeing outcomes to a significant degree, and this section provides evidence that outcomes in terms of household income will also improve, due to the economic effects of significant retrofit activity. Section 6 applies the health benefits drawn from the Healthy Homes Initiative and Warmer Kiwi Homes evaluations (Pierse et al, 2022, and Fyfe et al, 2022), to estimate the potential health benefits of the retrofit scenarios.

6 Health and wellbeing impacts of retrofit scenarios

The benefits of the three retrofit scenarios go beyond economic benefits to improve the health and social wellbeing outcomes of the households that live in the retrofitted houses. As the initiatives considered earlier in this report illustrated, households across the world have benefitted from improved health, social, education, and employment outcomes, as well as lower energy costs to run these retrofitted houses.

Because of the wide variety of factors (including, environmental conditions, building materials, house types, construction techniques, and household composition) that differentiate Aotearoa New Zealand from the countries where the programmes assessed in this research were implemented, the results of these interventions were unable to be applied directly to the Aotearoa New Zealand context. To illustrate the potential health and wellbeing benefits to Aotearoa New Zealand, the results of successful Aotearoa New Zealand initiatives, the Healthy Homes Initiative (HHI) and Warmer Kiwi Homes (WKH) have been applied.

6.2.1 The Healthy Homes Initiative (HHI)

The aim of the HHI is to increase the number of children living in warm, dry and healthy homes, and to reduce avoidable hospitalisations and ill health due to housing-related conditions. The HHI was established between December 2013 and March 2015 and initially covered 11 District Health Boards (DHBs) with high incidence of rheumatic fever (including Auckland, Waitematā, Counties Manukau, Northland, Waikato, Hutt Valley, Capital & Coast, Lakes, Bay of Plenty, Hawke's Bay and Tairāwhiti), and since July 2022 are being rolled out to the remainder of the country.

By December 2021 HHI had completed 28,901 referrals resulting in assistance for 75,858 people from 14,625 households. Initially the HHI targeted low-income families, with children at risk of rheumatic fever, who were living in crowded households. The breadth of the programme was expanded in 2016 to focus more broadly on warm, dry and healthy housing for low-income families with children up to five years old, and pregnant women (Pierse et al, 2022).

The HHI providers identify eligible families, undertake a housing assessment, and then work across agencies to facilitate access to a range of interventions to create warmer, drier, healthier homes. These interventions can include insulation, curtains, heating sources, minor repairs, and private/community/social housing relocation. They also provide information to families about practices to help keep a house warm and dry, and to reduce risks associated with household crowding (Pierse et al, 2022).

The three-year evaluation of the HHI to determine whether the HHI interventions have improved health and social outcomes concluded that "this programme is making a tangible impact for HHI whānau. They are spending less time in hospital, and more time in school and employment. There is unambiguous evidence of broad improvements in wellbeing" (Pierse et al, 2022, p.7). These impacts included:

- The number of hospitalisations per person reduced by 19.8 percent (9,744 hospitalisations).
- Increased school attendance with absences decreasing by three percent.
- After the intervention, adults aged 24 to 64 were on nine percent less benefits, and four percent more likely to be employed (Pierse et al, 2022).

The three-year evaluation of HHI concluded that the expected value of social benefits from the 28,625 HHI interventions, in the first year following the intervention, was approximately $71 million.

This included the savings from reduced hospitalisations, reduced hospitalisation severity, fewer days absent from employment, and reduced benefit payments. As Table 6.1 shows, the cost per unit ranges from $4,752 per hospitalisation to $75 per day absent. The most common outcomes were a reduction in the severity of hospitalisation which reduced by $485 per intervention and reduced benefit paid, a cost to government, which fell by $364 per intervention.

Table 6.1 Benefits of the Healthy Homes Initiative

	Count	Count per intervention	Count per person	Cost per unit ($)
Reduced hospitalisation	9,745	0.34	0.07	4,752
Reduced hospitalisation severity	43,356	1.51	0.29	320
Reduced days absent	1,870	0.07	0.01	75
Reduced benefit income	52,182	1.82	0.35	200

Source: Pierse et al, 2022.

6.2.1.1 Applying HHI results to the retrofit scenarios

If the proposed retrofit scenarios could achieve similar health outcomes to the HHI, the benefits (costs avoided) could be around $1 billion in the first year and these benefits would continue for many years afterwards. With a cost of $4,752, and 0.34 hospitalisation reductions per intervention, the reduced hospitalisation cost that resulted from HHI interventions produce the greatest benefit across all three scenarios. As Table 6.2 shows, reduced hospitalisation and hospitalisation severity account for 85 percent of the monetised benefits of retrofit programmes, if the outcomes of the programmes can at least match the outcomes of the HHI.

Table 6.2 Potential benefit of retrofit schemes if they can match HHI

	Retrofit benefits
Houses retrofitted	426,253
Reduced hospitalisation ($m)	689
Reduced hospitalisation severity ($m)	207
Reduced days absent ($m)	2
Reduced benefit income ($m)	155
Total ($m)	**1,054**

Source: BERL calculations

6.2.2 Warmer Kiwi Homes

The WKH programme includes the provision of clean heating devices in living areas for eligible households that do not already have suitable heating. The programme also includes installation of retrofitted insulation for houses without (or with insufficient) insulation. Much like the scenarios in this assessment, to be eligible the householder must be an owner-occupier and must either be situated in a disadvantaged neighbourhood (NZDep = 8, 9 or 10) or hold a Community Services Card.

The 2022 Evaluation of the Warmer Kiwis Homes Programme: Full Report including Cost Benefit Analysis produced by Motu provided a comprehensive evaluation of WKH (Fyfe et al, 2022a). The study population comprised mostly multi-person households, with an average of 2.7 people per household.

The evaluation combined the heat pump evaluation with prior analysis related to insulation and heating to provide a set of cost benefit CBA of the WKH programme. The CBA updated the Phase 1

CBA, that was based solely on secondary data, which in turn updated the CBA undertaken in the evaluation of the Warm-up New Zealand: Heat Smart (WUNZ:HS) insulation and heating subsidy programme (Grimes et al, 2012).

The outcomes the CBA focused on include warmth and dryness of the living area, personal comfort and wellbeing, heating and ventilation related behaviours, and electricity consumption.

The CBA of WKH was conducted from a societal perspective and included a wellbeing component, the costs and benefits accrued across all stakeholders including government, homeowners and employers, as well as wider society benefits (e.g. from reduced carbon emissions). Two approaches were adopted to calculate the benefit cost ratios (BCRs):

- **A wellbeing/energy BCR** – based on a wellbeing measure relating to house warmth from the Treasury CBAx model, plus energy and carbon saving benefits. This measure placed considerable weight on living in a warm house.
- **A health/energy BCR** - health benefits derived from prior evaluations, plus energy and carbon saving benefits (Fyfe et al, 2022a)

Where possible, the study calculated benefits using data collected from the WKH evaluation. This included electricity records, living area temperature readings, and survey responses. Where benefits were unable to be estimated from the evaluation, they were based on previous studies of similar subsidy programmes. For example, estimates of the number of prescriptions, hospitalisations, and deaths avoided as a result of the WKH programme, were based on evaluations of WUNZ:HS. Table 6.3 recreates the table of summary of benefits used in the CBA.

Table 6.3 Benefits of WKH

Description	Unit of measurement	Benefit per unit ($)	Notes
Heat pump			
Hospital admissions avoided	$ per inpatient visit per person year	6,100	8.60 inpatients per 1000 person years.
Pharmaceutical admissions avoided (cold associated)	$ per prescription avoided per person year	39	35.2 per 1000 person years
GP visits avoided	$ per visit avoided per person year	91	35.2 per 1000 person years
Net change in comfort living in a cold house	$ per point increase on Likert scale per person year	6,976	Measured per person per year
Days off work due to sickness	$ per day avoided per household per year	64	0.167 per household with a working adult
Days off work due to caregiving	$ per day avoided per household with school aged child per year	64	0.180 per household with a school age child where all adults work
Days off school due to sickness	$ per day avoided per household with school aged child per year	58	0.765 per household with a school aged child
Net change in electricity consumed	$ per kWh reduction in electricity consumption	0	Based on winter season
Net change in CO_2 from difference in kWh electricity consumed	$ per kWh reduction in electricity consumption	0	Calculated difference in average kWh electricity consumed.
Insulation			
Hospital admissions avoided	$ per inpatient visit per person year	6,100	9.26 inpatients per 1000 person years.
Pharmaceutical admissions avoided (cold associated)	$ per prescription avoided per person year	39	17.2 per 1000 person years
GP visits avoided	$ per visit avoided per person year	91	17.2 per 1000 person years
Net change in comfort living in a cold house	$ per point increase on Likert scale per person year	6,976	50 percent heat pump benefit per year (i.e. $3,488 per household
Days off work due to sickness	$ per day avoided per household per year	64	0.167 per household with a working adult
Days off work due to caregiving	$ per day avoided per household with school aged child per year	64	0.180 per household with a school age child where all adults work
Days off school due to sickness	$ per day avoided per household with school aged child per year	58	0.765 per household with a school aged child
Increase in survival (cold associated)	Value of a life year proportion of fewer deaths	34,768	25.3 per 1000 person years for over 65 with cardiovascular disease

Source: Fyfe, Grimes, Minehan, & Taptiklis, 2022a.

6.2.2.1 Applying WKH results to the retrofit scenarios

The wellbeing/energy BCR for the full WKH programme was estimated to be 4.36, while the health/energy BCR for the full WKH programme was 1.89.

If these BCRs are applied to the three scenarios used to demonstrate the potential for a large scale retrofit scheme in Aotearoa New Zealand, if they could achieve similar outcomes to WKH, there would be significant benefits accrued to Aotearoa New Zealand. As Table 6.4 shows, the wellbeing/energy benefits would be between $116 billion and $253 billion, and the health/energy benefits could be between $50 billion and $110 billion. This would result in net benefits of between $89 billion and $195 billion if using the wellbeing/energy BCR, and $24 billion to $52 billion using the health/energy BCR.

Table 6.4 Potential benefits of retrofit scenarios if WKH results can be achieved

		Wellbeing/energy		Health/energy	
	Cost ($m)	BCR	Total benefit ($m)	BCR	Total benefit ($m)
Scenario 1	58,078	4.36	253,219	1.89	109,767
Scenario 2	26,555	4.36	115,778	1.89	50,188
Scenario 3	42,255	4.36	184,232	1.89	79,862

Source: Fyfe et al, 2022a; BERL calculations

7 Final recommendations

1. Implement a pilot retrofit programme which can be scaled upwards

While there is data from the WKH programme and the HHI, the true costs and benefits, as well as challenges, of an ambitious retrofit programme are unknown without a pilot study. A replication of what was achieved in Ireland is possible and would ensure issues and opportunities unique to Aotearoa New Zealand are recognised early and integrated into the final nationwide programme. Māori households and providers must be included in the development and implementation of the pilot to ensure the resulting programme meets the needs of Māori.

2. Understand the needs of vulnerable households at a closer level, particularly Māori and Pacific People, by housing and household type

The achievements and challenges of the Kainga Ora retrofit programme should be collected and published, as the experiences of participants and organisers will provide important insights into the needs of vulnerable households before, during, and after a significant retrofit project. Homeowners should not all be assumed to be able to afford retrofits, so financing options must not be regressive.

A pilot programme should contribute towards understanding the needs of Māori, Pacific people, and disabled occupants in regard to retrofitting their homes, and how projects can be managed in ways that uphold their mana.

3. Continue to develop Warmer Kiwi Homes to provide more heating systems to a greater number of kiwi households

Warmer Kiwi Homes is a vehicle familiar to New Zealanders that delivers heating systems and insulation. While a retrofit programme is being explored and implemented, it will be important to ensure that homes in need continue to receive heat pumps and basic insulation measures.

4. Create a plan that combines healthy home standards, warmer kiwi homes, retrofit programmes, EPCs, and other government strategies into a clear and actionable plan to 2050, which aligns with Aotearoa New Zealand's emissions targets.

Currently the existing programmes and initiatives that aim to improve dwelling energy efficiency lack an overall cohesion with an overarching vision. An explicit national retrofit plan for Aotearoa New Zealand that ties all the policy instruments together would deliver a strong signal to industry, homeowners, and renters to expect, and invest in, improved housing. The plan should provide the strategy for encouraging the needed level of investment, skills, behavioural drivers, and regulation requirements to achieve an ambitious number of houses retrofitted each year. Efficiency improvements to reach the required 2050 emissions targets in the ERP can set the goal, while recognising the improvements to health, wellbeing, and energy network security will fulfil other targets, such as productivity and climate adaptation goals.

The analysis in this report has shown that vast improvements to Aotearoa New Zealand's residential housing stock are needed. The review of international programmes has revealed that creating renovation waves is possible and leads to widespread change across economies and communities. Modelling a renovation wave in Aotearoa New Zealand displayed that the economy will react inwards to significant investment in residential construction, which will ultimately raise household incomes through increased demand for higher-level skills to deliver retrofits. Beyond the economy's reaction, communities will be undeniably better off in the domains of health, wellbeing, productivity, and resilience to climate events.

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Appendix A CGE Methodology

Computable General Equilibrium (CGE) modelling is one of three main quantitative evaluation methods used in economics. The other two are multiplier modelling and regression analysis. In BERL's analysis for BRANZ CGE modelling was employed.

The key distinction between CGE and multiplier analysis is that the former is a *general* equilibrium while the latter is a *partial* equilibrium approach. The words *general* and *partial* refer to the number of industries the model imposes equilibrium conditions on. The *general* equilibrium approach imposes equilibrium conditions on all parts of the economy to understand how economic behaviour and decisions change after a shock and build a richer picture of the impact of a change.

A CGE model is a set of many simultaneous equations (often numbering hundreds or thousands) that describes the interrelationships between all sectors of an economy. For example, one subset of the simultaneous equations describes how consumers purchase different goods. Another subset describes how firms purchase inputs and produce outputs. Other subsets describe investment decisions, input decisions, and all other kinds of decisions in an economy.

CGE modelling is used widely internationally, albeit to a lesser extent in New Zealand, in policy, event, and programme evaluation. Notably, Gieseke used a CGE model to quantify the economic benefit of the Sydney Olympic Games in Australia.[5]

Previously, the BERL CGE model was used in a study in 2021 to quantify what the effect on the New Zealand economy would be if the Construction industry adopted Industry 4.0 technologies. These are technologies which improve communication or planning, and involve some degree of automation or artificial intelligence. BERL designed a BAU scenario of the New Zealand economy and then changed the inputs of the model to reflect different scenario describing such a technology shift.[6]

In theory, a CGE model can be as basic or as complex as the modeller prefers. However, in practice, very simple CGE models are not useful beyond teaching. CGE models adopted for real-world application are developed collaboratively between academic institutions. They are then licensed to practitioners for whom developing a bespoke CGE model is not practical. BERL's CGE model is closely related to a CGE model developed by Victoria University (Australia), but it has been modified by New Zealand academics.

A key feature in CGE modelling is that the model contains a greater number of variables, by default, than the number of equations. This means the model cannot be solved analytically without making assumptions about the excess variables. It is these assumptions which allow us to use the model to simulate an economy in multiple states, and then compare these states.

The basic methodology BERL uses is to make a set of assumptions which approximate the economy to reflect a "business as usual" world. Another set of assumptions which approximate the economy is then used, after a series of changes to the model. In the case of the current analysis, the change we modelled was the effect on the New Zealand economy if the output and investment of the construction industry is greatly increased in the model. We run our model such that we can approximate some idea of the New Zealand economy through time, and then increase construction activity in different years, depending on the scenario.

[5] Giesecke, J.A., Madden J.R. (2007). *The Sydney Olympics, seven years on: an ex-post dynamic CGE assessment.*
[6] BERL (2021). *How will Construction 4.0 benefit the economy?*

8.2.1 Caveats

While CGE modelling is a powerful tool for exploring the impact of policy and other changes in the economy, it is important, for the sake of transparency, to outline its limitations.

8.2.1.1 Approximation by design

A CGE model is necessarily an approximation of the economy at a point in time. It is limited by the underlying logic of understanding the economy as an accounting model of fixed relationships. This logic is necessary but cannot capture all the nuances of an economy.

Further, the equations in our CGE model have been made linear to make the solution computable analytically. This imposes a limitation on the model because a linear equation can, at best, only be an approximation of the real world.

Finally, the mechanism of solving a CGE is also an approximation. The mathematics of the approximation are complex, and this method of solution implies multiple types of approximations in the model.

8.2.1.2 Aggregation

A CGE model also necessarily must be highly aggregated. While we might conceivably be able to solve billions of equations using modern computing power, we still cannot have an equation for every firm, every industry, and so on. Further, the underlying data is also, by necessity, highly aggregated.

8.2.1.3 Comparative static analysis

BERL's CGE model simulates the New Zealand economy at a given point in time. We can simulate the economy at two points in time and compare them. However, the model does not contain equations which would allow us to simulate the path the economy takes between these two points. The analysis must be comparing two or more end-points, or states. We call this kind of analysis comparative static analysis.

8.2.1.4 Limited scope for decomposition

In this report, we summarise our results. These results show the net effect of the changes made under our scenarios. In each scenario, the changes made will affect all parts of the economy in multiple ways. It is out of the scope of this analysis to detail all the changes that compose the net effect.

Appendix B BER rating tables

Figure B1 - Indicative Building Energy Ratings for typical homes

Oil/gas central heating		Standard electric heating		Solid fuel central heating	
Year of construction	Typical energy rating	Year of construction	Typical energy rating	Year of construction	Typical energy rating
2012+	A3	2012+	A3	2012+	A3
2010-2011	B1	2010-2011	B1	2010-2011	B1
2008-2009	B3	2008-2009	C3	2008-2009	B3
2005-2007	C1	2005-2007	D1	2005-2007	C2
1994-2004	C3	1994-2004	E1	1994-2004	D1
1978-1993	D1	1978-1993	E2	1978-1993	D2
Pre 1978	D2/E1/E2	Pre 1978	G	Pre 1978	F

Figure B2 - Indicative annual CO_2 emissions and running cost for different rating bands for space and water heating

Rating	2 Bed Apartment		3 Bed Semi-D		4 Bed Semi-D		Detached House		Large house	
	Area (m^2)	75	Area (m^2)	100	Area (m^2)	150	Area (m^2)	200	Area (m^2)	300
	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)
A1	0.4	€140	0.5	€190	0.8	€280	1.1	€400	1.6	€600
A2	0.8	€280	1.1	€380	1.6	€560	2.2	€800	3.2	€1,100
A3	1	€350	1.4	€470	2	€700	2.7	€900	4.1	€1,400
B1	1.3	€440	1.7	€590	2.5	€900	3.4	€1,200	5	€1,800
B2	1.6	€570	2.2	€800	3.3	€1,100	4.3	€1,500	6.5	€2,300
B3	2	€700	2.7	€900	4	€1,400	5.3	€1,900	8	€2,800
C1	2.4	€800	3.1	€1,100	4.7	€1,600	6.3	€2,200	9.4	€3,300
C2	2.8	€1,000	3.7	€1,300	5.5	€1,900	7.4	€2,600	11	€3,900
C3	3.2	€1,100	4.2	€1,500	6.3	€2,200	8.4	€2,900	12.7	€4,400
D1	3.7	€1,300	5	€1,700	7.5	€2,600	10	€3,500	14.9	€5,200
D2	4.4	€1,500	5.8	€2,000	8.8	€3,100	11.7	€4,100	17.5	€6,100
E1	5	€1,800	6.7	€2,300	10.1	€3,500	13.4	€4,700	20.1	€7,000
E2	5.7	€2,000	7.6	€2,600	11.4	€4,000	15.1	€5,300	22.7	€7,900
F	6.8	€2,400	9.1	€3,200	13.6	€4,700	18.2	€6,300	27.2	€9,500
G	8.5	€3,000	11.3	€4,000	17	€5,900	22.7	€7,900	34	€11,900

Source: SEAI (2022)