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Evaluation of the Warmer Kiwis Homes Programme:

Summary Report including Cost Benefit Analysis

Motu economic & public policy research

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Warmer Kiwi Homes

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Keywords

Heat pumps; indoor temperature; electricity use; wellbeing; Warmer Kiwi Homes

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Abstract

We evaluate the heat pump component of New Zealand's Warmer Kiwi Homes (WKH) programme. The programme includes provision of heat pumps in living areas for eligible households (based on neighbourhood or income) that do not have such heating. It also includes installation of retrofitted insulation for houses with insufficient insulation. Staggered installation enables difference-in-difference estimates of impacts. Heat pump outcomes on which we focus include warmth and dryness of the living area, personal comfort and wellbeing, and electricity consumption. We combine the heat pump findings with prior findings related to insulation and heating to provide a set of cost benefit analyses of WKH. We find that household members overwhelmingly report increases in warmth, comfort and satisfaction with their home, and report decreases in condensation, damp and having to restrict heating due to cost. Some increase in life satisfaction is reported. Living areas of treated houses experience increases in temperature which are most pronounced around breakfast and evening times, and when outdoor temperatures are low. Houses also experience reduced humidity. Households that use the heat pump as an air conditioner experience reduced summer temperatures when outdoor temperatures are high. Winter electricity use falls in a house fitted with a heat pump relative to houses without a heat pump; savings are negligible at night and increase through the day, peaking at 5-9pm. No increase in electricity consumption is detected in summer. Benefit cost ratios (BCRs) are calculated using both wellbeing metrics and conventional health and energy components. The wellbeing-based BCR for the heat pump component (which places a high value on living in a warm home) is estimated at 7.49 while the more conventionally calculated (but overly conservative) BCR is 2.15. For the full WKH programme, the corresponding BCRs are calculated as 4.36 and 1.89. Complete details of each element of the evaluation are presented in the Full Report available as Motu Working Paper WP 22-14.

JEL codes

I18, I31, I38, Q48

Keywords

Heat pumps; indoor temperature; electricity use; wellbeing; Warmer Kiwi Homes

Summary haiku

Houses are warmer

Even in winter and spring

Heat pumps are worth it

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Executive summary

Objectives

The Warmer Kiwi Homes (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. To be eligible, the householder must be an owner-occupier and must either be situated in a disadvantaged neighbourhood or hold a Community Services Card.

This report provides a summary of a comprehensive evaluation of the heat pump component of WKH. The evaluation analyses the impact of heat pump installation on warmth and dryness of the living area, personal comfort and wellbeing, heating behaviours, and electricity use. The evaluation combines the heat pump findings with prior findings related to insulation and heating to provide a set of cost benefit analyses of the WKH programme. The Full Report of the evaluation, including technical details, is available as Motu Working Paper WP 22-14.

Evaluation coverage and components

Our sample for the heat pump analysis comprises 127 WKH participants who applied for a heat pump in 2021 (the 2021 cohort) and a further 37 WKH participants who applied for a heat pump in 2022 (the 2022 cohort). Of the 2021 cohort, 85 remained in the study in 2022 enabling analysis both of heat pump use in a second winter and over a first summer for this cohort. The specific evaluation periods that we cover are "winter" (June – September) 2021, "summer" (February – March) 2022, and "winter" (June – September) 2022. The first winter for each cohort is henceforth referred to as *First winter*, the second winter (for the 2021 cohort) as *Second winter*, and summer 2022 (for the 2021 cohort) as *First summer*.

The evaluation covers all three climate zones as defined by Standards New Zealand (NZS 4218: 2009) with households from: Auckland (zone 1), Waikato and Wellington (zone 2), and Christchurch (zone 3). The houses included in the evaluation cover a diverse set of house types and households.

The study incorporates: linked household survey data (both before and after heat pump installation, and from a subsequent survey for the 2021 cohort at the end of their second winter), an initial house condition report, half-hourly data on indoor environmental outcomes (temperature, humidity and CO_2) and half-hourly data on electricity consumption. The combination of these elements makes this evaluation more comprehensive than any prior evaluation of the impacts of heat pump use in New Zealand or elsewhere. COVID-19 and supply chain issues effectively randomised (from the household perspective) whether and/or when a study house received a heat pump during each of 2021 and 2022. This randomisation resulted in some features of a natural experiment which we have leveraged in our statistical work.

The study's cost benefit analyses are provided for the full WKH programme and for the heat pump and for the insulation components separately. Central estimates – which relate to societal benefits and societal costs – are based on the findings in this study supplemented by external data, each applied to Treasury's CBAx model. In addition, we calculate a fiscal benefit cost ratio that relates solely to state expenditures; this fiscal ratio, however, is not a measure of overall benefits and costs, so is relevant only to internal government fiscal calculations.

Key findings

Analysis across all components of the evaluation indicate a comprehensive set of benefits achieved through installation of WKH heat pumps. Key findings are as follows:

Indoor comfort, wellbeing and heating behaviours

Over *First winter*, for households that had a heat pump installed:

- 77% reported an increase in warmth in the living area;
- 87% reported an improvement in comfort;
- 89% reported a reduction in condensation on living room windows;
- 47% reported a reduction in damp in the living area;
- 81% reported being more satisfied with their home;
- 65% -71% reported a reduction in having to restrict their heating due to cost;
- A net 15% reported an improvement in their overall satisfaction with life (noting that this measure will also have been affected by the 2021 lockdowns and other factors).

These improvements were sustained over *Second winter*: 77% of heat pump recipients in each of the *First winter* and *Second winter* surveys reported a warmer house in winter after receiving their heat pump. Similar sustained gains are documented in householders' responses with respect to comfort, wellbeing and cost reductions.

Indoor environmental quality

- *First winter* living area temperatures show an increase following heat pump installation by an average of 1.1^{o}C relative to a house without a heat pump fitted under WKH.

- Higher temperatures are mirrored, or amplified, in *Second winter* indicating prolonged increases in warmth due to the heat pump.
- The indoor temperature gains are highest when outdoor temperatures are low with an estimated indoor temperature gain of 1.9°C when the external temperature is 0°C.
- Indoor temperature gains (relative to outdoor temperatures) are greatest at 'breakfast' time (1.6°C) and at 'dinner/evening' time (1.2°C).
- Draughty houses experience lower gains in indoor temperature with the average gain in a draughty house being 0.9°C compared with 2.1°C for a non-draughty house.
- Installation of a heat pump significantly reduces living area indoor relative humidity and CO_2.
- Houses that used the heat pump as an air conditioner over summer recorded lower indoor temperatures, with the temperature reduction peaking at 6-7pm.

Electricity use

- Electricity use through winter falls in a house fitted with a heat pump by an estimated 16% relative to a house without a heat pump installed.
- Electricity savings are negligible at night and increase through the day, peaking at 5-9pm.
- Peak electricity reductions occur when there are also indoor temperature gains reflecting replacement of previous energy inefficient heaters by more efficient heat pumps.
- Our analysis estimates no significant increase in electricity consumption over summer for houses that use the heat pump as an air conditioner.

Programme satisfaction

Over *First winter*, of households that had a heat pump installed:

- 86% stated that they were very happy or happy with the WKH subsidy programme;
- 85% reported that the heat pump had met or exceeded their expectations;
- 93% considered that the heat pump was the right choice for their home.

Cost benefit analysis

The cost benefit analysis (CBA) provides a comprehensive examination of the benefits and costs of installing a heat pump alongside insulation. Analysis of insulation alone is also provided together with calculation of a BCR (benefit cost ratio) for the full WKH programme (heat pump plus insulation). The CBA is conducted from a societal perspective and includes a wellbeing component. The societal perspective includes costs and benefits accrued across all stakeholders including government, homeowners and employers, as well as wider society (e.g. from reduced carbon emissions). Two alternative societal approaches are adopted to calculate the BCRs. The “wellbeing/energy BCR” is based on a wellbeing measure relating to house warmth from the Treasury CBAx model, plus energy and carbon saving benefits. This measure places considerable weight on living in a warm house. The “health/energy BCR” incorporates health benefits derived from prior evaluations, plus energy and carbon saving benefits. (A fiscal analysis is also included but these measures are not indicative of the programme’s societal benefits and costs).

The base case wellbeing/energy BCR for the full WKH programme is estimated to be 4.36. The heat pump component has an estimated wellbeing/energy BCR of 7.49 while the BCR for the insulation component is 3.51. The health/energy BCR for the full WKH programme is 1.89 with the heat pump BCR calculated at 2.15 and the insulation component BCR at 1.78.

Conclusions

The findings of this evaluation indicate that installation of a heat pump through the WKH programme results in households that are more comfortable in their homes, with living areas that are materially warmer and drier in winter. On average, living area temperatures are warmer by 1.1^{o}C during winter for a house with a WKH heat pump fitted relative to one without. These benefits occur at the same time as treated households, on average, reduce their electricity consumption, with reduced electricity use being especially marked in the late afternoon and evening. Households that used their heat pump over summer as an air conditioner also experienced reduced living area temperatures, so increasing their comfort, with no significant increase in electricity consumption.

The benefits experienced by households are reflected in the cost benefit analysis. Our central estimate of the societal benefit cost ratio (BCR) for the WKH heat pump component is 7.49 when our estimates are applied to the wellbeing-based yardsticks in Treasury’s cost benefit analysis model (CBAx). Estimates based on more conservative assumptions, which exclude many of the wellbeing gains, show a BCR for WKH heat pump installation of 2.15. Corresponding BCRs for the insulation component are 3.51 and 1.78. For the WKH programme as a whole, the corresponding BCRs are 4.36 and 1.89. Each of the heat pump and insulation components, and the wider WKH programme, are therefore estimated to have societal benefits that considerably exceed their costs.

1: Introduction and Background

Introduction*

This report summarises the results of an impact evaluation of the Warmer Kiwi Homes (WKH) programme conducted over 2021 and 2022. The evaluation, funded by EECA and undertaken independently by Motu Research, collected and analysed new qualitative and quantitative data on the effects of heat pump installation in New Zealand households situated mainly in lower socioeconomic neighbourhoods. The new information provided by these data is combined with information from other sources to formulate a cost benefit analysis (CBA) of the WKH programme. The CBA is conducted for: (i) the heat pump component of the programme, (ii) the insulation component of the programme, and (iii) the complete programme, comprising the heat pump and insulation components. The CBA is conducted at the societal level; we also provide estimates that are relevant at the fiscal level (i.e. related to government financial flows).

This study is the second of two phases of evaluation of the WKH programme. Phase 1 reviewed prior studies on clean heating and insulation from New Zealand and international sources, and identified evidence gaps.[1] This led to the commissioning of Phase 2, the 'Warmer Kiwis Study', which includes new primary research focused on the heat pump component of the programme. Interim results from this second phase were published in January 2022 (henceforth referred to as the *Interim Report*) covering data gathered over the first winter of the evaluation (June to September 2021).[2] The evaluation was initially designed to be conducted just through 2021 but was extended to include 2022 because of COVID-19 and supply chain complications in 2021, and to extend data gathering to monitor households for a longer timespan.

The current document covers the full evaluation, including analysis of data gathered from June 2021 to September 2022. The extension to September 2022 means that we include effects over two winters plus a summer for the first cohort of houses that were fitted with heat pumps in 2021. (We refer to these houses as the 2021 cohort.) The extension includes a second cohort of houses that were first included in the study in 2022 (the 2022 cohort); the latter houses have data pertaining to a single winter. The current document summarises results presented in the *Full Report* that describes and analyses the data gathered through the evaluation[3]. Box 1 shows the full set of reports that comprise the WKH evaluation.

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* All notes in the document are included as endnotes.

Box 1: An overview of the Warmer Kiwi Homes evaluation programme

Phase 1: Desk based review (2020)

Objectives

- Benefit: Cost Ratio estimated from similar programmes conducted in New Zealand and Internationally.
- Summary of evidence gaps and opportunities to gather new data within an evaluation of WKH.

Phase 2: Warmer Kiwis Study (2021/22)

Objectives

- Measure impacts on health and wellbeing, indoor environment and change in electricity use.
- Updated Benefit: Cost ratio for Warmer Kiwi Homes

Interim Report (January 2022)

- Initial findings from monitoring of 127 homes in the first winter after having a heat pump installed.
- Covers the monitoring period June-September 2021.

Final (Full and Summary) Reports (December 2022)

- Includes data from technical assessments of the effects of having a heat pump covering the extended sample of 164 homes, with a subset of homes monitored over two winters plus one summer.
- Cost benefit analysis of Warmer Kiwi Homes programme.

Background

The World Health Organization (WHO) recommends a minimum indoor temperature of 18°C,[4] a standard that many New Zealand houses fail to meet. In the 2018 New Zealand census, 21.2% of homes were described as "*too cold*" by occupants and 21.5% were described as "*damp*".[5] Cold houses are more prone to indoor damp and mould, and there is clear evidence internationally and in New Zealand of how this contributes to poor health and wellbeing outcomes.[6, 7, 8, 9,] A BRANZ study found that houses kept at temperatures of between 18°C and 20°C could avoid indoor dampness.[10] A cause of cold and damp prone housing is inadequate or ineffective insulation and heating.[11] In addition to the low levels of insulation in older houses, New Zealanders traditionally only heat main living areas and approximately one tenth of homes have no heating source or rely on portable gas heaters.[12] Poor quality heaters may also contribute to raised levels of nitrogen dioxide and other harmful particulates plus avoidable greenhouse gas emissions.

Warmer Kiwi Homes (WKH) is a government scheme run by EECA (Energy Efficiency Conservation Authority).[13] It has the primary objective of making New Zealand homes warmer, drier, and healthier, with a secondary objective of improving the energy efficiency of homes. Improving energy efficiency of houses can contribute to some combination of: (i) reduced energy use for a given indoor temperature, and (ii) increased indoor temperatures for given energy use.[14] The first aspect contributes to a reduction of carbon emissions and to alleviation of 'energy hardship';[15] the second to improved health outcomes.

WKH aims to help low-income owner-occupiers overcome financial barriers to energy efficiency by providing insulation and clean, effective and efficient heating to the main living area at low or no cost to the homeowner. Two core aspects of the programme are:

(i) Providing retrofitted insulation to older houses with insufficient existing insulation.
(ii) Providing clean heating devices to living areas in houses that do not have such heating.

In practice, most clean heating devices fitted within the WKH programme are heat pumps.[16] The scheme is available to homeowners where the house is located in a more deprived area (NZDep = 8, 9 or 10) or in which the homeowner holds a Community Services Card (CSC) which is available to people on low incomes. Homes which receive a heater must also have been insulated first, either through the Warmer Kiwi Homes programme or independently.

The Phase 1 report to EECA on WKH identified that considerable evidence exists to support positive effects of retrofitted insulation in the New Zealand context.[17, 18] Much of this evidence relates to prior evaluations of the Warm-Up New Zealand: Heat Smart (WUNZ:HS) retrofit programme.[19] Fyfe et al.,[20] extended previous health-related evaluations of this programme finding that retrofitted insulation reduced hospital admission rates, especially for respiratory disease, asthma and ischaemic heart disease in people aged over 65 years. Fyfe et al.[21] further showed that retrofitted insulation reduced both the incidence and severity of chronic respiratory disease.

Based primarily on benefits from retrofitted insulation, the Phase 1 report concluded that the WKH scheme had, as a central estimate, a benefit cost ratio (BCR) of 4.66; i.e. $4.66 worth of benefits for every $1 spent. This estimate excluded benefits relating to improved comfort and wellbeing following a retrofit. The report concluded that there was less thorough evidence regarding the net benefits of installing heat pumps as part of a retrofit programme, and the evidence that was available was conflicting. [22, 23, 24, 25, 26, 27, 28, 29]

Since the Phase 1 report, several new relevant studies have been published. Analysing the link between fuel deprivation and life satisfaction, Davillas et al.[30] show that subjective wellbeing is clearly associated with energy hardship. Based on this study, we might therefore expect to observe a link between the WKH heat pump intervention and householders' wellbeing if retrofitted heat pumps lead to improved energy efficiency within the home.

Several studies indicate that benefits of a heating intervention may be dependent on contextual factors relating to household type, house characteristics,[31] the environment, and the scheme itself.[32] For instance, a recent UK study[33] of a first-time central heating intervention for lower income households (most of whom were homeowners) found improvements in the indoor environment, finances, and mental well-being. Responses differed across participants, potentially reflecting diverse resident and housing characteristics. Similarly, an assessment of a retrofit scheme in Ireland[34] found persistence of behaviours affecting energy use following a retrofit which had the potential to cancel out some of the savings made through retrofitting. The authors of that study argued for an integrated approach that combines a housing retrofit with a programme to re-shape householders' energy use practices.

An interim evaluation of the UK's Warmer Homes Fund (WHF),[35] designed to reduce fuel poverty, includes effects of interventions for rural homes, some of which (but not all) include heat pumps. (The heat pump intervention is not differentiated from other interventions that include LPG-based solutions.) Based on questionnaires, 82% of respondents reported being able to keep their whole homes warm when it was cold outside compared with 16% before the intervention. Furthermore, 46% stated it was easier to afford their energy bills after the intervention, compared with 16% who found it more difficult to do so; 59% reported better physical health after the intervention and 44% reported better mental health.

Another UK intervention designed to reduce fuel poverty was undertaken in East Sussex over 2016 to 2018 with heating and/or insulation installed in 149 homes.[36] Unlike the WKH programme, the majority of interventions comprised new boilers or new central heating systems. Nevertheless, the results are instructive: Householders' self-rated health and wellbeing were significantly higher post-installation and interviewees reported fewer chest infections, reduced pain, feeling less anxious and depressed, and feeling happier and more relaxed. These benefits were accompanied, in many cases, by reported reductions in energy bills.

These findings from policy interventions regarding cold homes in the UK are consistent with findings from a recent study using data from the UK Household Longitudinal Survey.[37] That study found (after controlling for initial mental distress) that moving into a cold home is associated with almost double the odds of experiencing severe mental distress for those who initially had no mental distress, and over three times the odds of severe mental distress for those previously on the borderline of severe mental distress.

Barrington-Leigh et al.[38] examined a retrofit programme in China that subsidises heat pumps and electricity while banning coal. They found that households in higher income districts eliminated coal use with benefits for indoor temperature, indoor air pollution, and life satisfaction. However, there was only partial effectiveness of the programme in lower income districts. The authors concluded that extra support for the less affluent is essential in order to make such a scheme effective in poorer areas.

Perhaps the most similar evaluation of a programme to this evaluation of WKH is that of Sustainability Victoria examining impacts of the Victorian Healthy Homes Program.[39] The programme comprised a randomised control trial of approximately 1,000 low-income households in Victoria (each of which had a health or social care need). Treated houses received retrofits across multiple dimensions. Approximately half the treated houses received a new heat pump (reverse cycle air conditioner), but gas remained the main form of heating for many of the households. Results were not split according to treatment type (e.g. heat pump versus other forms of upgrade). Average indoor temperature for treated houses increased by 0.33^{o}C, with increases particularly strong in the morning; exposure to temperatures of less than 18^{o}C was reduced by 43 minutes per day. Treated householders were more than twice as likely as controls to report that their home felt warmer over winter and they reported reduced condensation. These gains occurred despite a significant reduction in gas use in upgraded homes, with no significant change in electricity use. Significant health benefits were reported, including reduced breathlessness and improved quality of life and mental health. A cost benefit analysis showed a benefit: cost ratio of 2.7, with the bulk of benefits coming through health-related avenues.

Together, the New Zealand and international research implies that policy initiatives which encourage more efficient heating and improved thermal comfort are likely to result in overall societal benefits. The science of evaluating the monetary equivalent value of some of these benefits (so that they can be included in a CBA) is, however, still in its infancy. A recent New Zealand contribution is that of Smith and Davies[40] which is based on Stats NZ data gathered through the General Social Survey (a randomly sampled survey of approximately 8,000 New Zealand adults, with a response rate of around 80%). Smith and Davies use cost-wellbeing techniques to value benefits attributable to various housing characteristics. Cost-wellbeing analysis is an extension of cost benefit analysis in which benefits of an intervention are assessed using their contribution to a person's subjective wellbeing (measured by their response to a question on overall life satisfaction) together with an estimate of the monetary-equivalent value of this change in subjective wellbeing. Across the full population, the study estimates that the cost of being in a house that is considered "sometimes cold" is $3,591 to $10,458 (relative to being in a house that is "never cold") while the cost of being "often or always cold" is estimated at $5,429 to $14,457.[41] Each of these ranges is wide, indicating considerable uncertainty in the monetary equivalent wellbeing effects of having a cold house. Smith and Davies also estimate costs of mould, and of poor mental or physical health associated with housing. It is important not to double count benefits, so in attributing wellbeing benefits, we count only temperature benefits, since the temperature benefits are likely to influence each of mould, mental health and physical health. In our application of these estimates, we adopt the figures, based on Smith and Davies, that are incorporated into Treasury's CBAx model.[42]

Given the findings summarised above, it is the case that there are still few studies of the specific benefits attributable to fitting heat pumps within a housing retrofit scheme. Our focus is to understand how heat pumps have contributed to occupants' heating behaviours, wellbeing and comfort, their electricity use, and to indoor environmental outcomes including temperature, relative humidity and CO_2. The eligibility criteria for WKH participation means that this study is applicable to homeowners living in poorer areas or who are on lower incomes. Being homeowners, most recipients will not be amongst the most disadvantaged in society but the other eligibility criteria imply that most will also not be amongst the most advantaged.

Report structure

Section 2 summarises the evaluation methods used in the study. The evaluation includes information gathered from specially designed household surveys, indoor environmental monitors placed in participants' living areas, and electricity records. The section also outlines logistical challenges which arose through 2021. Section 3 provides brief details of characteristics of houses and households that are included in the evaluation. Section 4 summarises the results based on information gathered from the household surveys, the internal environmental monitors and from electricity records. Section 5 provides the methods, data and outcomes of the CBAs relating to the WKH programme. Conclusions are presented in section 6.

2: Evaluation Methods

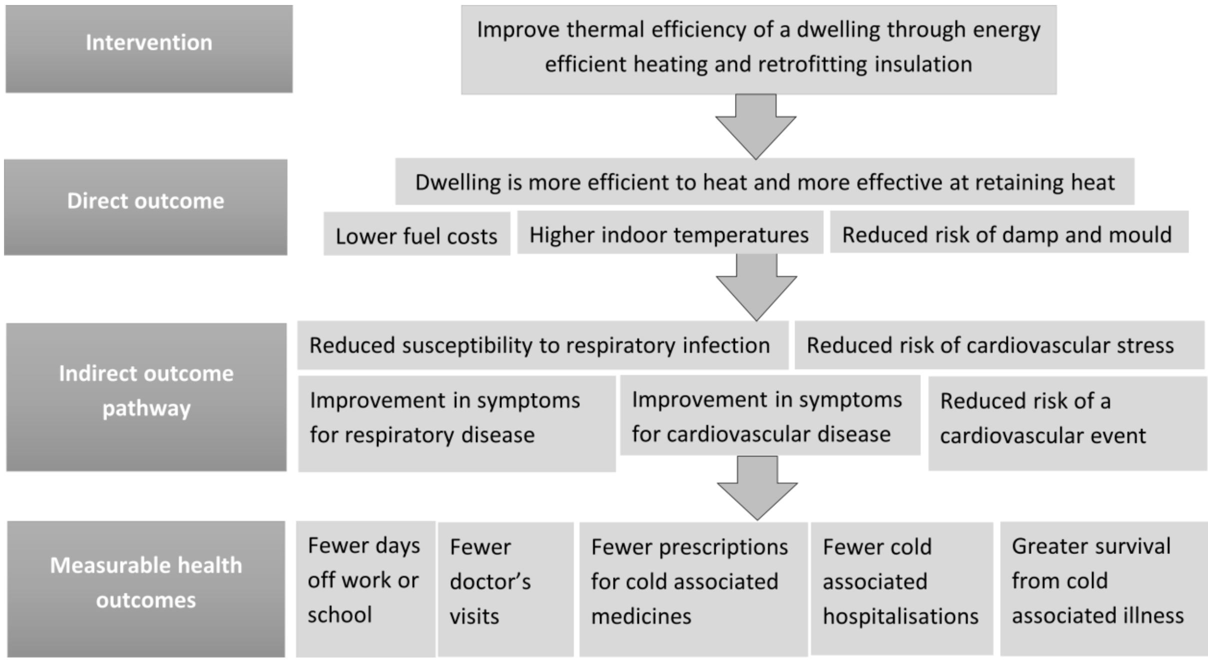
2.1 Outline

New information gained for this evaluation focuses on the effectiveness of the WKH heat pump intervention in improving household energy efficiency, comfort, health, and wellbeing. These findings are combined with other information to compile CBAs relating to the WKH heat pump component, the WKH insulation component and the combined (heat pump and insulation) elements of Warmer Kiwi Homes.

Figure 2.1 provides a conceptual outline of the hypothesised causal pathways from the WKH intervention through to health outcomes. The WKH intervention is designed to improve the thermal efficiency of a dwelling which has direct outcomes (e.g. higher temperatures). These direct outcomes affect the health of house occupants (e.g. fewer colds) via a causal pathway (e.g. reduced susceptibility to respiratory infection). The health outcomes have consequential societal (including fiscal) benefits. Separate to the health consequences, the intervention also affects carbon emissions via impacts on fuel use. The greatest gaps in our knowledge about these causal pathways regard the effects of heat pump installation on energy use, indoor temperatures and indoor dampness. These aspects therefore form key aspects of our evaluation.

For the evaluation, a before and after study design using an opportunistic sample of Warmer Kiwi Homes subsidy applicants was adopted. The study began in June 2021 in four locations across New Zealand covering each of New Zealand's three climate zones:[43] Auckland (climate zone 1), Waikato (climate zone 2), Wellington (climate zone 2) and Christchurch (climate zone 3). We group Waikato and Wellington (both climate zone 2) in our analysis. Of the 2021 cohort, 85 continued in the evaluation through to the final survey in 2022. The continuing 2021 cohort was supplemented by a new cohort of 37 houses beginning in 2022 drawn solely from Wellington.

Figure 2.1: Hypothesised causal pathways from WKH intervention to health outcomes



2.2 Study Components

The evaluation includes several components to provide a comprehensive assessment of the impacts of installing a heat pump in the living area of the home. These components comprise:

- An assessment of the physical impacts of the heat pump on living area temperature, relative humidity, and CO_2 levels through data gathered by installation of monitoring equipment in the main living area. For the continuing 2021 cohort, this monitoring extended over two winters plus a summer (with information gathered also for spring and autumn), while for the 2022 cohort, the monitoring covered one winter.
- An assessment of occupant wellbeing and behaviours which influence energy consumption and indoor environmental quality, through data gathered via household questionnaires administered before and after heat pump installation. The questionnaires are also used to understand heating and ventilation practices and occupant reported indicators of dampness and mould. The 2021 cohort received an 'after' questionnaire in spring 2021 and those continuing into 2022 received a subsequent post-installation questionnaire in spring 2022, so responded to three surveys (including the 'before' survey.) The third survey enabled us to ask about use of the heat pump as an air

conditioner over summer 2021/22. We refer to these three questionnaires henceforth as the Before, After and Subsequent surveys.

- An assessment of house condition through an inspection of the exterior of the house at the time of the Before survey.
- An assessment of the change in energy use of the household consequent on having the heat pump fitted by collecting smart meter electricity data from participating households. (For the 2021 cohort, we are also able to compare winter 2021 energy use of participating households with energy use from matched control households.)
- For the 2022 cohort, an assessment of heat pump energy use by installing an energy monitoring device connected to the heat pump.[44]
- A set of cost-benefit analyses (CBA) for the major components of WKH at the societal level. Analysis is also presented at the narrow fiscal level. The CBAs use the Treasury's CBAx tool to help align results to the Treasury's Living Standards Framework (LSF).

2.3 Study Population and Data Collection[45]

The study population for the 2021 cohort was recruited opportunistically through five Warmer Kiwi Homes approved heat pump providers: Energy Smart, EnviroMaster, Greenside, Mint and Sustainability Trust. The study population for the 2022 cohort was recruited similarly through Sustainability Trust and Energy Smart.[46]

In 2021, difficulties in recruiting households and in accessing heat pumps and monitoring equipment were encountered due to issues related to the COVID-19 pandemic, the Suez Canal closure and other supply chain delays. These issues led to significant delays in heat pump installation. Similar delays occurred in 2022 as a result of supply chain issues including service provider staff shortages. These challenges led to unavoidable variability in the amount of time available to conduct baseline monitoring of the indoor environment conditions. One advantage of the variable delays in receiving a heat pump (and in some cases, not receiving a heat pump at all in the relevant monitoring period[47]) was that the timing of heat pump installation had a large random element associated with it which gives the statistical analysis some properties of a randomised control trial in which some elements (but not all) were randomised.

2.4 The Questionnaires

Information on the demographic composition of the household, heating, ventilation and energy use habits, thermal comfort, health, and wellbeing was collected through web-based questionnaires. The Before survey was completed by participants when the fieldworker visited the house. Fieldworkers also collected data on physical characteristics of the house during this visit. The After and Subsequent surveys were conducted over the telephone. One additional question in the Subsequent survey referred to use of the heat pump as an air conditioner over the 2021/22 summer which enables us to test the impact on the outcome variables of using the heat pump as an air conditioner over summer.

2.5 Indoor Environmental Monitoring

In order to monitor the indoor environment, an EnviroQ device was used to collect data at half-hourly intervals on temperature, relative humidity, carbon dioxide, and light. In houses that did not have the network coverage required for the EnviroQ, a Hobo device (which records temperature and relative humidity at half-hourly intervals) was installed. In order to maximise consistency, the devices were placed on a perpendicular, internal wall at a distance between three and four metres from the heat pump wall at a height of 1.5m.

2.6 Electricity Monitoring

Data from participating households that had a smart meter were requested from electricity companies through the Electricity Authority (EA) Transfer Hub. Half-hourly data were requested for up to two years prior to the date of the request. Data supplied depended on what was available from the electricity company. Electricity use of participant households in each cohort acted as controls, utilising the staggered installation of heat pumps across both cohorts.

For the 2021 cohort, each individual house was also matched to up to 10 control houses that had received a heat pump in 2020. Matching was based on Stats NZ Statistical Area 2[48] and by electricity use in March 2021 (a month unaffected by summer vacations and when the heat pump was unlikely to be used for heating). The matched data enabled a deeper cohort of ‘control’ houses against which to compare our ‘treated’ houses (i.e. WKH houses with a heat pump installed) than is possible when limiting the sample solely to the recruited houses.

For the 2022 cohort, an Efergy energy monitoring device was also installed (by the heat pump installer). These monitors returned heat pump electricity use data at minute intervals, enabling precise readings both on heat pump use and electricity use. Detailed analysis of this data will be included in future research.

2.7 Weather Data

Weather data were collected from the weather station closest to participating households that had a full set of records for the study. Minimum, maximum, and mean temperature were downloaded from the NIWA Cliflo website.[49] These data were used as a control variable for the analysis of indoor temperature, CO_2, and electricity use. Relative humidity data were also downloaded from the same weather stations to act as a control variable in the analysis of indoor relative humidity (and indoor CO_2) in the living area.

3: Demographic Profile[50]

The 2021 cohort comprised 127 households while the 2022 cohort comprised 37 households. Of the combined cohorts, 56 (34%) were in climate zone 1 (Auckland), 82 (50%) were in climate zone 2 (Waikato and Wellington) and 26 (16%) were in climate zone 3 (Christchurch). All 164 households (across the two cohorts) completed the Before survey, 153 completed the After survey (of whom 129 had the same respondent as in the Before survey) and 85 completed the Subsequent survey (of whom 74 had the same respondent as the Before survey, and 67 had the same respondent for all three surveys).

The study population comprised mostly multi-person households (with an average of 2.7 people per house). Most respondents were of working age (18-64 years) and worked full or part-time. The majority of households reported having sufficient income to meet their needs, and over two-fifths (43%) received the Winter Energy Payment.

Self-reported health of respondents from the Before survey was generally positive with most rating their health as excellent, very good or good. Likewise, overall life satisfaction ratings were positive with 85% rating their life satisfaction at seven or above (on a scale of 0 to 10); the majority also rated specific areas of wellbeing positively (using the WHO5 questions that relate to current mental wellbeing).

In the Before survey, however, over three-fifths of respondents (61%) said their house was always or often too cold during winter. Only 18% of houses in the sample were self-reported as not being draughty. Moisture was identified as an issue with 63% of households reporting that there was always or often condensation on the living room windows during winter. Householder-assessed dampness, defined as "*a damp feeling, visible damp patches or a musty or mouldy odour in the living* *room or any of the bedrooms*", was always or often present in winter in 20% of houses. Visible mould in the living area or bedroom was always or often present during winter in 15% of houses.

Almost three-quarters of respondents reported that they sometimes, often or always limited their heating due to cost. Consistent with these figures, a majority of respondents reported applying for the WKH subsidy to improve their warmth, with the next strongest motivator being to reduce costs. Almost all of the study households heated their living room in winter (mostly by some form of electric heater) prior to the heat pump being installed.

4: Heat Pump Impacts[51]

4.1 Surveyed impacts on Households

Of the 117 houses (with usable survey responses) in the 2021 cohort, 100 had received their heat pump by the time of the After survey, while of the 35 houses (with usable survey responses) in the 2022 cohort, 28 had received their heat pump by the After survey. All 2021 cohort houses had a heat pump installed by the time of the Subsequent (second year) survey.

When interpreting the survey results that follow, the survey timings should be borne in mind. Each of the Before surveys was conducted in winter, whereas the After (and Subsequent) surveys were conducted in spring. It is possible that some responses may reflect recent weather in the respondent's location with warmer weather expected for the spring surveys.

The Interim Report described the self-reported behaviours of 2021 cohort respondents in relation to use of their heat pump once installed. Approximately two-thirds switched the heat pump on when they felt cold (rather than leaving it at a set temperature or using the timer). The modal temperature set by respondents was 20^{o}C (with a reasonably symmetric distribution between 15^{o}C and 24^{o}C).

The analysis of responses to the After versus Before survey and to the Subsequent versus Before survey is restricted to households in which the same respondent answered both surveys. The analysis shows several positive outcomes for households in the first winter of having their heat pump fitted. The first three columns of Table 4.1 show transitions from the Before to the After survey for wellbeing and related variables as reported by respondents, disaggregated according to whether they had had a heat pump fitted. The final three columns show transitions from the Before to the Subsequent survey (noting that all Subsequent survey respondents had had a heat pump fitted). The transitions show whether the respondent's wellbeing response improved, remained constant, or worsened.

The broadest (evaluative) wellbeing question is the life satisfaction question used in Stats NZ's General Social Survey: "*Please think about your life as a whole these days. This includes all areas of your life. Where zero is completely dissatisfied, and ten is completely satisfied: How do you feel about your life as a whole?*". A further five wellbeing questions correspond to the WHO5 measure of current mental wellbeing (also used by Stats NZ) relating to cheerfulness, being calm and relaxed, being active and vigorous, feeling fresh and rested, and having daily life filled with interest. The questions are asked, for example, as: "*In the last 2 weeks, how often have you felt cheerful and in good spirits?*". In each case, response categories for the WHO5 questions comprise "*All of the time; Most of the time; More than half of the time; Less than half of the time; Some of the time; At no time; Don't know; Refused*".

In the After versus Before survey columns, the first line in each category reports transitions (worsened, constant, improved) between surveys for respondents who had had a heat pump fitted, while the second line reports transitions for those yet to receive their heat pump. Some questions in the After survey were applicable only to respondents who had received a heat pump so the 'No' row is empty for these questions.

We initially look at transitions from the Before to the After survey. The transitions for Life satisfaction show that, of those who had received their heat pump, 44% of respondents recorded improved life satisfaction compared with 29% whose life satisfaction had declined (the others remaining constant). For those who had yet to receive their heat pump, the responses were 39% and 28% respectively. No clear associations are apparent between heat pump installation and changes in any of the WHO5 measures or with the self-reported health measure.

A strong association is observed between heat pump installation and whether a household reported changes in their living area being cold. Of the households that had a heat pump fitted 77% reported a reduction in cold with just 7% reporting a worsening. Those without a heat pump fitted also reported a net improvement with respect to cold but the net proportion relating to an improvement was much lower than for those who had had a heat pump installed. Households with a heat pump installed overwhelmingly reported improvements with respect to condensation (89% improved), dampness (47% improved) and comfort (87% improved).

Table 4.1**:** Wellbeing transitions with and without a heat pump installed (After versus Before, and Subsequent versus Before survey responses)

Indicator	Heat pump fitted	After vs Before			Subsequent vs Before		
		Worsened	**Constant**	**Improved**	**Worsened**	**Constant**	**Improved**
Life satisfaction	**Yes**	31	30	47	20	26	27
	No	5	6	7			
Cheerful, good spirits	**Yes**	20	49	35	18	33	21
	No	2	11	5			
Calm and relaxed	**Yes**	28	45	33	25	25	22
	No	5	5	8			
Active and vigorous	**Yes**	25	40	40	20	29	23
	No	6	9	3			
Fresh and rested	**Yes**	34	31	41	20	29	23
	No	5	10	3			
Filled with interest	**Yes**	33	38	35	17	18	27
	No	3	9	6			
Self-reported health	**Yes**	21	61	27	11	42	21
	No	4	8	6			
Perceived cold	**Yes**	8	17	85	2	13	50
	No	4	5	9			
Perceived condensation	**Yes**	1	11	96	2	16	55
	No						
Perceived dampness	**Yes**	1	56	50	1	37	35
	No						
Perceived comfort	**Yes**	4	9	89	0	1	73
	No						
Restricted heating due to cost (HP)	**Yes**	5	25	75	2	17	51
	No						
Restricted heating due to cost (Other)	**Yes**	10	27	69	4	21	45
	No						

Notes: After vs Before shows the transition from the Before to the After Survey (covering both cohorts); Subsequent vs Before shows the transition from the Before to the Subsequent survey (covering all 2021 cohort houses with eligible responses in both surveys). In all cases, responses are limited to surveys with the same respondent in each survey. The perceived condensation, dampness, comfort and cost questions were targeted at houses that had received a heat pump by the time of the relevant survey so the 'No' category for houses without a heat pump in the After survey is empty. All houses had a heat pump installed by the Subsequent survey. The question on whether a household restricted heating due to cost in the previous winter is split into two (in the After and Subsequent surveys) covering each of restricting use of the heat pump and restricting use of other heating devices in the house.

Households with a heat pump also reported an improvement in whether they had had to restrict heating due to cost reasons, with 71% reporting an improvement (measured as not having to restrict heat pump use due to cost relative to the previous winter) while 65% reported that they also had not had to restrict the use of other heaters due to cost (relative to their answer in the previous winter's survey).

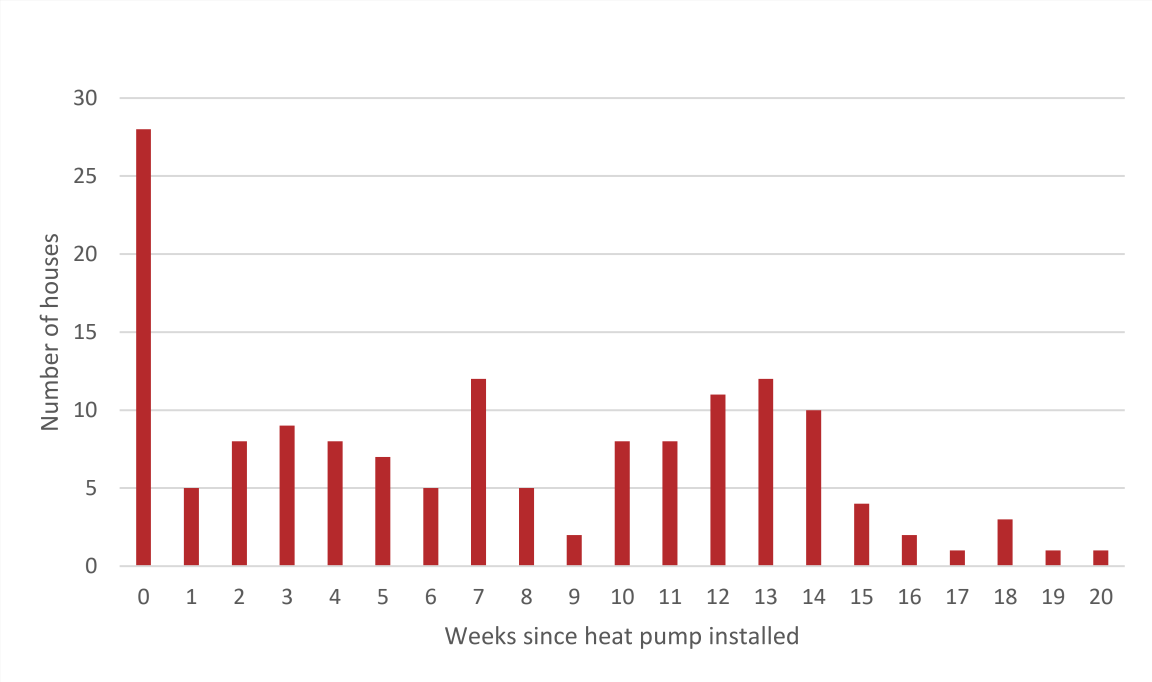
Turning to the transitions from the Before to the Subsequent surveys, we see several of the features from the first year repeated into the second year. In particular, there remains a very marked improvement in respondents' perceptions of cold, condensation and dampness, plus some indication of a net improvement in self-reported health. Households continued to be much less restricted in their use of heating because of cost. Over 80% of respondents who had received their heat pump felt more satisfied with their home, stated that the heat pump had met or exceeded expectations, were very happy or happy with the Warmer Kiwi Homes subsidy programme, and considered that the heat pump had been the right choice for their home.

The data described above indicate that heat pump installation had positive effects on several factors that contribute to householders' wellbeing. We use the data to model the impacts that heat pump installation had on two key factors associated with the householder's wellbeing: (i) perceived cold of the house, and (ii) life satisfaction. Each question is asked of respondents in each survey whether or not the respondent had yet received their heat pump, so in each case we have a control group. However, this control group is only available for the After survey (rather than for the Subsequent survey) so our statistical modelling is restricted to analysis of the After versus Before survey responses.

Figure 4.1 shows the number of houses in the *First winter* sample according to the number of weeks since their heat pump had been installed at the time of the After survey. Of the 150 houses in this sample, 28 had yet to have the heat pump installed by the After survey (or had had it installed for less than one week) while the number of weeks since installation varies considerably.

It is possible that wellbeing responses to the heat pump depend on length of experience with the heat pump. Accordingly, in our modelling, we adopt three different approaches to measure heat pump installation. In one approach, we include a variable that simply indicates whether a heat pump had been installed at least one week prior to the After survey. In the other two approaches, we include one or more variables to indicate the length of experience with the heat pump. Technical details for all three approaches are in the Full report. Our modelling also controls for three region and household variables that may impact on installation timing and/or on the dependent wellbeing-related variables. These control variables comprise the climate zone in which the house is situated (*Climate zone*), the household's perceived income situation in the Before survey (*Income meets needs*), and household occupancy numbers in the Before survey (*Occupancy*).

Figure 4.1: Houses by number of weeks a heat pump had been installed as at After survey



Source: Data from After survey.

The two wellbeing outcomes are Likert scale variables, so we initially model each variable using an ordered logit estimator. In each case, we have the (same) householder's responses for both the Before and After surveys for the same variable, enabling us to control for the respondent's prior response for that variable in our estimation. Subsequently, we treat the wellbeing outcome variables as cardinal variables and estimate relationships for the **change** (between surveys) in each of *Perceived cold* and *Life satisfaction* as a function of the heat pump and control variables using ordinary least squares (OLS). The signs and significance of coefficients are similar across the two methods; the OLS results have the advantage of easy interpretability. Both sets of results are presented in the Full Report; here we focus on the more easily interpreted OLS modelling results.

The OLS results for *Perceived cold* indicate that the impact of heat pump installation corresponds to approximately two-thirds of a step change in perception of cold (on a 4-point scale). The estimates are similar whichever heat pump measure is included in the equation and the results are in each case significant at the 1% level.

The OLS results for *Life satisfaction* are not significant at the 10% level although a separate modelling approach shows significance at the 10% (but not the 5%) level. While imprecise, the estimates are consistent across different regression specifications and indicate that life satisfaction rises by approximately half a step (on an 11 point scale).

Given the Covid-related and other factors that affected life satisfaction of respondents, the lack of precision for the *Life satisfaction* estimates is not surprising. In contrast, one can expect a much more direct relationship between installation of a heat pump and perception of cold in the respondent's living area and this is what we find. Accordingly, we use the estimated effects of heat pump installation on *Perceived cold* (in conjunction with the relationship estimated by Smith and Davies between life satisfaction and *Perceived cold*, which is reflected in the Treasury's CBAx model) as a wellbeing-based input into our cost benefit analysis in this evaluation.

4.2 Indoor Environmental Quality

We model the effect of heat pump installation on each of indoor (living area) temperature (°C), indoor relative humidity (%RH), and CO_2 (parts per million, ppm). We also provide descriptive statistics for three separate 'seasons': *First winter* (defined as June-September 2021 for the 2021 cohort and as June-September 2022 for the 2022 cohort), *Second winter* (defined as June-September 2022 for the 2021 cohort), and *First summer* (defined as February-March 2022 for the 2021 cohort). For *First winter*, we have a control group of houses that had yet to receive their heat pump. We have no such control group for *Second winter* so confine our analysis of those outcomes to descriptive statistics on indoor temperatures (which we can compare with those in *First winter*). We also do not have a control group of houses without a heat pump over the summer; instead, we utilise the survey response to whether the household used the heat pump as an air conditioner over summer to divide the sample into a treated group and a control group. Our dataset includes monitoring data that began prior to heat pump installation and continued post installation. We also draw on data from the Before household survey and house inspection survey, and draw on Cliflo weather data compiled by NIWA.

Table 4.2 provides descriptive statistics for the prevalence of uncomfortable temperatures in study houses for the three periods on which we concentrate. For each of *First winter* and *Second winter*, we show the percentage of half-hourly readings that are less than 16°C and also readings that are less than 18°C. For *First winter*, we show the proportions separately for houses that have heat pumps installed and those that do not at the time of the temperature reading. To help control for timing of heat pump installation over the 'winter' period (when external temperature conditions could be quite different), the *First winter* readings are confined to the two weeks prior and two weeks after heat pump installation (and exclude the week of installation) for each house. For *First summer*, we show the percentage of half-hourly readings that exceed 25^{o}C, split by whether the household stated they used their heat pump as an air conditioner and those that did not. In each case, regional splits are shown.[52] All houses had a heat pump by *Second winter* so readings are only shown for houses with a heat pump for that season.

Table 4.2: Prevalence of uncomfortable temperatures (percent of half-hourly readings)

		Total	Auckland	Wellington and Waikato	Christchurch
		Percentage of half-hourly temperatures < 16^{o}C			
First winter:	No heat pump	26.8	18.0	28.7	35.7
	Heat pump	22.1	20.1	24.2	19.6
Second winter:	Heat pump	18.2	11.8	24.3	19.9
		Percentage of half-hourly temperatures < 18^{o}C			
First winter:	No heat pump	46.7	38.4	49.3	53.2
	Heat pump	41.9	40.5	45.4	33.8
Second winter:	Heat pump	37.4	32.6	46.8	29.6
		Percentage of half-hourly temperatures > 25^{o}C			
First summer:	Heat pump not used	18.6	38.1	11.7	5.7
	Heat pump used	22.3	29.6	23.9	5.3

Note: All 2021 cohort houses had a heat pump in *Second winter*, so there is no row for 'No heat pump' in those cases. *First winter* readings are confined to the two weeks prior and two weeks after heat pump installation (and exclude the week of installation) for each house.

For the Total sample, the proportion of temperatures below each of 16^{o}C and 18^{o}C fell in *First winter* once a house had received a heat pump. The fall was very marked in climate zone 3 (Christchurch), less marked in climate zone 2 (Wellington and Waikato) and not observed at all in climate zone 1 (Auckland) in which the percentages increased slightly. In *Second winter*, the proportion of temperatures below each of 16^{o}C and 18^{o}C fell in every climate zone with the effect again being most strongly observed in Christchurch. No clear results are indicated for the use of the heat pump as an air conditioner over summer, although the warmest climate zone (Auckland) does show a marked decrease in temperatures exceeding 25^{o}C for houses that use the heat pump as an air conditioner.

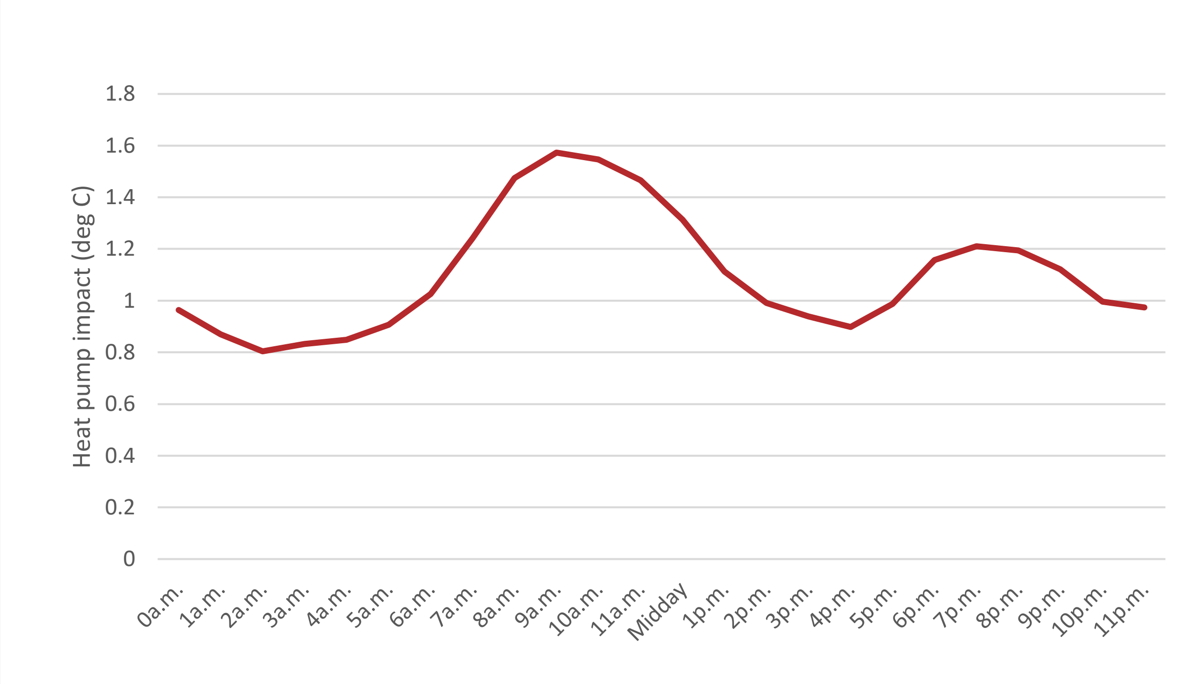
These descriptive statistics do not control explicitly for external temperatures and so provide only illustrative evidence on the impacts of heat pump installation on indoor temperatures. Our subsequent modelling of heat pump impacts on *First winter and First summer* temperatures do account for external temperatures. For *Second winter*, we have no control group so we rely on the descriptive statistics in Table 4.2. These descriptive statistics provide a strong indication that any findings we observe with respect to warmer temperatures in our modelling of *First winter* are likely to be maintained, or amplified, for *Second winter*.

Our formal modelling adopts a 'difference-in-difference' (DiD) approach to assess the impact that installation of a heat pump has on the indoor (living area) environment in *First winter*.[53] We control for a number of time-varying factors including light, external temperature and humidity, and we control for: (i) each house in the study; (ii) each half-hour of the day; and (iii) each separate day of the study for each climate zone (which also controls for the two separate cohorts and for time-varying national and region-specific effects including regional lockdowns). We leverage the fact that heat pumps were installed on different days throughout the programme, with some 2021 cohort properties not receiving a heat pump during winter 2021, and some 2022 cohort properties not receiving a heat pump during winter 2022. For those that did receive their heat pump, the timing of installation was essentially random from the perspective of the household. Thus, we have some features of a natural experiment in which treatment (and its timing) can be regarded as random from the perspective of the household.

Key findings from the modelling for the effect of a heat pump on indoor living area temperatures in *First winter* include:

- The average indoor temperature in the living area of a house with an installed WKH heat pump is 1.1°C higher than in a house without a heat pump fitted (after controlling for outdoor temperature).
- The effect of the heat pump on indoor temperature is greatest at low outdoor temperatures with an estimated 1.9°C increase in living area warmth when the outdoor temperature is 0°C.
- Houses that have a heat pump on average reach an indoor temperature of 18°C when the outdoor temperature is approximately 5°C; houses without a heat pump on average only reach 18°C when the outdoor temperature is approximately 12.5°C.
- As shown in Figure 4.2, the indoor temperature gains (relative to external temperatures) are greatest around the breakfast hours (an extra 1.6°C) and in the early to late evening (an extra 1.2°C).
- The efficacy of the heat pump on temperature is curtailed when a house is draughty with draughty houses having a temperature gain of only around 0.9°C compared with an average temperature gain of 2.1°C for houses that are not draughty. Draught-stopping within houses may therefore be an important complement to heat pump installation.

Figure 4.2: Average temperature impact of heat pump by hour of day

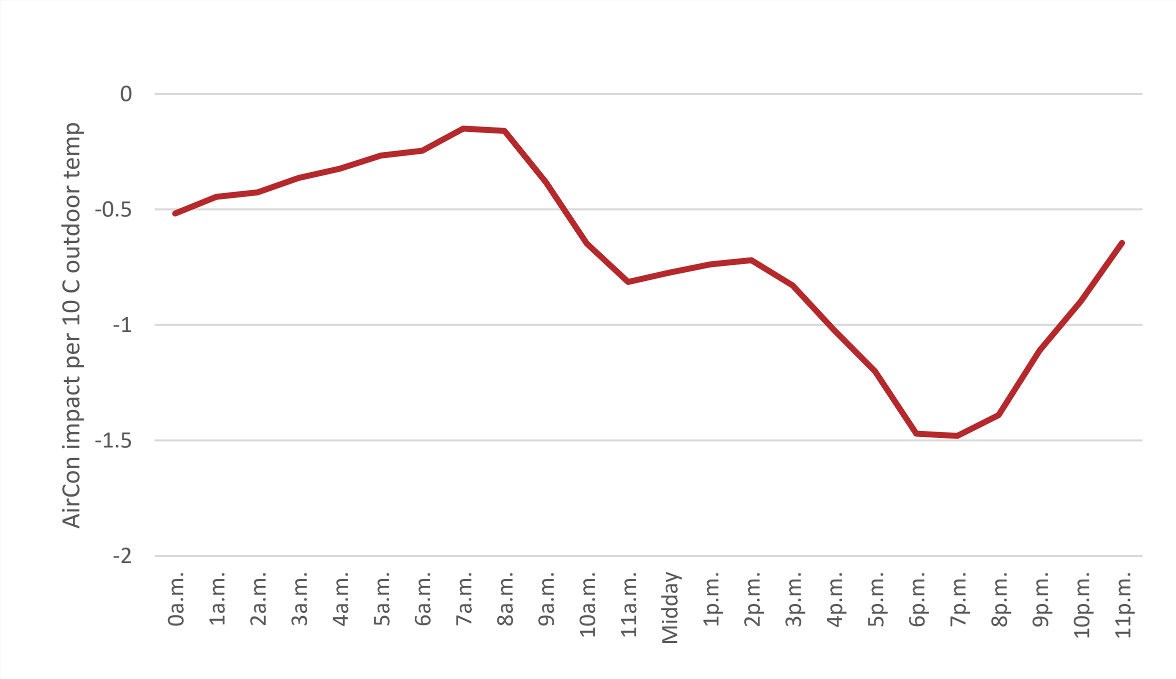


We have modelled the effect of a heat pump on *First winter* indoor relative humidity in an analogous manner. The key finding is that installation of a heat pump significantly reduces relative humidity in the living area, with an average humidity reduction of approximately 5%. Similarly, we find that heat pump installation is associated with a significant reduction in living area CO_2.

Modelling of *First summer* effects shows that households who use their heat pump as an air conditioner have lower living area temperatures in summer relative to houses that do not use it to cool their homes. The temperature reductions rise throughout the day peaking at 6-7pm. Figure 4.3 shows that, on average, a house that uses a heat pump for air conditioning on average has a living area temperature at 6-7pm that is 1.5°C cooler per 10°C increase in outdoor temperature (relative to a house that does not use the heat pump as an air conditioner).

These indoor environmental outcomes of heat pump installation are important for the cost benefit analysis that follows. Our CBA estimates that follow include benefits that are estimated in other studies relating to improvements in health consequent on installation of a heat pump. The results in this study provide strong evidence that a causal pathway exists from installing a heat pump in the living area through to temperature, relative humidity and CO_2 outcomes that are consistent with improved health and wellbeing.

Figure 4.3: Average temperature impact (°C) of air conditioner use per 10°C increase in outdoor temperature by hour of day (*First summer*)



4.3 Electricity Use

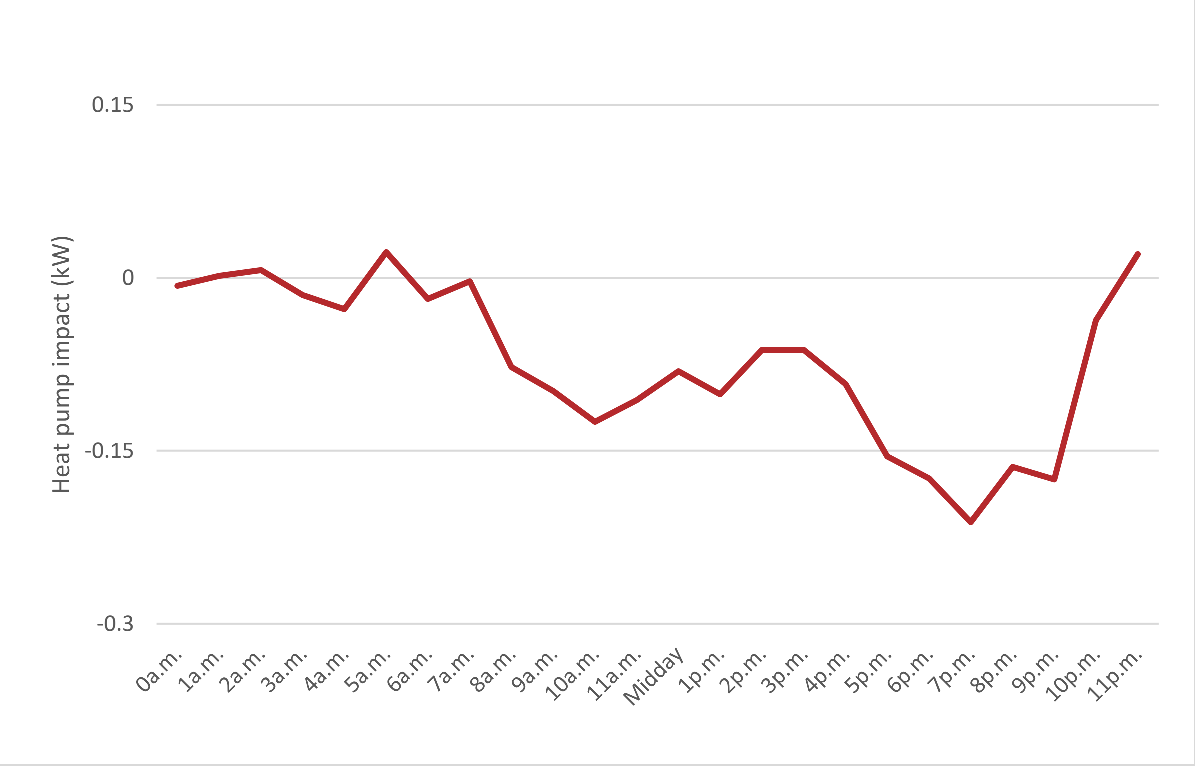
We model how installation of a heat pump in WKH houses affects household electricity use in each of *First winter* and *First summer* (Fyfe et al. 2022b). The modelling is conducted using two separate approaches. The first approach uses the same difference-in-difference approach applied to our WKH sample as used for the indoor environmental modelling. The second approach adds a matched control group of houses drawn from WKH houses previously fitted with a heat pump against which the houses in our study are compared. The two approaches give almost identical estimates of electricity savings so we present only the approach confined to our WKH sample to be consistent with the indoor environmental modelling results.[54]

Key findings (for *First winter*) include:

- Electricity use (through winter) falls in a house fitted with a heat pump by an estimated 16% relative to a house without a heat pump installed.
- The estimates show negligible change in night-time electricity use after heat pump installation.

- The estimates then show consistent electricity savings from 8am through to 9 pm. The savings reach a peak, both in terms of magnitude and statistical significance, between 5pm and 9pm (Figure 4.4).
- The greatest electricity reductions occur in the evening despite temperature gains also being experienced at this time. This result is likely to reflect households previously heating their living area in the evening using less efficient heating appliances prior to the heat pump being fitted.
- Alongside the statistical significance of the electricity results (especially for the late afternoon and evening), the pattern of reductions in electricity consumption provides a strong measure of reassurance that the results reflect genuine savings in electricity use as a result of heat pump installation compared to previous heating patterns.

Figure 4.4: Electricity use impact of heat pump by hour of day (*First winter*)



The *First summer* electricity modelling indicates no significant increase in electricity consumption over summer for houses that use the heat pump as an air conditioner. However, we note that the summer estimates are unable to control for how frequently or intensely each house uses air conditioning, so some houses may use more electricity but we are unable to detect these effects when they are averaged across a diversity of households.

The electricity consumption results are important inputs into the cost benefit analysis that follows. Decreases in energy use have a direct resource effect that are accounted for in a CBA, and they also have an externality effect through reduced greenhouse gas emissions that the CBA also accounts for.

5: Cost benefit analysis

5.1 Purpose

The purpose of the cost benefit analysis (CBA) is to provide a comprehensive analysis of the benefits and costs of installing an energy efficient heater alongside insulation (all homes receiving a heater are insulated as per the insulation component of the programme). A comparative analysis of insulation alone is also provided together with calculation of a BCR (benefit cost ratio) for the full WKH programme (heat pump plus insulation). The CBA updates 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 subsidy programme.[55] Details of costs and benefits, plus other details regarding technical aspects of the CBA, are included in the Full report. Here we summarise the key methods, assumptions and results.

5.2 Methods

The CBA was conducted from a societal perspective and for the first time included a wellbeing component. The societal perspective includes costs and benefits accrued across all domestic stakeholders including government, homeowners and employers, as well as wider society – for example from reduced carbon emissions. Two alternative societal approaches were adopted. The first was based on the wellbeing measure within Treasury's CBAx model, which is based on the work of Smith and Davies (reviewed in section 1), plus energy and carbon saving benefits; we refer to this measure as the wellbeing/energy BCR. The second incorporates direct and indirect health benefits based on outcomes from the WUNZ:HS programme (Preval et al., 2017; Fyfe et al., 2020; Fyfe et al., 2022)[56] in addition to energy and carbon saving benefits; we refer to this measure as the health/energy BCR. An analysis from a fiscal perspective was also undertaken to determine the benefit to cost ratio for present and future government spending only. We stress that the fiscal measures are relevant only for internal budgeting purposes by government and are not measures of societal benefits and costs of the programme. Sensitivity analysis is conducted on different components within the CBA to determine the robustness of the BCRs. A net present value (NPV) of annual savings resulting from the programme is also calculated for each component of the CBA, adjusted to Q2 2021 prices.

Costs

The number of houses insulated and the average cost of insulating a house through WKH were obtained from EECA for the period July 2021 – June 2022. The opportunity cost of the next best alternative heating source is based on average heater size required to heat the living area of a surveyed WKH participant's home. This is included as a negative cost as it represents a resource saving by virtue of the participant not purchasing an alternative heating appliance. The baseline survey of WKH participants indicated that over 90% of households heated their living area in winter, over 80% using some form of electric heating. The number and size of alternative heaters needed is based on an average of MBIE heating calculator estimates for kilowatts required to heat a WKH household.

An annual cost for servicing the heat pump is not included in the base case for the CBA. This is consistent with the analysis conducted in Phase 1 of the WKH evaluation and is consistent with the treatment of alternative heating sources for which no servicing costs are included. An estimated servicing cost for the heat pump is included in the sensitivity analysis.

Benefits

Where possible, benefits have been calculated using data collected from the WKH evaluation: electricity records, living area temperature readings and survey responses. Where benefits are unable to be estimated from the evaluation, they are 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 are based on evaluations of WUNZ:HS.

Direct health benefits – GP visits, prescriptions and hospitalisations avoided – are calculated per person based on the study population of 2.7 people per household. Indirect health benefits – days off school or work avoided – are based only on the subgroup of interest (school children and working adults) and are calculated using the average number of people per WKH evaluation household that were in that subgroup. The same approach is taken to survival, where Preval et. al. (2017) found a significant improvement in survival (for insulation) only for a subgroup of the WUNZ:HS population: those over 65 years with a previous hospitalisation for circulatory disease. The average number of people aged over 65 years per household is calculated and then scaled to those likely to have a circulatory disease based on prevalence of circulatory disease in the WUNZ:HS population aged over 65.

Wellbeing benefits are calculated per household using the results from this evaluation with respect to improvements to "*living in a cold house*" following heat pump installation. We conservatively attribute wellbeing benefits only to the respondent to avoid any risk of double counting (for instance, if the respondent's answer reflected the views of others in the household). Conservatively, we also attribute the wellbeing benefits only to the winter months (June – September). Electricity and carbon benefits are calculated per household and are also scaled to the winter months only. Where the wellbeing component is included, all other health outcomes pertaining to the heat pump component are excluded to avoid double counting.

Where possible, the values listed in the Treasury CBAx tool[57] are assigned to benefits, using the more conservative of values listed and adjusted to Q2 2021 prices using the Reserve Bank inflation calculator.[58] This approach is taken to maintain consistency in valuing the different benefits. Where CBAx values are not available, values are derived from appropriate information sources. For example, the average value per kilowatt energy saved is taken from the MBIE[59] Quarterly Survey of Domestic Energy Price (QSDEP). The price of carbon savings per kilowatt reduction in domestic electricity use is sourced from the EECA website.[60]

An explicit value for wellbeing based on CBAx estimates "*living in a cold house*", could only be identified for the heat pump component of the study. We note from prior studies that the insulation component of the programme also contributes to combatting the effects of "*living in a cold house*" and we have included a wellbeing benefit from insulation in the wellbeing/energy BCR with the contribution from insulation to wellbeing assumed at half that identified for the heat pump.

An explicit value for time off work or school avoided could only be sourced for the insulation component of the study. Noting that having an efficient and effective source of heating is also likely to contribute to fewer days off work or school, we have included these benefits in the health/energy BCR with the benefits assumed to be the same as those accrued from insulation.

Base case scenario

The base case scenario assumes 75% additionality for programme benefits and variable costs (based on the figure used in the CBA of WUNZ:HS); this assumption means that 75% of recipients of the WKH subsidy would not have availed themselves of insulation or a heat pump in the absence of the programme, while 25% would have privately installed these components if the programme had not existed. We use the Treasury recommended discount rate of 5% on costs and benefits accrued over the life of the heat pump (10 years) and insulation (30 years). A 20% fiscal multiplier is applied to (outlays and savings) of government expenditure.

Separate analyses have been undertaken for the whole WKH programme (heat pump and insulation), the heat pump component and the insulation component.[61] Societal BCRs are calculated separately for wellbeing/energy and for health/energy while the fiscal calculations refer only to health/energy.

Sensitivity analysis is conducted, varying the following components (individually) to determine robustness of the estimated BCRs:

- Additionality is adjusted to 100% and 50%.
- An (alternative) 2% discount rate, as recommended for sensitivity analysis by Treasury, is applied.
- Costs are adjusted to include $150 p.a. for heat pump servicing.

5.3 Findings

A summary of outcomes based on the central assumptions above are detailed in Table 5.1. The base case societal BCRs all indicate a net benefit (BCR>1) from the programme as a whole and independently for each of the two components (heat pump and insulation). Whilst the average cost per household is similar for insulation ($2,923) and a heat pump ($2,707), benefits accrue from insulation over a longer period (30 years) compared to 10 years for the heat pump. However, the heat pump also generates benefits from reduced electricity use and reduced carbon emissions. These items represent benefits to the household and the community rather than to government. In addition, government bears the bulk of costs so the fiscal BCRs are less than one in each case. (We again note that the fiscal BCRs are relevant only to government financial flows and are not relevant to considering whether the programme is worthwhile.)

The base case wellbeing/energy BCR for the full WKH programme is estimated to be 4.36. The heat pump component, with a wellbeing/energy BCR of 7.49, has a higher BCR than does the insulation component (3.51); however net savings overall are greater from the insulation component, due to the greater number of houses that had insulation installed (for details, see the full report).

The health/energy BCR for the full WKH programme is 1.89. Again, the heat pump component has a higher BCR (2.15) than does the insulation component (1.78).

Table 5.1: Cost Benefit Analysis: summary table

Base case BCR	Societal perspective	Fiscal perspective*
Whole programme: wellbeing/ energy benefits	4.36	
Whole programme: health/ energy benefits	1.89	0.80
Heat pump: wellbeing/energy benefits	7.49	
Heat pump: health/energy benefits	2.15	0.52
Insulation: wellbeing/energy benefits	3.51	
Insulation: health/energy benefits	1.78	0.98

* The wellbeing/energy approach is not relevant to the fiscal perspective so these cells are left empty.

Sensitivity analysis

As shown in Table 5.2, at a discount rate of 2%, the BCRs increase across all components (and, from a fiscal perspective, the BCR increases to above one for both the whole programme and for the insulation component). Altering additionality to 50% or 100% makes little difference to the BCRs. Including a $150 p.a. servicing cost for the heat pump reduces the heat pump and overall programme BCRs slightly; however a net societal benefit for each component remains.

Comparison to other studies

Whilst a comparative CBA using a wellbeing perspective could not be identified, Liddell and Guiney (2014)[62] developed a framework for measuring the impact of cold and damp homes on mental wellbeing. They formulated a cumulative stressor model based on thermal discomfort, exposure to cold and damp and anxiety around heating costs. New Zealand modelling of the impacts of living in a cold home developed by Smith and Davies were included in the Treasury CBAx tool. However, to our knowledge, this is the first time a wellbeing perspective has been used to investigate an intervention to improve the thermal comfort of housing. A particular strength of this approach is that it encompasses all the interrelated, cumulative, benefits from addressing cold housing in a single measure; from housing quality issues such as dampness and mould, to mental and physical health outcomes and the economic consequences of inefficient heating and poor thermal efficiency.

Table 5.2: Cost Benefit Analysis: Sensitivity analysis summary table

Societal BCR	**2% discount rate**	**50% additionality**	**100% additionality**	**$150 p.a. service cost**
Societal BCR				
Whole programme: wellbeing/energy	5.70	4.11	4.29	4.15
Whole programme: health/energy	2.44	1.78	1.96	1.80
Heat pump: wellbeing/energy	8.46	7.27	7.60	6.96
Heat pump: Health/ energy	2.43	2.09	2.18	2.00
Insulation: wellbeing/energy	4.97	3.48	3.52	3.51
Insulation: health/ energy expenses	2.42	1.77	1.79	1.78
Fiscal BCR				
Whole programme: health/energy	1.09	0.77	0.81	0.84
Heat pump: Health/ energy	0.59	0.51	0.52	0.52
Insulation: health/ energy expenses	1.39	0.95	1.00	1.00

The current CBA takes a conservative approach in attributing health benefits, resulting in values that are lower than in some previous analyses. For example, the WUNZ:HS CBA estimates and the base case for the Phase 1 WKH evaluation each attributed a higher value to the benefit of survival based on the NZTA estimate, rather than the Pharmac estimate that is used in this evaluation. When the Phase 1 evaluation instead used the Pharmac estimate for value of life, its BCR for insulation (1.83) was very close to the health/energy BCR derived here (1.78).

The base case BCR result for the insulation component in this study is also similar to that identified by Chapman et. al. (2009). A follow-up analysis by Preval et al. (2010) examining the impact of providing heaters to households with asthmatic children identified a BCR of 1.09, approximately half that of the health/energy BCR in the current study. The difference is due, in part, to the updated health benefits from reductions in hospitalisations, GP visits and pharmaceuticals dispensed[63] as well as the inclusion of energy and carbon savings in the current evaluation.

5.4 Caveats

A limitation of the estimates presented here is the lack of consistent measures for both health and wellbeing benefits between the heat pump and insulation components of the study. Whilst a wellbeing measure was determined from data collected in the evaluation, collecting similar data for insulation was not within scope of this study. As a consequence, the wellbeing benefit for insulation was assessed at 50% of that for heating. This approach was taken based on the premise that whilst benefits to thermal comfort from insulation are well documented, they are less immediate and less visible than those experienced from an efficient and effective heater.

Data on the impacts on time off work or school as a result of heat pump installation was also unavailable from prior studies. We attempted to collect this data as part of this evaluation, but these data were considered unreliable due to the effects of the COVID-19 pandemic on work and school attendance over the study period. As a result, the corresponding benefits attributed to heating were assumed to be equivalent to those identified for insulation.

Related to the caveats above, we do not have information relating to the combined effects of a heat pump and insulation. It is possible, for instance, that one form of treatment may substitute for the other, while it is also possible that each treatment could magnify the other’s effect. In the absence of this information, we have assumed that the effects are simply additive.

6: Summary of main findings

The findings of this evaluation indicate that installation of a heat pump through the WKH programme results in households that are more comfortable in their homes, with living areas that are materially warmer and drier in winter. On average, living area temperatures are warmer by 1.1°C during winter for a house with a WKH heat pump fitted relative to one without. These benefits occur at the same time as treated households, on average, reduce their electricity consumption, with reduced electricity use being especially marked in the late afternoon and evening. Households that used their heat pump over summer as an air conditioner also experienced reduced living area temperatures, so increasing their comfort, with no significant increase in electricity consumption.

The benefits experienced by households are reflected in the cost benefit analysis. Our central estimate of the societal benefit cost ratio (BCR) for the WKH heat pump component is 7.49 when our estimates are applied to the wellbeing-based yardsticks in Treasury's cost benefit analysis model (CBAx). Estimates based on more conservative assumptions, which exclude many of the wellbeing gains, show a BCR for WKH heat pump installation of 2.15. Corresponding BCRs for the insulation component are 3.51 and 1.78. For the WKH programme as a whole, the corresponding BCRs are 4.36 and 1.89. Each of the heat pump and insulation components, and the wider WKH programme, are therefore estimated to have societal benefits that considerably exceed their costs.

Notes

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[42] The Treasury’s CBAx value for the wellbeing cost of living in a cold home is $6,974, which we scale back (by 0.66) reflecting our estimated effect of heat pump installation on the household’s survey response relating to a cold home.

[43] The climate zones are as defined by Standards New Zealand (NZS 4218: 2009). See Fyfe et al. (2020) for a map of New Zealand's climate zones.
[44] Analysis of the data from this aspect of the evaluation does not feed directly into the CBAs and so will be analysed in future work.
[45] Ethics approval for the study was obtained through New Zealand Ethics Committee (NZEC Application 2021-16). Consultation also occurred with the Office of the Privacy Commissioner prior to data being gathered and stored. Verbal consent to collect data (including smart meter energy records) for the evaluation was obtained over the telephone when study participants were recruited. For a fuller description of recruitment processes, see the Full Report.
[46] In addition to helping us recruit participants, service providers helped us in 2022 by fitting energy monitoring devices on the heat pump during installation.
[47] The 2021 installation delays were not evenly distributed with Wellington lagging Auckland and Christchurch. Details on the timing of heat pump installations for the 2021 cohort relative to lockdown periods are provided in Figure 4.1 of the Interim Report.
[48] https://www.stats.govt.nz/methods/geographic-hierarchy
[49] https://cliflo.niwa.co.nz/
[50] The Full report provides details of the demographic profile of study participants and of house characteristics, including house condition.
[51] This section provides a summary of key findings from the analyses in the Full Report.
[52] The choice of temperature boundaries (16°C , 18°C , 25°C) reflect those highlighted by Stats NZ in releasing the 2018 General Social Survey results for The Household Energy End-Use Project See: https://www.stats.govt.nz/news/around-a-third-of-homes-too-cold-in-winter-and-too-warm-in-summer#:~:text=The%20Household%20Energy%20End%2DUse,as%20a%20comfortable%20indoor%20temperature.
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[60] https://www.eeca.govt.nz/insights/eeca-insights/record-jump-in-energy-and-carbon-savings-from-efficient-product-sales/
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