Motu

WARMER KIWI HOMES EVALUATION 2020: Phase 1

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WARMER KIWI HOMES EVALUATION 2020: Phase 1

EXECUTIVE SUMMARY

This Phase 1 evaluation of WKH comprises **four parts**:

1. A summary of New Zealand and international evidence on costs and benefits of WKH-related retrofits.
2. An estimated benefit: cost ratio (BCR) for the WKH programme based on prior cost benefit analysis (CBA) estimates for similar schemes.
3. A summary of evidence gaps on the impacts of retrofits, with assessment of opportunities to use a WKH evaluation to address some of the evidence gaps.
4. An outline of a proposed evaluation of WKH containing three major components.

Part 1: The summary of New Zealand and international evidence indicates that the CBA of WUNZ: HS conducted in 2011 remains the most comprehensive and up to date CBA relevant to WKH. The WUNZ: HS analysis found a BCR of approximately 4 for the insulation component of that scheme, with the largest benefits relating to reduced mortality of household members aged 65 and over who had had a prior circulatory or respiratory hospitalisation. Few statistically significant benefits were estimated for the scheme's clean heating component, likely a reflection of the small sample size available for heating. International studies provide some useful lessons, although the size of estimated benefits varies widely. Benefits of retrofit schemes are likely to be highly dependent on contextual factors relating to household type, house characteristics, the environment and the scheme itself. Given these contextual factors, care needs to be taken when making general conclusions about the magnitude of benefits of retrofit schemes.

Part 2: This calculation builds on the WUNZ: HS BCR in the following ways:

- It utilises the most recent health and energy use benefit estimates for WUNZ: HS where multiple estimates have been published.
- It interrogates and, in some cases, updates modelling assumptions.
- It applies the findings specifically to the WKH retrofit programme.

The primary BCR estimate for the WKH scheme is 4.66; i.e. $4.66 worth of benefits for every $1 spent. (This estimate excludes benefits relating to improved comfort and wellbeing following a retrofit.) The primary estimate is based on findings relating to the WUNZ: HS scheme, considered the most comparable scheme to inform the analysis. We include a range of sensitivity analyses for the BCR. The BCR is most sensitive to the treatment of mortality benefits. The primary estimate uses a transport sector valuation for human life; if Pharmac's estimated value of life is used instead, the BCR falls to 1.83. The BCR is also sensitive to a lowering of the estimated lifespan of insulation from 30 years (primary model) to 15 years, with the BCR declining to 2.99. Both these sensitivity analyses still indicate a strongly beneficial effect of WKH. In each case, the benefits are dominated by the insulation component of the WKH scheme.

Part 3: Evidence gaps include a need for more knowledge about:

1. Impacts of clean heating (for which evidence is sparse relative to insulation);
2. Distributions of benefits, rather than average benefits;
3. The (possibly non-linear) relationship between health outcomes and indoor temperatures;
4. Benefits of (a) wood and pellet burners; (b) pipe lagging; (c) ground moisture barriers; (d) draft stopping; and (e) ventilation;
5. Impacts of prior house characteristics for the benefits derived from retrofits;
6. Impacts of household characteristics for the benefits derived from retrofits;
7. Mental health and comfort benefits derived from retrofits;
8. Impacts of retrofits on peak energy demand (time-of-day and day-of year);
9. Why some households choose to retrofit while others do not.

Opportunities to address the evidence gaps within a WKH evaluation include the ability to:

1. Control better for prior heating and other house characteristics;
2. Control better for the demographic composition of the treated household;
3. Obtain comprehensive temperature, humidity and noxious gas information to incorporate into an evaluation.
4. Estimate time-of-day and day-of-year energy savings due to retrofits;
5. Estimate the effect of the Winter Energy Payment (WEP) on energy use;
6. Obtain information on comfort, mental health and physical health outcomes from retrofits using questions included in Stats NZ population surveys;
7. Assess why some households do, or do not, adopt subsidised retrofit opportunities;

Part 4: Six research questions are outlined covering:

1. How does the distribution of benefits differ across houses and households (including by receipt of WEP)?
2. What are the impacts of occupant behaviours on outcomes?
3. What are the determinants of whether a household chooses to retrofit?
4. How do comfort levels and health outcomes change as a result of a retrofit?
5. How do temperatures, humidity and noxious gases change as a result of a retrofit?
6. How do comfort and health outcomes relate to changes in temperatures, humidity and noxious gases?

Three evaluation components are outlined to address these research questions:

1. A detailed statistical study of time-of-use energy records to address research question 1.
2. Two qualitative surveys (i.e. before and after a retrofit) to address research questions 2, 3 and 4.
3. Placement of measurement instruments in newly treated houses to address research questions 5 and 6 (with the latter being linked to the qualitative survey).

If only one of the evaluation components were possible, the choice between the first and second component would be finely balanced, and would depend on which research question(s) were given priority. If only two could be undertaken, it is recommended that the first two components should be prioritised.

WARMER KIWI HOMES EVALUATION 2020: Phase 1

INTRODUCTION

This Warmer Kiwi Homes (WKH) evaluation (phase 1 of 2) has four parts:

Part 1: documents New Zealand and international evidence relating to products subsidised under the WKH programme: insulation, heating, moisture barriers, and hot water pipe lagging. This evidence review explores the evidence linking these products with increased indoor temperature and other improvements in indoor conditions. It also presents evidence relating to benefits and costs resulting from these products and relating to attempts to value these costs and benefits.

Part 2: combines economic assessments of the benefits of products available under WKH with EECA programme data to produce a range of estimated benefit: cost ratios (BCRs) for the WKH programme.

Part 3: identifies current evidence gaps informed by the evidence review in Part 1.

Part 4: proposes an approach to future evaluation of WKH.

BACKGROUND: WARMER KIWI HOMES

WKH is the latest in a series of national programmes administered by EECA which subsidise home insulation and heating products. Prior to WKH, EECA administered similar large-scale programmes such as Warm Up New Zealand: Healthy Homes (WUNZ: HH) and its predecessor Warm Up New Zealand: Heat Smart (WUNZ: HS).

The ongoing operation of these programmes reflects a need to address the historically poor quality of New Zealand's housing stock which results in inefficient energy use and negative health externalities. Foundational evidence for the benefit of insulation and heating retrofits includes two randomised controlled trials (RCTs) carried out by He Kainga Oranga, the Housing and Health programme of the Public Health Department of the University of Otago, Wellington, between 2003 and 2008, that demonstrated a range of positive health and energy-use benefits of retrofitted ceiling and floor insulation[1] and improved heating[2]. International reviews have also linked insulation and heating retrofits with positive health outcomes[3].

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[1] Howden-Chapman, P., Matheson, A., Crane, J., Viggers, H., Cunningham, M., Blakely, T., Cunningham, C., Woodward, A., Saville-Smith, K., & O'Dea, D. (2007). Effect of insulating existing houses on health inequality: Cluster randomised study in the community. BMJ, 334(7591), 460–469.

[2] Howden-Chapman, P., Pierse, N., Nicholls, S., Gillespie-Bennett, J., Giggers, H., Cunningham, M., Phipps, R., Boulic, M., Fjallstrom, P., & Free, S. (2008). Effects of improved home heating on asthma in community dwelling children: Randomised controlled trial. BMJ, 337(a1411), 848–862.

[3] Marmot Review Team (2011), The Health Impacts of Cold Homes and Fuel Poverty, Friends of the Earth and the Marmot Review Team, London.

The causal mechanisms for the negative health impacts of poor/absent insulation and inefficient/unhealthy space heaters include exposure to lower indoor temperatures and increased dampness and mould. Other potential causal mechanisms include exposure to nitrogen dioxide and other harmful products of combustion if heat sources are inappropriate (for example unflued gas heaters or open fireplaces). Finally, inefficient use of gas and electricity to heat homes results in avoidable greenhouse gas emissions which contribute to a well-documented range of negative long-term health and environmental outcomes at the global level.

While New Zealand building codes have increasingly addressed these issues, and new homes are required to meet higher standards for ceiling and floor insulation[4], the long average life-span of New Zealand homes (90 years) means that building decisions from the previous century (particularly pre-1978 when insulation was not mandatory) will continue to impact New Zealand for a long time in the absence of intervention. It is hypothesised that these issues have not been addressed by the market due to a range of market failures such as split incentives between landlords and tenants, imperfect information, and the externalisation of health and environmental costs which are bourne by society as a whole and by future generations.

The economic justification for WKH and previous national retrofit programmes can be linked to a body of New Zealand and international evidence that suggests that retrofitting insulation and heating produces net economic benefits. For example, economic assessments of the two He Kainga Oranga RCTs found favourable benefit: cost ratios[5,6]. This evidence informed the development of WUNZ: HS, a $343 million insulation and retrofit programme which built on previous smaller retrofit programmes administered by EECA.

Part of the funding for WUNZ: HS was allocated to an extensive evaluation, which was intended to inform decisions regarding the continuation and future focus of the programme. The evaluation was carried out by a consortium of researchers from He Kainga Oranga, Motu Economic and Public Policy Research and Covec and identified a range of benefits resulting from the programme. The benefit: cost ratio estimated was 3.86:1, a highly favourable result which contributed to the continuation of the programme and to the justification of future programmes such as WUNZ: HH and WKH.

Since the completion of the WUNZ:HS evaluation, and the subsequent publication of results from that evaluation and additional analyses of the data, relatively little primary research has been carried out in New Zealand on the benefits or costs associated with the products subsidised by WKH: insulation retrofits, heating upgrades, installation of moisture barriers or hot water pipe lagging. One exception is the current research of PhD candidate Caroline

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[4] Although New Zealand minimum standards have risen, they are still lower than the current requirements of many comparable nations.

[5] Chapman, R., Howden-Chapman, P., Viggers, H., O'Dea, D., & Kennedy, M. (2009). Retrofitting houses with insulation: A cost-benefit analysis of a randomised community trial. Journal of Epidemiology and Community Health, 63(4), 271–277.

[6] Preval, N., Chapman, R., Pierse, N., & Howden-Chapman, P. (2010). Evaluating energy, health and carbon co-benefits from improved domestic space heating: A randomised community trial. Energy Policy, 38(8), 3965–3972.

Fyfe (University of Otago, Wellington), the results of which are still to be released. The gaps in our current understanding are explored in Part 3 of this report and are noted throughout the report where relevant.

PART 1: EVIDENCE OF COSTS AND BENEFITS

The focus of this section is on the costs and benefits of insulation, heating, moisture barriers, and hot water cylinder insulation regardless of whether they have been quantified in dollar terms. An example of a benefit that is hard to quantify in dollar terms is the He Kainga Oranga finding that heating retrofits rates reduce the frequency of asthma symptoms for asthmatic children[7]. More generally, improved comfort and associated psychological benefits can be assumed to result from insulation retrofits and heating retrofits in homes where pre-retrofit temperatures were not optimal (below 18°C), however these benefits are difficult to monetise.

The evidence summaries which follow, briefly describe how cost and benefit data were derived. Key methodological assumptions and other points of interest are noted. Given that the purpose of this section of the evidence brief is to inform a CBA of WKH, we focus on retrofit options which are also available under WKH. We also highlight any exploration of variation in benefits by geographic location or socio-economic status of household and note important modelling assumptions.

NEW ZEALAND EVIDENCE

Lloyd, Bishop and Callau (2007), *The efficacy of an energy efficient upgrade program in New Zealand*[8]

The authors analysed the energy savings from a range of insulation and heating upgrades using two unoccupied Housing New Zealand (HNZ) homes in Dunedin. The study identified an optimal order for a sequence of retrofits, with all options paying for themselves within ten years via energy-use savings. The sequence is as follows (p 47):

1) Insulate the ceiling
2) Insulate the floor
3) Install a low emissions wood burner or pellet fire
4) Install a heat pump to replace electric heaters used elsewhere in the house
5) Improve air-tightness
6) Insulate walls
7) Install double glazing (or drapes)

It is interesting to note that this study deliberately excludes the take-back effect, because temperatures were held constant. Another study by the same team which looked at 100 HNZ homes that received floor and ceiling insulation, found that insulation resulted in a small increase in average internal temperatures (0.6°C during winter months) but a

[7] Howden-Chapman, P., Pierse, N., Nicholls, S., Gillespie-Bennett, J., Viggers, H., Cunningham, M., Phipps, R., Boulic, M., Fjallstrom, P., & Free, S. (2008). Effects of improved home heating on asthma in community dwelling children: Randomised controlled trial. BMJ, 337(a1411), 848–862.

[8] Lloyd, B., Bishop, T., & Callau, M. (2007). Retrofit alternatives for State Houses in Cold Regions of New Zealand. Energy Management Group, Physics Dept., University of Otago.

statistically insignificant change in energy use[9]. This contrast emphasises the central importance of the take-back effect.

Context/ distinguishing features: Technical analysis that did not account for human behaviour.
Methodology: Combination of energy-use modelling and physically modifying the structure of the two test homes to provide data.
Indicators/ results: The authors identified an optimal retrofit sequence.
Key lessons: As noted above.

Chapman et al. (2009), ***Retrofitting houses with insulation: A cost-benefit analysis of a randomised community trial***[10]

Chapman et al. evaluated outcome data from one of the key He Kainga Oranga trials, the RCT of insulation retrofits. Each participant household in the Housing, Insulation and Health study included at least one occupant who had symptoms of respiratory disease; households were predominantly from low-income communities. Study households were randomly assigned to either the treatment group or the control group. The study collected one year of winter baseline data[11] prior to the retrofit and then a second year of winter data after the treatment group had received the insulation retrofit. The retrofit package included floor and ceiling insulation retrofits plus moisture barriers and draught stopping where appropriate. Insulation products met the then current 2001 Building Code Standards. Data recorded for a sub-sample of homes demonstrated a statistically significant increase in temperature of 0.5°C, and a reduction in each of: relative humidity, the average number of hours per day colder than 10°C, and average hours/day with more than 75% humidity.

Models of health and energy-use outcomes compared treatment and control means after adjusting for baseline year outcomes using a standard Difference-in-Difference approach.

The following benefits were quantified in dollar terms:

- Reductions in inpatient hospital admissions for children (under 19) and people aged 65 and over during winter
- Reductions in outpatient visits for people aged 65 and over (but an increase for children) during winter
- *Increased* GP visits during winter (see below)

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[9] Lloyd, C. R., Callau, M. F., Bishop, T., & Smith, I. J. (2008). The efficacy of an energy efficient upgrade program in New Zealand. Energy and Buildings, 40(7), 1228–1239.
[10] Chapman, R., Howden-Chapman, P., Viggers, H., O'Dea, D., & Kennedy, M. (2009). Retrofitting houses with insulation: A cost-benefit analysis of a randomised community trial. Journal of Epidemiology and Community Health, 63(4), 271–277.
[11] Baseline data were collected for outcome measures (e.g. days off work) and relevant household characteristics. Models controlling for baseline outcomes produce more plausible results than would be obtained in the absence of a baseline i.e. simply comparing treatment and control households across a single winter and assuming that all differences in outcomes either reflect unchanging household characteristics which can be controlled for in models or the impact of the treatment (insulation). Baseline outcome data allows models to control for unmeasured confounding factors that could influence outcomes.

- Decreased days off work and school during winter
- 318 kWh reduction in energy use over winter (a 13.2% reduction)

Benefits reported in the original RCT which could not be monetised in dollar terms included reductions in wheeze and improvements in self-reported health (measured via participant questionnaires).

A primary benefit: cost ratio of 1.87: 1 was estimated where costs were limited to the costs of insulation retrofits charged by the organisations that carried out the retrofits.

It is of note that the GP visit savings were negative (i.e. insulation retrofits were associated with increased costs). This was suspected to be an artifact of the data (GP visit data were only collected from the primary GP identified by participants, but participants were known to use multiple GPs and self-reported visits were lower for the treatment group). This meant that comparisons based on self-reported visits were favourable; however the GP records were used as the principal outcome measure.

It is also of note that the hospitalisation savings that were valued were not statistically significant (although plausible). For this reason the primary value of this RCT in terms of assessing the benefit of WKH is the valuing of outcomes derived from participant surveys and GP records: equivalent information was not available in the national level datasets used to analyse programmes such as WUNZ:HS. It is worth noting that if insulation standards were higher (i.e. 2008 Building Code Standards) then benefits may have been greater, which means that imputing these benefits to the WKH programme is conservative, however we cannot quantify the size of this underestimate confidently.

Context/ distinguishing features: Key New Zealand evidence of impact of insulation retrofit – highly influential and widely cited.
Methodology: RCT – households received retrofitted ceiling and floor insulation plus other minor retrofits. Households were from predominantly lower socio-economic status areas and had an occupant with a respiratory condition.
Indicators/ results: Data recorded for a sub-sample of homes demonstrated a statistically significant increase in temperature of 0.5°C, and a reduction in relative humidity, in the average number of hours per day colder than 10°C, and in average hours/day with more than 75% humidity. Occupants demonstrated reduced wheeze and better self-reported health, reduced rates of hospitalisation (not statistically significant), increased GP visits, reduced outpatient visits and decreased days off work and school in the winter.
Key lessons: Insulation retrofits shown to have real impact in New Zealand context and to be economically rational from a policy perspective.

Preval et al. (2010) ***Evaluating energy, health and carbon co-benefits from improved domestic space heating: a randomised controlled trial***[12]

Preval et al. completed a cost benefit analysis of the Housing, Heating and Health RCT that was carried out by He Kainga Oranga. The trial built on the previous insulation trial and was informed by the observation that, while insulation retrofits were shown to increase indoor temperatures, many households in the previous trial still experienced substantial exposure to indoor temperatures lower than 18°C. Improving heating was an obvious next step, particularly given the prevalence of harmful, inefficient or ineffective heater use in New Zealand homes at the time.

The RCT used a similar design to the previous insulation trial. Each participant household included at least one asthmatic child aged 6-12 and households were located in the South Island or Lower North Island. Treated homes received an energy efficient and healthy (non-polluting) heat pump, pellet burner or wood burner. All homes received an insulation retrofit prior to baseline data collection.

Key outcomes included a statistically significant increase in average intervention group living room temperatures of 1.1°C and of 0.53°C in asthmatic children's bedrooms as well as reduced exposure to temperatures below 10°C in both rooms. Levels of indoor NO2 were also halved. Asthmatic children demonstrated fewer symptoms and an analysis of school records showed that these children missed fewer days of school. Work by Pierse et al.[13] informed by data from the trial further clarified that children's asthma symptoms are strongly linked to exposure to temperatures below 12°C, and the benefit of improved space heating in reducing the symptoms of asthmatic children was primarily the result of reducing their exposure to such temperatures.

Preval et al. used standard linear regression analysis to assess the impact of treatment status on outcomes such as health service use to inform a cost benefit analysis. Analysis controlled for baseline characteristics (i.e. energy use during the baseline winter).

The following outcomes were valued where results were statistically significant:

- GP visits
- Energy use (combination of metered data and participant survey data)
- Time off school (asthmatic children) – data obtained from school records
- Days off work (questionnaire)
- Health service use (questionnaire)
- Asthma medication use (questionnaire)

[12] Preval, N., Chapman, R., Pierse, N., & Howden-Chapman, P. (2010). Evaluating energy, health and carbon co-benefits from improved domestic space heating: A randomised community trial. Energy Policy, 38(8), 3965–3972.

[13] Pierse, Nevil, Richard Arnold, Michael Keall, Philippa Howden-Chapman, Julian Crane, and Malcolm Cunningham. "Modelling the Effects of Low Indoor Temperatures on the Lung Function of Children with Asthma." *Journal of Epidemiology and Community Health* 67, no. 11 (2013): 918–25.

A primary benefit cost ratio of 1.09:1 was calculated, notably lower than that found in the previous CBA pertaining to insulation (1.87:1). A major driver of benefits was time off school and associated caregiving costs for asthmatic children. The authors grappled with the impact of different assumptions about future occupancy over the lifetime of the heater – this was a concern because every study household contained an asthmatic child aged 6-12 but, given high residential mobility in New Zealand it seemed implausible to assume such high rates of asthma in future occupants.

As with the previous CBA, the main relevance of this work for assessing potential benefits of receiving heating retrofitted as part of WKH is estimating benefits that could not otherwise be measured such as GP visits and time off school as a result of obtaining heating.

Context/ distinguishing features: Most comprehensive exploration of impact of heating retrofits carried out in New Zealand.
Methodology: RCT retrofitted homes with heaters (predominantly heat pumps). Baseline insulation was retrofitted to remove the confounding impact of variation in insulation. All households included an asthmatic child aged 6-12 and were located in the lower North Island.
Indicators/ results: Increased indoor temperatures, reduced wheeze for asthmatic children, reductions in GP visits, energy use (combination of metered data and participant survey data), time off school (asthmatic children), days off work, health service use and asthma medication use (questionnaire).
Key lessons: Heating was shown to have numerous tangible impacts but, with a benefit cost ratio of 1.09: 1, the CBA did not demonstrate the level of benefit observed in CBA of the previous insulation RCT.

Grimes et al. (2011) *Cost benefit analysis of the Warm Up New Zealand: Heat Smart Programme*[14]

Warm Up New Zealand: Heat Smart (WUNZ: HS) was a multiyear $347 million programme (July 2009–2014) that primarily provided part-funding for floor and ceiling insulation and heating retrofits (primarily heat pumps in practice). Ground moisture barriers and draught stopping measures were also available. Heating retrofits were only available to homes that met minimum floor and ceiling insulation standards, either due to pre-existing insulation or as a result of having also received retrofitted insulation under the programme. Homes had to be built prior to 2000 and households could participate as Community Service Card (CSC) holders which entitled them to higher rates of subsidy.

A major evaluation was carried out based on the first 46,000 homes to participate in the programme. A control cohort was developed by matching treated houses with up to ten physically similar houses in similar locations using data held by Quotable Value. Anonymised health and demographic data were obtained for the occupants of treatment and control

[14] Grimes, A., Denne, T., Howden-Chapman, P., Arnold, R., Telfar-Barnard, L., Preval, N., & Young, C. (2011). Cost Benefit Analysis of the Warm Up New Zealand: Heat Smart Programme. Prepared for MED, revised 2012.

addresses from the Ministry of Health based on the National Health Index records linked to those addresses at a point in time. Electricity and reticulated gas use data were obtained directly from energy companies.

Analysis involved the development of three separate reports and the synthesis of these reports in a final cost benefit analysis.

The first report addressed industry impacts. The key point of note here is that an extensive analysis of the market for insulation and heating retrofits estimated additionality of 74%, meaning that 74% of retrofits under WUNZ: HS would not have happened in the absence of the programme. The authors state that cost benefit analysis needs to adjust benefits and costs to reflect additionality, i.e. in this case 26% of benefits and costs should be ignored (other than the deadweight cost of taxation[15]). The analysis also explored the opportunity cost of labour at the time and looked at industry impacts of the programme which factored in the production of some insulation products within New Zealand during a period of (post-GFC) recession[16].

The second report explored the metered energy-use impacts of the programme and showed that insulation retrofits slightly reduced metered energy consumption (1%), while heater retrofits slightly increased metered energy use consumption. The absence of information about non-metered energy use was acknowledged as a limitation.

A detailed model was built as part of the combined cost benefit analysis report which incorporated the energy use impact of retrofits across the year (energy savings in winter and additional usage during summer via air conditioning), accounted for variations in electricity cost by time-of-day, and also the location of participant households (net energy savings were greater in colder parts of the country). Analyses of energy use savings presented in Part 2 of this report are based on the average annual savings/costs from the WUNZ: HS study, rather than mirroring the exact details of WKH households. Given the small energy effects involved, it is unlikely that a more detailed analysis would produce results which materially impact the benefit: cost ratio presented.

The third report looked at the impact of WUNZ: HS participation on hospitalisation admissions, pharmaceutical use and mortality. Hospitalisation admissions and pharmaceutical use covered all occupants of treated houses, while the mortality analysis was for the sub-group of household members aged 65 and over who had had a circulatory or respiratory hospitalisation during the baseline year of the study[17].

Analysis of hospitalisation *rates* did not detect any impact of retrofits; however, when costs were summed at the household level and modelled using a Difference-in-Difference

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[15] Deadweight cost of taxation reflects standard Treasury best practice advice that all government spending should be multiplied by a standard multiplier to account for the distortion/inefficiency resulting from changes in household and firm behaviour in response to taxation. Treasury recommend a multiplier of 1.2.

[16] Denne, T., & Bond-Smith, S. (2011). Impacts of the NZ Insulation Fund on Industry & Employment.

[17] Telfar Barnard, L., Preval, N., Howden-Chapman, P., Arnold, R., Young, C., Grimes, A., & Denne, T. (2011). The impact of retrofitted insulation and new heaters on health services utilisation and costs, pharmaceutical costs and mortality: Evaluation of Warm Up New Zealand: Heat Smart.

approach, statistically significant positive reductions in average hospitalisation costs per year were associated with receiving an insulation retrofit. Similarly, small statistically significant changes in household-level average pharmaceutical costs were observed.

Results were estimated separately for CSC households and non-CSC households, and consistent with theory, greater health benefits were observed for CSC households. Interestingly, subsequent analysis did not detect a statistically meaningful impact of CSC status outcomes (see Preval 2015 below). The relevance of this point to the WKH CBA is discussed in Part 2 below.

The impact of participating in the programme (regardless of product received under WUNZ:HS) on mortality rates for people aged 65 and over with a baseline-period hospitalisation was analysed using a negative binomial statistical model and showed that participating in the insulation component of the programme resulted in a statistically significant reduction in the likelihood of death for individuals with a baseline circulatory hospitalisation over the period studied. The value of this reduction in mortality was estimated by using the transport sector Value of Statistical Life (VSL) measure as a basis to estimate the Value of a Statistical Life Year (YSLY). Additional assumptions were made regarding the number of years an individual would gain by avoiding mortality on average (50% of what would be predicted based on a standard life expectancy table). Finally, in order to assess the impact over the lifetime of the product it was necessary to make assumptions about the proportion of each household who met the criteria who would occupy the homes over the estimated 30 years in which insulation would provide benefit: the starting assumption was that occupancy rates would remain consistent over time. Variation in mortality benefits by the CSC status of occupants was estimated by simply calculating the average number of vulnerable individuals that were part of CSC and non-CSC households in the dataset. As this figure was greater for CSC households the estimate per CSC household was greater.

Benefits were imputed from the CBA of the two He Kainga Oranga RCTs. The authors conservatively decided to only impute benefits from previous studies to *CSC* households, reflecting the characteristics of participant households in these studies. Of note, some decisions were made to standardise benefits from the two RCTs, for example standardising assumptions about childcare costs associated with children’s days off school: these were not valued in the CBA of the Housing, Insulation and Health Study. Benefits were imputed based on a breakdown of average household occupant characteristics in the WUNZ:HS dataset i.e. if each household had on average 0.1 child with asthma, and heating was estimated to result in $100 benefit per year per asthmatic child, then the average benefit per household per year was estimated at 0.1*$100= $10.

The cost benefit analysis of WUNZ: HS brought together the costs and estimated benefits of the programme and estimated a benefit cost ratio of 3.86:1 for the primary model, as well as a range of sensitivity analyses. Mortality-related benefits were the primary source of benefits estimated. The benefit: cost ratio was much higher for CSC households than for non-CSC households, again driven by greater estimated health benefits.

Insulation retrofits accounted for the majority of benefits. The measured health benefits of clean heating were estimated to be minor, with no statistically significant benefits arising from clean heating for hospitalisation, pharmaceutical use or mortality. One caveat here is that the sample of houses that received clean heating under WUNZ: HS was much smaller than the insulation sample, and the resulting reduction in statistical power may have disguised any health effects that were, in practice, present. It was not possible to capture benefits of moisture barriers or draught stopping measures in the WUNZ: HS CBA.

Modelling decisions relevant to the CBA of WKH presented in part two of this review include a central discount rate of 4% p.a., estimate of additionality (74%), deadweight cost of taxation multiplier (1.2), and the assessment of industry impacts (which had only a very minor effect on the BCR) and opportunity costs of labour at the time of the programme.

Context/ distinguishing features: Major evaluation of New Zealand retrofit programme.
Methodology: Linked WUNZ: HS participant addresses with suitable control addresses and then identified home occupants for treatment and control addresses via address linkage with MoH NHI data. Models then compared outcomes for treatment and controls using a variety of regression techniques. Officials did not collect data on recipient households and did not randomise treatment, so the analysis is an observational (difference-in-difference) study with incomplete information about treated and control households and their houses.
Indicators/ results: BCR for primary model of 3.86: 1. Benefits included small reductions in hospitalisation and pharmaceutical-use costs and small energy savings. The major benefit was mortality reduction benefits for people aged 65 and over who had had a circulatory hospitalisation during the baseline period. Benefits predominantly related to the insulation component of the scheme with few statistically significant findings in relation to health benefits of clean heating, while clean heating contributed to a small rise in measured energy use.
Key lessons: the WUNZ: HS evaluation was the first New Zealand analysis of housing retrofits with sufficient power to detect rare outcomes such as reductions in mortality.

Blick and Davies (2014) *Cost benefit analysis for a minimum standard for rental housing*

Blick and Davies were commissioned by the Ministry of Business, Innovation and Employment (MBIE) to assess the combined benefits and costs of proposed rental minimum standards including insulation and heating (the standards had 49 components including safety features such as handrails). Their assessment of the benefits of insulation and heating drew on the CBA of WUNZ:HS and they did not identify any additional sources of data regarding the benefits of insulation, heating, draught stopping or pipe lagging that might be relevant to the CBA of WKH. Of note, they adopted an effective lifespan estimate of 15 years for all retrofits including insulation.

Context/ distinguishing features: Does not provide new information but gives a good state of play for the evidence as at 2014.
Methodology: Standard CBA methodology.
Indicators/ results: Benefit cost ratios for a variety of policy settings.

Key lessons: The authors used a lower estimated lifespan for insulation than other cost benefit analyses such as Chapman et al[18].

Preval (2015) ***Statistical and Policy evaluation of large-scale public health interventions***[19]

Preval built on the previous analysis of the health impacts of participation in WUNZ: HS which informed the WUNZ: HS CBA. The statistical models for the impacts of insulation and clean heating retrofits were further refined, and the dataset was also refined, for example by removing individuals with anomalous ages. Key differences in approach to modelling mortality included replacing the negative binomial model with a Cox Proportional Hazard model (recognising that people can only die once) and modelling the impact of insulation and heating retrofits separately. Hospitalisation and pharmaceutical cost models were extended to account for monthly average temperatures and other potential confounders.

The key message of interest in terms of the WKH CBA is that when CSC status was introduced as an interaction term in mortality, hospitalisation cost and pharmaceutical use cost models (as an alternative to the stratification[20] used in the previous analyses), there was little evidence of any statistically significant impact on the size of benefits observed. The author concluded that there was little evidence of impact of CSC status on individual outcomes but acknowledged that this could reflect limitations of statistical power. (However there were still more vulnerable individuals in CSC households, and this aspect is reflected in our benefit calculations below.)

Preval explored the economic impact of adjusted mortality, hospitalisation cost and pharmaceutical use costs by attempting to combine them with the previous CBA. As the spreadsheets informing the previous CBA calculations were not accessible this exercise required a number of assumptions, but of note is the fact that the benefit cost ratio estimated using primary assumptions was 6.4: 1 (p 192) – a substantial increase relative to the ratio reported by Grimes et al. (2011) of 3.86: 1 driven by higher annual health savings attributed to reduced mortality.

Key mortality results were later published in the BMJ Open[21]. The approach to analysis was not changed so this article is not reviewed separately.

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[18] Chapman, R., P. Howden-Chapman, H. Viggers, D. O'Dea, and M. Kennedy. "Retrofitting Houses with Insulation: A Cost-Benefit Analysis of a Randomised Community Trial." *Journal of Epidemiology and Community Health* 63, no. 4 (2009): 271–77.

[19] Preval, N. (2015). Statistical and policy evaluation of large-scale public health interventions (University of Otago). In Public Health: Vol. PhD dissertation. http://otago.hosted.exlibrisgroup.com/primo_library/libweb/action/dlDisplay.do?vid=DUNEDIN&search_scope=default_scope&docId=OTAGO_ALMA21198072740001891&fn=permalink

[20] Stratification in this context means analysing CSC and non-CSC household data separately using separate models.

[21] Preval, N., Keall, M., Telfar-Barnard, L., Grimes, A., & Howden-Chapman, P. (2017). Impact of improved insulation and heating on mortality risk of older cohort members with prior cardiovascular or respiratory hospitalisations. BMJ Open, 7(11), e018079.

Context/ distinguishing features: As per the WUNZ: HS evaluation described above.
Methodology: As above, but various modifications made including extending hospitalisation and pharmaceutical-use models, improving modelling of mortality outcomes, and interrogating variation in effect by CSC.
Indicators/ results: Mortality, total hospitalisation costs (with standard exclusions for pregnancy related costs, transfers etc.)
Key lessons: A robust exploration of previous results gives greater confidence that the health (especially mortality) benefits are real. Variation in modelling assumptions relating to mortality costs shown to have a major impact on cost benefit calculations.

Grimes et al. (2016) *Does Retrofitted Insulation Reduce Energy Use? Theory and Practice*[22]

Grimes et al. revisited energy use data analysed as part of the WUNZ: HS CBA. As with the previous report, analysis was limited to the impact of insulation retrofits and heat-pump retrofits. The key outcome from this article from a WKH perspective is that a refined modelling approach estimated slightly greater energy savings per household as a result of receiving an insulation retrofit – these refined estimates are used in the present study.

Context/ distinguishing features: As per WUNZ: HS CBA described above.
Methodology: Panel-based difference-in-difference model – a slight variant on approach used to analyse metered energy consumption as part of the original WUNZ: HS evaluation.
Indicators/ results: Retrofitted insulation resulted in a statistically significant reduction in metered household energy consumption of approximately 2% across a full year with highest energy savings when outside temperatures were cold, declining to a zero saving when outside temperatures reached 20°C. Clean heat (heat pump) treatment resulted in increased electricity use but little change in total metered energy use other than an increase in energy use at warmer temperatures, when heat pumps may have been used as air conditioners.
Key lessons: Actual energy savings from insulation were approximately one-third of the modelled energy savings predicted by an EECA engineering model (AccuRate), reflecting the take-back effect.

NZIER (2018) *Healthy Homes Standards: Cost Benefit Analysis*[23]

In 2018 NZIER completed an extensive cost benefit analysis of a range of policy options for the proposed Healthy Home Standards for rental properties which included insulation standards, heating standards, moisture ingress standards and draught stopping standards.

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[22] Grimes, A., Preval, N., Young, C., Arnold, R., Denne, T., Howden-Chapman, P., & Telfar-Barnard, L. (2016). Does Retrofitted Insulation Reduce Household Energy Use? Theory and Practice. The Energy Journal, 37(4). https://doi.org/10.5547/01956574.37.4.agri
[23] NZIER. (2018). Healthy Homes Standards: Cost Benefit Analysis of proposed standards on rental home insulation, heating, ventilation, draught stopping, moisture ingress and drainage. Ministry of Business, Innovation and Employment.

This analysis provides an excellent summary of New Zealand and international research to 2018 and builds on the WUNZ: HS CBA findings.

The NZIER model accounted for the characteristics and location of rental properties across New Zealand (which is relevant due to different expected energy and health outcomes in different climate zones) and utilised the EECA Net Benefit Model and AccuRate heating estimator.

Of particular interest to the WKH CBA was NZIER's demonstration of the potential to quantify health gains from previously unevaluated retrofits such as draught stopping if health benefits can be expressed in dollars saved per degree of indoor temperature increase and if evidence can be found linking such retrofits with temperature increases. The basis of this calculation was an estimate that insulation received under the WUNZ: HS programme would produce, on average, a 1.5°C temperature increase (pp 11-12) which allowed benefits per degree to be estimated (excluding mortality related benefits). The authors acknowledged the limitations of this approach and the fact that an additional degree of temperature is likely to have greater health benefits when moving from 15 to 16°C than when moving from 20 to 21°C. Although this technique allowed the authors to assess the value of benefits from estimated temperature increases resulting from draught stopping retrofits, they were not able to use this technique to assess the impact of ground moisture barriers such as those available under WKH due to a lack of information about the impact of these products on indoor temperatures.

Context/ distinguishing features: CBA is based on previously generated results and was intended to inform policy decisions/discussion regarding future minimum standards for rental properties.
Methodology: Combined primary research on benefits and costs with EECA's AccuRate tool and Net Benefit Model to draw detailed conclusions about the size of potential benefits based on location of New Zealand's rental population. The key innovation was the combination of predicted temperature increases for various retrofits with benefit data to estimate the value of benefits per °C temperature increase – this was used to estimate the health benefits of draught stopping which had not been explicitly studied. The authors use an estimated lifespan of 15 years for all retrofits and explicitly factor in annual heat-pump maintenance costs ($20 per year) which were not addressed in the WUNZ: HS CBA.
Indicators/ results: Benefit cost ratios for a variety of policy combinations possible under the then proposed Healthy Homes Standards.
Key lessons: The authors critique the approach used to value mortality in the WUNZ: HS CBA and state a preference for a PHARMAC informed approach which would value a life year gained much lower at approximately $45,000. However, they do ultimately incorporate the value of mortality avoided figures from the WUNZ: HS CBA. The authors also show the potential to evaluate health gains from previously unevaluated retrofits based on modelled temperature increases.

Telfar-Barnard and Preval (2018) *Healthy Homes Guarantee Standard Cost Benefit Input Warm Up New Zealand evaluation rental sector sub-analysis* [24]

The authors revisited the data from the WUNZ: HS CBA in order to explore policy questions relevant to the implementation of the Healthy Homes Guarantee Bill which was passed in 2017. Analysis was limited to homes identified as rental properties that received ceiling insulation retrofits (except for mortality analyses where the tenure restriction limited statistical power too greatly and thus was dropped). A particular focus of the report was on assessing whether the health benefits of insulation varied by whether there was partial/substandard ceiling insulation prior to the retrofit or no ceiling insulation. The authors were also asked to explore whether there was evidence of variation in outcomes for vulnerable groups such as under-fives which had not been explored previously and to explore whether any benefits were associated with other elements of the WUNZ: HS programme such as ground moisture barriers.

The authors found *no* evidence that ceiling insulation retrofit "top-ups" were associated with fewer health benefits, in terms of mortality or health cost reduction, than complete retrofits. The authors note that this result is not consistent with theory but state that this lack of evidence of variation may reflect limitations of statistical power. The single exception was a substantially larger hospitalisation cost saving (and hospitalisation rate reduction) for under-five children who lived in homes that had no ceiling insulation prior to a retrofit relative to those who lived in homes which had partial ceiling insulation. The authors were not able to identify any impacts of draught stopping or ground moisture barriers due to limitations of statistical power.

This report potentially contributes to the WKH CBA in two ways: (i) the result for under-fives indicates that it is worth testing for differences according to pre-existing insulation, and (ii) the absence of variation in most outcomes by prior ceiling insulation status provides further evidence that caution is required in assuming a linear relationship between predicted temperature increase (assumed to be greater if no ceiling insulation is present prior to retrofit) and increased health benefits.

Context/ distinguishing features: Relative to other WUNZ: HS analyses, the key difference is the focus on rental properties.
Methodology: Repeat of previous analyses but limited to rental properties. Focussed on impact of partial vs. no ceiling insulation prior to retrofit and was the first focussed exploration of hospitalisation impacts for children under five.
Indicators/ results: Reductions in respiratory hospitalisation rates for children under five was a novel finding. The other finding of particular importance was the absence of variation in most outcomes by baseline ceiling insulation status.
Key lessons: The paucity of variation in outcomes by baseline ceiling insulation status is another reason to be cautious when attempting to extrapolate health or energy-use

[24] L. Telfar-Barnard, & Preval, N. (2018). Healthy Homes Guarantee Standard Cost Benefit Input Warm Up New Zealand evaluation rental sector sub-analysis: Differences in health events and costs by existing insulation status. Prepared for Ministry of Business, Innovation and Employment.

benefits by attributing linear relationships between increased temperature and improved health as NZIER had done.

Fyfe (2020)

Fyfe is currently undertaking an analysis of data from the *entire* WUNZ:HS programme (2009-2014) which will extend the previous analysis both in terms of the number of retrofits included in the dataset (over 200,000 homes vs. 46,000 homes) and also by using a different analytical design (controls selected from households that later received a retrofit under the programme). The timing of the initial WUNZ: HS evaluation made this approach to selecting control houses infeasible at that stage, but it is an approach suitable for WKH given that WKH is now a well-established programme. Caroline Fyfe's first publication, an analysis of hospitalisation rates is currently being reviewed by the British Medical Journal which unfortunately means that her results cannot be reported here; however she has stated that results are "favourable" (personal communication).

INTERNATIONAL EVIDENCE

The Grimes et al. (2016) paper, cited above, summarised a range of international studies that looked at energy savings resulting from housing retrofits. It highlighted several studies relating to the US Department of Energy's Weatherization Assistance Program (WAP). The WAP is a scheme targeted at low income households that have a deficiency in insulation or heating that has been demonstrated through an energy audit. (Note that the requirement for an energy audit prior to receiving assistance differentiates this scheme from New Zealand schemes such as WUNZ: HS or WKH which do not require a prior energy audit.) The program includes assistance for air sealing, insulation, furnace repair and replacement, refrigerator replacement and ventilation.

Some studies have found sizeable energy savings resulting from the program; for instance Schweitzer (2005)[25] found that WAP participation reduced natural gas use in a typical WAP household by 22.9%. Tonn et al. (2014)[26] found a combination of energy efficiency benefits and non-energy benefits of WAP participation including mental and physical health improvements and fewer doctor visits. By contrast, Fowlie et al. (2018)[27] find results that are more akin to those of Grimes et al. (2016) with respect to energy savings. For the WAP, Fowlie et al. find that savings in the present discounted value of energy costs are approximately only one half of the upfront investment costs and (reflecting the take-back

[25] Schweitzer M. 2005. *Estimating the National Effects of the US Department of Energy's Weatherization Assistance Program with State-level Data: A Metaevaluation Using Studies from 1993 to 2005*. ORNL/CON-493. Washington, DC: US Department of Energy. http://dx.doi.org/10.1016/j.enpol.2010.03.020

[26] Tonn B., et al. 2014. *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program*, ORNL/TM-2014/345. Oak Ridge National Laboratory, Oak Ridge.

[27] Fowlie M., et al. 2018. "Do energy efficiency investments deliver? Evidence from the Weatherization Assistance Program". *Quarterly Journal of Economics*, 133(3), 1597–1644.

effect) and are only one-third of those projected by an engineering model. In addition, they find no increase in indoor temperatures as a result of WAP retrofits.

Maidment et al. (2014)[28] provided a meta-analysis of the health benefits of household energy efficiency policies (including insulation, central heating and double glazing retrofits). The analysis, covering 36 studies, included a range of estimates that included both negative and positive impacts of retrofits. Overall, they found a small, albeit statistically significant, impact of retrofits on the health of residents. The variation in results, both within this meta-analysis and in the evaluations of WAP, indicates that contextual factors relating to the household type (e.g. income level and number of household members), house characteristics (e.g. age and size), the environment (e.g. outdoor temperatures and humidity), and the scheme itself make it difficult to generalise results from one scheme in one country to another scheme in another country. We are therefore cautious about extrapolating international findings to the New Zealand context since a range of characteristics may differ. Examples include: retrofit materials, outdoor temperatures, prevalence of central heating, double glazing, price of electricity, socioeconomic characteristics, cultures, norms and practices (Milne and Boardman, 2010)[29].

Grimes et al. (2016) summarised the international evidence on the take-back effect, for which estimates again vary widely. Defining take-back as the proportion of potential energy savings from a retrofit that is “spent” via additional consumption of energy, Sorrell et al. (2009)[30] found an average temperature take-back effect of 20% across a range of studies. In contrast, in a study of the effects of air conditioner replacement with newer models, Davis et al. (2014)[31] found what is known as a backfire effect in which replacement of older with newer more efficient models increased energy use. These variations in results again show the need to estimate impacts of retrofits on a programme- and context- specific basis.

The NZIER (2018) literature review, summarised above, provides a starting point for other recent international literature relevant to evaluating WKH retrofits. That review, however, was not able to identify further international studies that would directly contribute additional knowledge to the cost benefit analysis of WKH presented in Part 2 below. From a cost benefit perspective, in addition to evidence on impacts of insulation and clean heating, we had a particular focus on the following questions for which New Zealand evidence is lacking:

- Can we quantify the benefits of hot water pipe lagging?
- Can we quantify the benefits of ground moisture barriers?

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[28] Maidment C.D., et al. 2014. “The impact of household energy efficiency measures on health: A metaanalysis”, Energy Policy, 65, 583-593.

[29] Milne G., B. Boardman. 2000. “Making cold homes warmer: The effect of energy efficiency improvements in low-income homes.” *Energy Policy*, 28, 411-424.

[30] Sorrell S., J. Dimitropoulos, M. Sommerville. 2009. "Empirical estimates of the direct rebound effect: A review." *Energy Policy*, 37, 1356-1371.

[31] Davis L., A. Fuchs, P. Gertler. 2014. "Cash for coolers: Evaluating a large-scale appliance replacement program in Mexico." *American Economic Journal: Economic Policy*, 6, 207–238.

We were not able to obtain any new evidence on these two issues that would allow us to value their benefits in economic terms.

While cross-country differences mean that it is not appropriate to extrapolate numerical findings from overseas programmes to New Zealand, there are two relevant studies that we highlight. The first is a recent summary of the WHO's stance with respect to house temperatures and insulation. The second is a health study, highlighted for its methodological approach that can be extended to New Zealand evaluations of retrofit programmes.

WHO (2018) Housing and Health Guidelines[32]

Some key points from these updated WHO guidelines regarding housing and health that are relevant to WKH are as follows:

Context/ distinguishing features: Explored the questions "whether residents living in housing where indoor temperatures are below 18 °C have worse health outcomes than those living in housing with indoor temperatures above 18 °C?" and "Do people living in housing with insulation have better health outcomes than those living in housing without insulation?"

Methodology: Systematic review.

Indicators/ results: The review concluded that there is strong evidence of an association between cold indoor temperatures and adverse health effects.[33] The review acknowledges that there is a lack of precision regarding the temperatures at which adverse outcomes occur, but nevertheless affirms the long standing WHO advice of a minimum indoor temperature of 18° C: *"[w]hile current evidence is insufficient to establish the precise temperature below which adverse health effects are likely to occur, there is high certainty that taking measures to warm cold houses will have significant health benefits and a minimum of 18 °C is widely accepted*."

The other relevant element of the WHO review was an assessment of the evidence that insulation produces health benefits. The review concluded that the evidence for insulation impacting health was "high" but ultimately, *"[h]aving considered the certainty of the evidence, the values and preferences associated with indoor thermal condition, the balance of benefits to harm related to increasing indoor temperatures and installing insulation, and the feasibility of taking these measures, the GDG made a **strong** recommendation regarding cold and a **conditional** recommendation regarding insulation*".

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[32] WHO (2018) Housing and Health Guidelines. Geneva: World Health Organization.

[33] Consistent with these conclusions, are findings that New Zealand has 1,600 excess winter deaths per annum as a result of cold indoor temperatures; see: Howden-Chapman et al. 2012. "Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts," *Energy Policy*, vol. 49(C), 134-142.

Key lessons: The discussion of temperature in this review, combined with a separate exploration of previous WHO temperature guidelines[34] which we carried out, confirmed that the WHO minimum temperature recommendations are not informed by precise evidence on the temperatures at which harm occurs, although they remain the WHO's advice.

Liddell and Guiney (2014) *Living in a cold and damp home: frameworks for understanding impacts on mental well-being*[35]

Context/ distinguishing features: A review of evidence from nine papers identified from a 2013 Cochrane review regarding the relationship between living in cold damp homes and mental health/wellbeing.

Methodology: The review places findings from the nine studies in the context of frameworks for understanding "positive and negative mental health" in psychology and psychiatry. Evidence of the impact of living in cold damp homes is organised in terms of the two domains.

Indicators/ results: The authors develop frameworks for explaining the complex relationship between mental health outcomes and exposure to low indoor temperatures and damp. A cumulative stressor model is suggested: key stressors include worry about the money required to adequately heat homes, worry about health impacts of exposure to cold and damp, and thermal discomfort.

Key lessons: A number of the cited studies measure impacts using standard tools such as the SF-36 questionnaire. The efficacy of this approach indicates the potential in New Zealand to link retrofits to predicted changes in wellbeing (measured using current mental health and broader health survey tools). The improvements to wellbeing following retrofits can then be assessed in dollar terms either using (Australian-sourced) values identified in the New Zealand Treasury's CBAx tool or, preferably, using cost-wellbeing analysis[36] based on values assessed from the NZ General Social Survey (GSS) or New Zealand Health Survey (NZHS). The techniques for identifying monetary-equivalent benefits from questions that mirror those in surveys such as the GSS are quite straightforward and enable New Zealand-based estimates to be derived in ways that have not yet been utilised in New Zealand CBAs of retrofit programmes.

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[34] WHO (1985) Health Impact of Low Indoor Temperatures. Copenhagen: World Health Organization.

[35] Liddell, C., & Guiney, C. (2014). Improving Domestic Energy Efficiency: Frameworks for Understanding the Impacts on Mental Health. *University of Ulster*.

[36] For instance, see: Fujiwara, D. & P. Dolan (2016). "Happiness-based policy analysis." Chapter 10 (pp.286-317) in: Adler M.D. & M. Fleurbaey (eds.) *The Oxford Handbook of Well-being and Public Policy*, Oxford: Oxford University Press; and Layard, R. (2016). *Measuring wellbeing and cost-effectiveness analysis: Using subjective wellbeing*. Discussion Paper 1, What Works Centre for Wellbeing. https://whatworkswellbeing.org/product/measuring-wellbeing-and-cost-effectiveness-analysis-using-subjective-wellbeing/

PART 2: ESTIMATE OF BENEFIT: COST RATIO FOR WARMER KIWI HOMES PROGRAMME

In the absence of recent primary research in New Zealand on the benefits of insulation, heating, hot water pipe lagging and ground moisture barriers, the cost benefit analysis of WUNZ: HS is an obvious starting point for an estimated CBA of WKH. This section builds on the WUNZ: HS CBA in the following ways:

- We utilise the most recent health and energy use benefit estimates for WUNZ: HS where multiple estimates have been published
- We interrogate and, in some cases, update modelling assumptions.
- We apply the findings specifically to the WKH retrofit programme.

This last point means that we apply the WUNZ: HS findings to the balance between insulation and clean heating retrofits observed within WKH. The principal benefits found for WUNZ: HS related to the insulation component of the scheme, so this also carries forward to the balance of benefits estimated for the WKH insulation and clean heating components.

Period analysed

The period analysed was from the start of WKH (1 July 2018) to the first day of level 4 lockdown (26 March 2020). We chose the start of lockdown as a cut-off date to reflect a likely change in the opportunity cost of labour as unemployment has rapidly risen during the pandemic which makes data from the lockdown period and beyond more complex. It is likely that other elements of the WKH programme such as the cost of retrofit components that are imported may also be impacted by the pandemic. In addition, as of 28 April, the subsidy rate for the WKH programme increased to 90%.

Assumptions about CSC status of households

WKH is limited to owner-occupiers who either live in an NZDep 8-10 area or have a CSC, and who live in a home built before 2008. This is relevant because a number of the benefits informing the WUNZ: HS CBA varied by household CSC status. Unfortunately, CSC status was not recorded for households who participated in WKH under the NZ Dep 8-10 criteria. Given that CSCs are available to low-middle income individuals and NZ Dep 8-10 areas are the highest deprivation areas of New Zealand, it seems reasonable to assume that a high proportion of WKH households are CSC households (as defined in the WUNZ: HS CBA). Our primary assumption is that 80% of WKH households are eligible for a CSC. We explore the impact of varying this assumption.

Assumptions about household size and composition

In the absence of information about WKH household size and occupant composition we assume that they are identical to households in the WUNZ: HS dataset. This is important because estimated health benefits are sensitive to estimates of the number of elderly occupants with circulatory conditions per household. The assumption that WKH participant households are, on average, equivalent to CSC households in the WUNZ: HS study is also relevant as household composition varied by CSC status in WUNZ: HS, with a higher average number of vulnerable older people living in CSC households.

Assumptions about benefits of different heating types

The majority of New Zealand evidence for the benefit of space heaters relates to heat-pumps. We are not aware of any New Zealand evidence that specifically values the benefits of wood-burners or pellet-burners. While the Housing, Heating and Health RCT and WUNZ: HS did allow participants to choose between all three heating options, the vast majority of participants chose heat-pumps. In the absence of better evidence, we assume that all of the benefits which accrue to households with heat-pumps also accrue to households with pellet burners and wood-burners. This assumption is of only minor importance given the low uptake of wood-burners and pellet-burners under WKH.

Assumptions about benefits of hot water pipe lagging and ground moisture barriers

Neither our evidence review nor the extensive 2018 NZIER literature review were able to provide information required to value the likely benefits of these products. Accordingly, any benefits due to these programme elements would be additional to the benefits included here.

Assumptions about additionality

The original WUNZ: HS CBA used an additionality estimate of 74% with sensitivity tests for additionality at 36% and 113%[37]. While we do not have evidence that will allow us to confidently update this estimate, we note that given the availability of heat-pumps (and subsidy schemes) over the past 15 years, low-middle income New Zealand households who have not yet purchased a heat-pump may be less likely to do so in the absence of a subsidy programme than was the case at the time of WUNZ: HS. We use three estimates of additionality: a central assumption of 75%, with robustness tests using 100% and 50% to explore the impact of this model component.

Assumptions about the opportunity cost of labour

The original WUNZ: HS used an estimate of the opportunity cost of labour which factored in the relatively high level of unemployment at the time of the global financial crisis. This is likely to align well with high unemployment rates in post-lockdown New Zealand; however, prior to the pandemic, unemployment was relatively low in New Zealand, meaning a greater opportunity cost of labour. The current report does not adjust for an opportunity cost of labour that differs from its market value. Looking forward, this is likely to lead to a conservative bias in the estimated benefit: cost ratios (BCRs) in this report given the current recessionary circumstances. Nor does this report include consideration of producer surplus,

[37] The authors explain that an additionality estimate of greater than 100% reflects promotion of retrofits as a side effect of the WUNZ: HS programme; i.e. people who purchased retrofits because of awareness raised by the programme but did not participate in it.

although that aspect is likely to be minor given the current high degree of competition in the sector.

Assumptions about energy use

It was not possible to recreate the sophisticated model used to value the kWh savings observed in the original WUNZ: HS CBA. Here we simply value changes in energy-use reported in Grimes et al. (2015) using single national prices for electricity and reticulated gas per kWh. We adopt the current price of carbon dioxide per tonne. It is not clear whether these simplifications will bias our results or – if they do – in which direction. A related assumption of note is that, in the absence of information about the proportion of households in the WKH dataset that use reticulated gas, we have assumed that the same proportion do so as was observed in the WUNZ: HS dataset.

Choice of discount rate

We use a 4% p.a. real discount rate, consistent with the WUNZ: HS evaluation. Treasury currently suggest a 6% discount rate in their CBAx tool which we have also explored. We note that due to the method used to estimate the value of a statistical life year (YSLY) adopting a higher discount rate results in a higher VSLY estimate. This complicates interpretation of variation by discount rate, a point that is explored in greater detail below.

Assumptions about lifespan of retrofits

Our primary cost benefit model follows the WUNZ: HS CBA model in assuming that insulation retrofits have a functional lifespan of 30 years and heaters 10 years. We vary these assumptions by assessing the impact of reducing the functional lifespan of insulation to 15 years.

Accounting for inflation

We adjust benefit values derived from previous studies to June 2019 levels using the Consumer Price Index. This quarter was selected as it is approximately half-way through the programme to date. Programme costs are not adjusted for inflation: there may be some small potential to standardise costs across multiple years of the WKH programme, but this is unlikely to have a material impact given the very low inflation rate and so was not explored as part of this review.

COSTS

EECA provided information about every grant funded under the programme including costs, both the figure paid by EECA and the total value. EECA (personal communication) explained that in addition to the value of each grant there are charges such as a $70 administration fee for each grant and incentive payments to retrofit suppliers which vary depending on meeting performance criteria. EECA provided total grant costs as per end of financial year accounts for the 2018-2019 financial year. Based on these figures, we estimated the proportion of administrative and incentives costs to be 6.1% of total grant costs; we imputed these costs for the 2019-2020 financial year, as this information is not yet available.

We also have access to 2018-2019 operating expenses associated with the programme (15.5% of total grants paid by EECA). However, rather than impute year two operating expenses from year one we have followed EECA's advice and assumed that operating expenses are lower in year two of the programme (7.8% of total grants paid by EECA) given that certain operating costs were related to the set-up phase of the programme.

As a further note, we used the timing of the grant payment, rather than the date on which the retrofit was physically carried out, to categorise the financial year in which grants occurred. This reflects the need to combine grant costs with EECA annual reports to estimate expenses.

Table 1: WKH costs

	18-19 FY	19-20 FY*	Total
No. households receiving floor/ceiling insulation	8723	11573	20296
Total value of insulation grants (EECA + 3rd party)	$24,243,252	$31,319,053	$55,562,305
No. households receiving heater	3	3867	3870
Total value of heater grants (EECA + 3rd party)	$6,203	$9,978,238	$9,984,440
Incentive payments and administrative costs	$1,059,063	$1,692,153	$2,751,217
EECA Operating expenses	$2,673,717	$2,282,191	$4,955,908
TOTAL COSTS	**$27,982,235**	**$45,271,635**	**$73,253,869**

* To 26 March 2020

BENEFITS

The tables below set out our preferred health and energy use benefit estimates; sources are stated, and all health benefits are valued as at July 2019 using the Consumer Price Index to adjust for inflation. We follow the previous WUNZ: HS CBA in limiting health and energy use benefits to those which are statistically significant (at the $p<0.05$ level). Values are presented for CSC households and non-CSC households separately[38].

Although there is value in the approach pioneered by NZIER in assigning benefits to each 1°C increase in indoor temperature, one cannot be precise about the estimated average increase in indoor temperatures likely to result from insulation retrofits or heating retrofits under WKH. In addition, the marginal impact will differ depending on the base temperature prior to treatment. For these reasons, we assume that insulation and heating retrofits

[38] The decision was made to only impute health benefits from Chapman et al. (2009) and Preval et al. (2010) to individuals living in CSC homes (given that these studies pertained to low income communities). Mortality benefits were estimated at the individual level and then multiplied by the number of vulnerable elderly people per CSC or non-CSC home respectively (since the numbers of vulnerable elderly people per household differed across the two categories). Hospitalisation and pharmaceutical use costs were estimated at the household level and CSC status did not impact results, so these do not vary by CSC status (Preval 2015).

carried out under WKH will have the same average impacts as those carried out under WUNZ: HS.

Table 2: Non-mortality health benefits of insulation retrofits

	Value per house retrofitted per year $ NZ 2019			
	CSC household	Non-CSC household	Source	Calculation details
All-cause hospitalisation cost savings	$41.81	$41.81	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Household level data modelled using standard panel data analysis. Dependant variable is difference in monthly hosp costs of treatment house and its matched controls. Model controls for age structure and household size variation over time, also includes various seasonal measures. See p 152 for equation. Note there was no evidence of variation by CSC status.
All-cause pharmaceutical cost savings	$26.35	$26.35	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	As above but dependant variable is difference in monthly pharmaceutical costs.
Value of caregiver time	$16.96	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Savings were imputed from Chapman et al. (2009) based on the approach developed in Preval et al. (2010) to costing caregiver time benefits resulting from heating retrofits.
Value of day off school	$57.98	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Savings are derived from Chapman et al. (2009) - saving assumed to only apply to CSC households given the characteristics of the participants of that study. Saving per child multiplied by number of school age children in an average CSC household in the WUNZ: HS dataset.
Value of days off work	$64.36	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Savings are derived from Chapman et al. (2009) as above.
Value of change in GP visits	-$17.91	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Additional costs are derived from Chapman et al. (2009) - assumed to only apply to CSC households given the characteristics of the participants of that study.
TOTAL	$189.55	$68.16		

Table 3: Non-mortality health benefits of heating retrofits

	Value per house retrofitted per year $ NZ 2019			
	CSC-holding household	Non-CSC holding household	Source	Calculation details
All-type pharmaceutical cost savings	$39.48	$39.48	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Household level data modelled using standard panel data analysis. Dependant variable is difference in monthly pharmaceutical-use costs of treatment house and its matched controls. Model controls for age structure and household size variation over time, also includes various seasonal measures. Note there was no evidence of variation by CSC status.
Value of Caregiver time	$6.80	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Saving per child derived from Preval et al. (2010) and multiplied by estimated number of school aged children with asthma in average WUNZ: HS CSC household. Note benefit only predicted for CSC households.
Value of day off school	$9.06	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Saving per child derived from Preval et al. (2010) and multiplied by estimated number of school aged children with asthma in average WUNZ: HS CSC household. Note benefit only predicted for CSC households.
Value of change in GP visits	$1.08	$0.00	Preval, N.(2015) Statistical and policy evaluation of large-scale public health interventions. Thesis.	Saving derived from Preval et al. (2010) as above.
TOTAL	$56.41	$39.48		

Changes in energy use build on the figures reported in Grimes et al. (2016). Of note, the negative figures in Table 3 below indicate increased energy consumption, consistent with a rebound effect for heater retrofits.

Table 4: Energy use benefits of insulation and heating retrofits

	Average monthly reduction in electricity use (kWh) per household	$NZ 2019 value of this reduction	Average monthly reduction in reticulated gas use (kWh) per household	$NZ 2019 value of this reduction	Reduction in total metered energy use (kWh) per year	$NZ 2019 value of this reduction
Insulation	12	$3.46	2	$0.27	168	$44.75
Heating	-10	-$2.89	6	$0.80	-48	-$25.06

Mortality savings due to an insulation retrofit are valued at $1,097.83 per CSC per year and $462.66 per non-CSC household based on the estimates reported in Preval (2015). The difference between CSC and non-CSC households reflects differences in the average composition of households in terms of the predicted number of vulnerable elderly occupants (as discussed above in Part 1). These figures were estimated using a 4% discount rate. No mortality savings are included for the clean heating component since there is, to date, no evidence of such benefits.

Using the Treasury's preferred rate of 6% we estimate savings of $1,444.15 and $608.61, respectively. This increase is an artefact of the calculations which convert VSL to VSLY[39]. The increase in VSLY offsets the effect of the increase in the discount rate, so leaving the benefit: cost ratio almost unchanged when the discount rate changes (given the importance of mortality benefits to the BCR). Consequently, we do not report this sensitivity test below.

As a more informative sensitivity analysis for the mortality benefits, based on the NZIER's critique of the WUNZ: HS CBA approach to valuing mortality, we substitute the NZIER's suggested value per life year gained based on Pharmac's figure ($45,000). This modification greatly reduces the estimated benefit: cost ratio; however it still remains favourable.

COST BENEFIT ANALYSIS

Table 5 presents costs, benefits and the benefit: cost ratio (BCR) for a variety of scenarios. The primary model assumes the following:

- 4% discount rate
- 30-year lifespan insulation
- 10-year lifespan heating
- 80% of WKH homes were equivalent socio-economic status to CSC-households under WUNZ: HS
- 75% additionality
- No maintenance costs for heat-pumps.

Benefits are drawn from the tables presented above. The BCR for this primary model is 4.66, implying $4.66 of benefit to society (including, but not limited to, recipient household members) for every $1 spent in the scheme. Each row of the table other than the primary (first) row, presents the impact of varying a single key assumption, as indicated in the first column.

Initially, we vary the additionality assumptions from the base level of 75% to 50% (meaning that half the recipients would have retrofitted their house in the absence of the scheme) and then to 100% (meaning that none of the recipients would have retrofitted without the scheme). The BCR falls with the low additionality and rises with high additionality but, in each case, the BCR remains above 4.

Next, we vary the proportion of recipient households that are CSC holders from the base level of 80%, variously to 60% and to 100%. The low CSC proportion leads to a drop in the BCR to 4.06, while if all recipients were a CSC household the BCR would rise to 5.25

[39] To convert a given VSL figure to VSLY we imagine a person with an age of 40 (midpoint between 0 and 80). That person has 40 remaining years of life (on average). We rearrange the standard discounting formula to identify, for a given discount rate (e.g. 4%), an annual figure that, when summed over 40 years with appropriate discounting, adds up to the VSL figure. The annual figure identified is the VSLY. A higher discount rate results in the estimate of a higher VSLY for a given VSL. In our case, VSL corresponds to the value used by NZTA for transport appraisals. For a more complete discussion, see Preval (2015) pp 113-127.

reflecting the greater benefits of retrofits estimated for households with a CSC holder. While both estimates remain highly favourable, the difference between them shows the value of collecting good information about the characteristics of WKH households in order to obtain precise estimation of programme benefits. Other relevant information could include the demographic composition of participant households and the size of households. Without the collection of this information potential insights are lost, particularly if there is a desire for future evaluation relating to sub-analyses by household characteristics.

A more substantive variation to the BCR occurs if we assume that the lifespan of insulation is only 15 years rather than the primary assumption of 30 years. With this assumption, the BCR falls to 2.99. Nevertheless, a return of $3 for every $1 spent still indicates a highly favourable return to the WKH programme.

Varying mortality benefits has the most material effect on the BCR calculation. If we were to adopt the Pharmac estimate of value of life (which is considerably below that used by NZTA for transport analyses), the BCR would fall to 1.83. While a sizeable fall, this BCR still indicates a return of almost $2 for every $1 spent on WKH.[40]

Finally, we check the materiality of assigning maintenance costs to installed clean heaters (at $20 p.a.). Given the relatively small cost involved, this addition leaves the BCR almost unchanged from that of the primary model (4.66).

As a final comment, the primary model presented in Table 5 plus the accompanying sensitivity tests indicate that even under a wide range of assumptions, the WKH programme produces a high value of benefits per dollar spent. The finding that benefits materially exceed costs for the programme is robust to changes to additionality, the demographic make-up of households, a halving of the lifespan of insulation, a much reduced value attributed to mortality savings, and the addition of a cost of servicing clean heaters. Furthermore, the benefits factored into the CBA (for both the insulation and clean heating components) do not include other non-pecuniary benefits that flow through to greater comfort and wellbeing as a result of higher temperatures within the home.

In Part 3, we itemise gaps in knowledge that have been identified through Parts 1 and 2, and these gaps inform the design of potential WKH evaluations discussed in Part 4.

[40] Treasury's cost benefit analysis tool, CBAx, includes *both* the transport sector's estimate of the value of statistical life (VSL) and Pharmac's estimated value for a quality-adjusted life year (QALY). As observed in our sensitivity analysis, the VSL estimate places a much higher value on an extra life year than does the QALY estimate.

Table 5: CBA results

	Resource costs adjusting for deadweight cost of taxation	NPV of heater maintenance costs	NPV of mortality benefits (insulation)	NPV of other health benefits (insulation)	NPV of other health benefits (heating)	NPV of energy use savings (insulation)	NPV of energy savings (heating)	Total NPV of benefits	BCR
Primary model	$67,160,755	$0	$255,532,458	$43,501,910	$2,661,420	$11,778,539	-$590,035	$312,884,292	**4.66**
Additionality of 50%	$50,774,069	$0	$170,354,972	$29,001,274	$1,774,280	$7,852,359	-$393,356	$208,589,528	**4.11**
Additionality of 100%	$83,547,442	$0	$340,709,944	$58,002,547	$3,548,560	$15,704,718	-$786,713	$417,179,056	**4.99**
60% of households have CSC	$67,160,755	$0	$222,094,696	$37,111,735	$2,491,404	$11,778,539	-$590,035	$272,886,339	**4.06**
100% of households have CSC	$67,160,755	$0	$288,970,220	$49,892,086	$2,831,436	$11,778,539	-$590,035	$352,882,246	**5.25**
Lowering lifespan of insulation to 15 yrs	$67,160,755	$0	$164,301,608	$27,970,747	$1,711,233	$7,573,335	-$590,035	$200,966,888	**2.99**
Pharmac estimate per life yr gain ($45,000)	$67,160,755	$0	$65,616,131	$43,501,910	$2,661,420	$11,778,539	-$590,035	$122,967,965	**1.83**
Maintenance costs: $20 p.a. per heater	$67,160,755	$186,810	$255,532,458	$43,501,910	$2,661,420	$11,778,539	-$590,035	$312,697,482	**4.66**

Note: All costs and benefits are adjusted for additionality.

PART 3: EVIDENCE GAPS

We begin Part 3 with an assessment of general evidence gaps, i.e. gaps in which little is known from the existing global (including New Zealand) body of evidence regarding the efficacy of insulation, clean heating and related retrofits (where related retrofits include pipe lagging, ground moisture barriers and draft stopping). In some cases, a small amount of evidence exists but greater depth and consistency of evidence is sought given how dependent certain results are on the context of the intervention. We then focus on how evaluation of WKH can help address specific evidence gaps.

General evidence gaps

Evidence gaps in which knowledge about the effect of retrofits is lacking, or insufficient, or contradictory, include the following aspects:

1. Much of our knowledge about the benefits of retrofitted insulation and clean heat focuses on average effects of a retrofit element, but there is much less knowledge about the distribution of effects. Why, for instance, do some households reap larger energy benefits from an insulation retrofit than do other households; what are the demographic or attitudinal characteristics that determine different responses? The importance of determining distributional as well as average effects is relevant both to existing knowledge (e.g. on health benefits of insulation) and to each of the gaps in knowledge listed below.
2. The WHO's recommended indoor temperature of 18°C appears to be supported by a sparse evidence base. One New Zealand study cited earlier (Pierse et al., 2013) indicated that children's asthma symptoms are strongly linked to exposure to temperatures below 12°C, which is materially different to the WHO's recommended temperature. Substantially more evidence is required to ascertain the relationship between indoor (living area and bedroom) temperatures and a variety of health outcomes. These relationships are likely to be non-linear, i.e. exhibit declining additional benefits for each extra degree of warmth in the house. Note that this issue is relevant both to understanding benefits of retrofits for houses that have not previously been treated and for houses that have previously received treatment but possibly not up to current standards.
3. There is very little available evidence to indicate the health, temperature or energy use benefits obtained through retrofits of: (a) wood and pellet burners; (b) pipe lagging; (c) ground moisture barriers; (d) draft stopping; and (e) ventilation. The first three of these factors form part of the WKH scheme. Obtaining evidence on the efficacy of each of these components is important to gauge whether they should be included in future public policy retrofit schemes.
4. There is a surprising lack of evidence on the impact of pre-retrofit house characteristics on the benefits obtained through retrofits. For instance, there is not

yet a deep body of findings relating to whether houses with pre-existing (but possibly poor quality) insulation benefit from an insulation retrofit to the same degree as houses without prior insulation. This is an important aspect on which to obtain further evidence since it could alter policy decisions of whether or not to include houses with pre-existing insulation in any subsidised insulation scheme.

5. A lack of depth and clarity is also apparent on the importance of observable household characteristics for health and energy-use benefits of retrofit products.[41] For instance, to what extent do benefits vary by age, income or place of birth? The lack of consistent evidence on these issues to date may reflect limitations of statistical power in various studies (including New Zealand studies), or may reflect deficiencies in the ability to control for other (potentially correlated) factors.

6. While evidence on effects of insulation on health and other outcomes is widespread and is moderately consistent, the evidence on the impacts of heater retrofits (especially on health and energy use) is not consistent. In New Zealand, previous studies have had limited statistical power to detect changes in outcomes resulting from heating retrofits and further information on the benefits of heater retrofits in New Zealand conditions is required. One aspect that needs to be controlled for better than previously is the type of heating already available within the dwelling. Failure to adequately control for prior heating types (due to a lack of data) may have led to wide confidence intervals surrounding estimates of benefits of clean heating, rendering findings statistically insignificant even where there truly are effects.

7. An important policy (and statistical) issue that has received very little (if any) analysis, is why some households make use of a scheme (such as WUNZ: HS or WKH) to retrofit their dwelling while other, apparently similar, households do not. The reasons for uptake, and the reasons for disparity in uptake by demographic groups, is of major policy interest since these factors may affect the design or targeting of the scheme.

8. Physical health benefits from adopting insulation have been well documented. There is a smaller amount of evidence on the mental health effects of both insulation and the installation of clean heating. Evidence in New Zealand on these aspects is particularly sparse. A study that builds on the insights (cited above) in Liddell and Guiney (2014) – but focused on the effects of interventions rather than on damp and cold temperatures per se – is warranted to gather further evidence in this regard. The advantage of an intervention-based study is that it would gather information before and after the intervention so mitigating the associative effects of people with poorer mental health living in damp, cold dwellings due to other factors (e.g. low incomes). The definition of mental health here should be kept broad to include comfort (wellbeing) benefits as well as diagnosed mental health conditions.

[41] Estimating differential effects according to observable household characteristics goes some way to addressing evidence gap 1 above, but the former is broader in that there will still be a distribution of outcomes even once observable characteristics are controlled for.

9. Average energy use effects of retrofits (both insulation and clean heat) have been estimated, but little is known about the effects of retrofits on peak energy demand. Information may not have been available internationally to conduct such a study. There is a clear opportunity in New Zealand to undertake a study that estimates both time-of-day and day-of-year effects so that seasonal, day-of-week and hourly savings can be estimated and related to peak energy demand periods.

Opportunities to use WKH evaluation to address evidence gaps

1. An evaluation of WKH could estimate (for the first time internationally) the time-of-day and day-of-year impacts of WKH retrofits on household energy use. This information can be gathered using smart meter data for WKH houses before and after a retrofit. The findings should provide important guidance on the effects of (different types of) retrofits on peak energy demand.
2. Following on from the previous point, the Winter Energy Payment (WEP) is a relevant policy feature that may affect health and energy benefits from WKH. The WEP, while not being tied to energy expenditures, is a cash payment to beneficiaries (including NZ superannuatants) with associated messaging that it is an aid to meeting increased energy bills in winter. If WEP alleviates cash-flow constraints faced by recipients at that time of year it could increase winter energy use and thereby reduce energy savings while contributing to extra health benefits. To date, there is no evidence of its effects on these outcomes. Given the strict cut-offs in eligibility for the WEP, its time-limited availability during the year, and its sizeable variation in level of support over the past three years, the effect of this intervention in conjunction with retrofits affords the opportunity to fill this major evidence gap. This analysis is relevant both to understanding the impacts of retrofits on energy use and to understanding the energy expenditure effects of a major social policy intervention.
3. Data gathered as part of the WKH approval process indicates whether partial insulation is already available (although it does not include the date when the insulation was installed or whether this was part of a prior retrofit programme). Information is not currently available on prior heating devices or on other relevant house characteristics for treated houses (e.g. presence of an underfloor moisture barrier). Addressing these evidence gaps through the gathering of supplementary evidence on prior insulation, heating and related physical characteristics will improve any evaluation of WKH. It could especially help to pin down the energy and health benefits of clean heat retrofits.
4. As with a number of prior evaluations (including of WUNZ: HS), WKH does not currently gather evidence on the number and demographic composition of people living in a treated house. Nor does WKH gather evidence on whether a household living in a Dep 8-10 area has a member who has a CSC card. Prior evidence shows that household-level deprivation (for which CSC is a loose proxy) affects benefits

received from a retrofit, while demographic composition of the household will clearly have an influence on the scale of benefits. More complete evidence on household characteristics in these regards would improve any evaluation of WKH.

5. Pre- and post-treatment qualitative data through (pre- and post-) surveys on self-assessed mental health and comfort levels, as well as self-assessed physical health, would fill a major evidence gap regarding wellbeing benefits from WKH and from retrofit schemes more generally. Information about health status should be gathered using the current self-assessed (mental and physical) health questions in Stats NZ’s General Social Survey (GSS) and/or New Zealand Health Survey (NZHS) to enable comparability with the wider population and with specific sub-populations.

6. A qualitative survey could also very usefully gather evidence on: (a) reasons for uptake of the WKH scheme, plus reasons why the household had not undertaken the same retrofit earlier; (b) attitudes to the importance of warmth for comfort; and (c) financial stress, using the same questions as in the GSS, to gauge whether income constraints were a likely factor in the decision to utilise WKH. This sort of information has not been gathered in prior evaluations, but is important to inform the design of policy interventions.

7. While there is some evidence on temperature effects of different types of retrofits, the conclusions across studies are not always consistent and may depend on the treatment of the take-back effect. (Unlike statistical estimates of impacts of retrofits, engineering models must impose some assumption about the take-back effect.) Systematically collected pre- and post- treatment evidence on internal temperatures, humidity and level of noxious gases through instrument readings in houses treated under WKH would add a valuable evidence base to existing knowledge. In particular, if these instrument readings are collected for the same households that complete the qualitative questionnaires, the relationships between health/comfort outcomes and physical outcomes (temperature, humidity, gas levels) can be ascertained.

8. The opportunities listed above all relate to an evaluation of WKH. At a broader level, there is also the chance to step back and ascertain through a large-scale survey: (i) the number of houses in New Zealand that have nil, partial or full insulation, (ii) adequate clean heating, and (iii) other features such as draft stopping, moisture barriers, ventilation systems, etc. In addition, it may be timely to re-investigate the trend of excess winter mortality in New Zealand, and to examine whether there is a relationship between excess mortality and the adequacy of insulation and heating as revealed in this survey.

PART 4: PROPOSED EVALUATION DESIGN

4.1 Research questions

WKH evaluation can provide novel information to fill the following key evidence gaps:

1. What is the distribution of time-of-day and day-of-year energy use impacts of retrofits; how do these impacts relate to energy use during peak energy load periods; how do these impacts differ according to house characteristics (e.g. pre-existing insulation and heating); and how do these impacts differ according to household characteristics including having residents who receive Winter Energy Payment (WEP), CSC card holders and Māori and Pacific households?
2. What are the impacts of occupant behaviour in terms of their operation and settings of heating devices and other energy-related equipment in the home such as doors, windows and ventilation?
3. What are the determinants of whether a household chooses a WKH retrofit, including how the decision relates to attitudes (e.g. to the relationship between warmth and comfort) and to financial stress?
4. How do comfort levels, self-assessed mental health and self-assessed physical health change as a result of alternative retrofit elements?
5. How do temperatures, humidity and noxious gases within the house change as a result of alternative retrofit elements?
6. How do comfort levels, self-assessed mental health and self-assessed physical health changes relate to changes in temperatures, humidity and noxious gases within the house following a retrofit?

4.2 Three evaluation components

In order to address these six research questions, we propose three separate evaluation components (although the second and third components can be combined to be applied to a single set of treated houses). The three evaluation components (each discussed further below) are as follows:

1. A detailed statistical study based on energy records of treated houses where (time-of-day) energy use is gathered before and after treatment for each WKH house. If possible, houses and households would be matched to the IDI to enable demographic controls, and would be matched via the Ministry of Social Development (MSD) to determine whether a resident receives WEP. This component is designed to address research question 1.

2. Two qualitative surveys, timed for one month prior to treatment and two months after treatment covering all newly treated houses over a 12 month period. The qualitative surveys would be designed to address research questions 2, 3 and 4.
3. Placement of measurement instruments (for temperature, humidity and noxious gases) in newly treated houses, with readings logged automatically. Placement would be one month prior to treatment and would extend until two months after treatment and would cover all newly treated houses over a 12 month period. The instrument readings would be used to address research question 5. If the instruments were placed in the same houses as covered by the qualitative questionnaire (and at the same time), the combined responses from the instrument readings and the questionnaire could be used to address research question 6.

Each of these evaluation components is outlined in more detail below. None of these components requires any change to the coverage of WKH, although additional consent requirements are recommended.

4.3 Energy use outcomes: Statistical analysis (research question 1)

Interventions

WKH conducted 26,055 retrofits between 11 July 2018 and 11 June 2020. Of these retrofits, 21,607 related to insulation while 4,448 related to clean heating. Insulation included ceiling and/or underfloor insulation. Most clean heating comprised installation of a heat pump, with a small number of wood burners and pellet burners. In addition, 1,852 dwellings received hot water pipe lagging.[42] Detailed data on the type and amount of insulation, type of clean heater, and amount of pipe lagging is available from EECA.

Data availability and challenges

Household information

Information is available from EECA for each dwelling including:

- address;
- date of installation;
- service provider;
- presence of lead;
- amount of funding (EECA and total);
- deprivation decile of the dwelling.

Low-income status

The deprivation decile can be used to subset on presumed community service card (CSC) holders since retrofits under WKH for dwellings located outside of deciles 8 to 10 are only

[42] Note that a house which received insulation and clean heat (and/or pipe lagging) treatment is listed in each of the insulation, clean heat and pipe lagging data above.

for households with at least one CSC holder. Thus, to conduct a CSC cohort analysis, one can subset on recipients who live in areas outside of deprivation deciles 8 to 10. In total, 8242 retrofits are for dwellings outside of deciles 8 to 10.

Energy consumption records and ICP

Some, but not all, treated dwellings have given consent for EECA or their agent to retrieve their energy consumption records from energy companies (via the Electricity Authority). In addition to consent, the ICP number for each dwelling will need to be identified through the EA system based on the physical address. The ICP number can then be used to access the energy records. It is estimated that up to half of the retrofitted dwellings have formally given consent, and substantial manual work would be required to identify which dwellings these are.[43] The final figure for dwellings with customer consents will not be known until a check has been conducted of the customer consent records. Over three-quarters of treated dwellings are expected to have smart meters enabling time-of-day energy readings.

Based on these estimates, if even only a quarter of the dwellings were to have customer consents (with identified ICP addresses), and using a smart meter penetration of 75%, then full time-of-day energy use information would be available for approximately 4,000 dwellings that received insulation, 800 houses that received clean heating and 350 houses that received pipe lagging.[44] With the possible exception of pipe lagging, these numbers are large enough to conduct an evaluation of the time-of-day energy use effects of treatment under WKH. Furthermore, the number of CSC-related retrofits should enable separate estimates for this group at least for the effects of insulation.

Time-of-day energy use

A key requirement to carry out the time-of-day energy use evaluation is the receipt of time-of-day energy data for retrofitted dwellings before and after the retrofit. This requirement will slightly reduce the number of dwellings able to be included in the evaluation since very early and very late retrofitted dwellings will not have the requisite data. A key aspect of the evaluation will be to ensure that the energy use data is 'cleaned' sufficiently to ensure that poor quality data does not cause the econometric estimates to have wide confidence intervals that prevent inference of the effects of the retrofit on energy use.

Provided the energy data are available in usable and clean form (from the energy companies), an econometric technique such as a difference-in-difference estimator can be utilised to detect the effects of (single or multiple) treatment on overall energy use for each household. More complex approaches will be required in order to estimate time-of-day energy use. One option is to continue with a single equation difference-in-difference

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[43] An alternative approach could be to consider having all analysis conducted within a single energy supplier relating solely to customers of that energy company. However this approach would materially reduce sample size (and hence statistical power) given that WKH recipients will be spread over multiple energy companies. It is likely also to preclude any analysis of WEP status on energy use.

[44] WKH is still in operation so the dwellings available for evaluation will increase further prior to the start of any evaluation. However the drastically changed circumstances of households during and after the covid lockdown (e.g. time spent within the home) may warrant analysis only for houses treated up to some months before lockdown started.

estimator with time-of-day interaction effects. Another option may be to estimate a system of equations where each equation represents households' use for a particular period of the day. A systems estimator, such as Seemingly Unrelated Regressions (SUR), would then be required to account for household characteristics that affect a household's energy use (at each time-of-day) and to account for correlation of residuals due to the same houses being included across the various time-of-day equations.

House characteristics

Fixed effects regression (i.e. inclusion of a dummy variable for each house representing the unchanging unobservable features of that house and household) can be used to account for house-specific factors that affect energy use. However, in order to provide estimates of effects that vary according to particular types of houses, the WKH houses would have to be matched to either Quotable Value, REINZ or council data that record relevant house characteristics (e.g. size, number of bedrooms, age, building materials, number of stories, etc). This aspect will necessitate data matching protocols to be arranged between data providers and data analysts.

Timing

In terms of timing, this first evaluation component can be undertaken as soon as the data can be obtained; i.e. there is no need to wait until further treatments are undertaken. If the evaluation were commissioned shortly and the energy and house characteristics records were obtained by September 2020, the evaluation could potentially be completed in the first half of 2021.

WEP extension

As discussed above, one influence on energy use, and hence on the potential effects of WKH treatment on energy use, is the financial status of the household. The introduction of the WEP may have reduced binding cash-flow constraints for some households especially during the WEP payment period. WEP was paid from 1 July to 29 September 2018, and from 1 May to 1 October in each of 2019 and 2020. The 2020 payment rate is double that of 2019. The financial benefits from WEP may have enabled households to use more energy during the WEP payment period, and this effect could have been amplified by the implicit messaging that the WEP should be allocated to extra energy payments (though this is not actually part of the scheme). If the WEP has had these effects, we might find that the WKH treatment has a reduced effect on energy savings of WEP recipients (relative to non-recipients) during the months when WEP is paid.

We understand that the Ministry of Social Development (MSD) is interested in analysing the effects of the WEP on energy use of recipients. If MSD and EECA are both interested in exploring the effects of WEP on energy use, then it should be possible to match WKH treated houses that have given permission to access their energy records to households in receipt of WEP (via confidential data matching within MSD). This would enable analysis of whether there is a difference in energy use savings between treated and untreated households with and without WEP, both in months when WEP is paid and when WEP is not paid. Again time-of-day variations can be estimated, in this case with respect to receipt of WEP.

Given MSD's interest in this aspect, there is the potential for this extension to the WKH evaluation to be jointly commissioned by EECA and MSD. The extension seems to be a natural and useful extension to the first stage evaluation component outlined above. This additional evaluation component can be undertaken as soon as the data can be obtained so there is no need to wait until further treatments are undertaken or to wait for the gathering of additional ancillary information.

Data matching would take some time, so realistically, this evaluation component would most likely be completed in mid-late 2021.

4.4 Attitudes, health & comfort: Qualitative survey (research questions 2, 3 & 4)

A second component of a WKH evaluation could gather information from treated households about their behaviour and perceived outcomes before and following treatment by way of two qualitative surveys. The first survey would be conducted one month before treatment (i.e. following approval) and the second two months after treatment. The two month gap following treatment is designed to allow households time to adjust to their retrofit, but with a short enough space between surveys (three months) so that recollections of prior behaviours are still fresh. (A slightly longer gap, e.g. with the second survey occurring three or four months after treatment, could also be considered provided the gap was consistent across households.) By surveying *changes* in behaviours and outcomes for the same household, the 'before' experience of houses acts as the control group for the 'after' experiences, based on the assumption that no behaviour or outcome changes would have occurred over that short time period without the WKH retrofit.

This evaluation component would optimally be applied to all retrofits conducted over a period of 12 months to ensure that seasonal variations in outcomes are accounted for. The survey information would be gathered to address the following matters:

i. Demographic information including number of adults 65 years and over, number of other adults (>18 years), number of school-aged children (5-18 years), and number of pre-school children (<5 years) in the household, whether at least one person is at home on week days during the bulk of normal working hours, annual household income, and the GSS question on financial stress (all questions to be asked in the first survey only).
ii. Reasons for the household choosing to retrofit using the WKH scheme, plus reasons why a retrofit had not previously been undertaken for that house (first survey only).
iii. Number and types of heating devices (including portable/unflued gas heaters) in the house prior to treatment, plus a qualitative assessment of whether, in the

winter prior to treatment, these were used: (i) not at all, (ii) occasionally, or (iii) frequently (first survey only).

iv. Choices made about: (a) increased or decreased use of existing and new heating devices after relative to before treatment in bedrooms and living areas; (b) thermostat settings for heat pumps following treatment; and (c) other relevant aspects such as ventilation after treatment (second survey only for each component).

v. Perceived changes in energy costs after relative to before treatment (second survey only).

vi. The attitude of the householder towards the importance of warmth for comfort levels within the home (first and second surveys).

vii. Perceived warmth changes (in each of bedrooms and living areas) after vs before treatment (second survey only).

viii. Perceived humidity/dampness changes (bedrooms and living areas) after vs before treatment (second survey only).

ix. Whether any person in the house had a chronic or severe health condition, or any form of respiratory condition, prior to the retrofit (first survey only).

x. Self-assessed health, using standard survey measures in GSS and/or NZHS plus question(s) specifically on respiratory health (first and second surveys), and self-assessed changes in health after relative to before treatment (second survey only).

Question (i) provides demographic information to help frame the remainder of the analysis and to enable sub-population analyses. Question (ii) is designed to assist policy development by increasing understanding of why people do, and do not, choose to retrofit their homes. Question (iii) provides important background information relating to prior heating relevant to assessing energy and comfort/health changes. Questions (iv) and (v) are designed to provide greater information than can be obtained purely from the first evaluation component about the actions that lead to energy use changes following a retrofit. With respect to question (v), if energy records can also be obtained for these households then this information can be used also to test reliability of recall since perceptions can be checked against actual energy use changes. Question (vi) checks on the householder’s attitude to warmth; this aspect could conceivably differ markedly depending on age, ethnicity, place of birth, etc. An understanding of these differences could be important in framing future policy programmes, and any changes in attitudes following treatment will indicate whether people’s attitudes adapt in response to their lived experience. Questions (vii) to (x) are designed primarily to test health outcomes using the same scales as used in the GSS and/or NZHS to ensure comparability against the wider population; a question regarding respiratory health is also recommended for inclusion, preferably sourced from a standard health question for this matter.

Together, the answers from these qualitative surveys will provide significant information that can help frame future policy programmes and provide new estimates of benefits from retrofits. Cost-wellbeing analysis[45] can be used to provide monetary equivalents to the health benefits provided the same questions are used as in GSS, since cost-wellbeing analysis applied to that survey enables monetary equivalents of overall physical and mental health status to be derived.

Ideally, a further follow-up survey twelve months after the second survey would also be conducted on the same households. This extra survey would provide a longer-term perspective, and allow greater adjustment to the retrofits. It would cover the same issues (and using the same questions) as the second survey.

To ensure a high completion rate (which is necessary for statistical validity), the retrofit treatments over the relevant period would ideally be provided conditional on a household member (who was engaged in the decision to retrofit) agreeing to complete the surveys. It would also be desirable to make the retrofit conditional on permission being granted for access to the household's energy records. The latter addition would enable objective energy readings to be matched with the qualitative responses to test how valid the qualitative energy responses appear to be.[46]

Testing of questionnaire design and obtaining ethics approval will be required before questionnaires can be distributed to WKH recipients. In addition, if the questionnaires are to cover twelve months of new WKH recipients, the timeframe from distribution of the first questionnaire to the last of the second questionnaires would be fifteen months (and this would extend to 27 months if a third questionnaire was instituted). For these reasons, this questionnaire evaluation component should be initiated at the same time as initiation of the first evaluation component.

4.5 Temperature, humidity, gases: Device placement (research questions 5 & 6)

A number of studies have presented measurements of indoor temperature, humidity and noxious gas impacts of retrofitted insulation and clean heating. However there is not yet a deep body of consistent knowledge on these aspects.

A third evaluation component could be designed to address research questions 5 and 6 through the placement of devices to measure and automatically log temperatures, humidity and certain noxious gases in living areas and bedrooms of a house. The timing would be chosen to match the qualitative survey, i.e. be in place from one month prior to treatment and two months after treatment (three month period) for each house retrofitted over one year. This design would enable these objective readings to be matched to the qualitative responses (and possibly also to the energy records) of the same households.

[45] See footnote 40.

[46] This is not a necessary part of the second evaluation component, although it is a helpful add-on. It can also be seen as a test of the 'Hawthorne effect' whereby treatment per se may be judged to be positive even if no objective changes occur. One advantage of conducting a third survey (twelve months later) is that any Hawthorne effect should have disappeared by then. Note that making treatment conditional on consent would have to be tested within the accompanying ethics approval process.

Design testing and ethics approvals would again be required for this intervention. Intuitively, it is likely that there would be greater resistance by many householders to having "intrusive" measurement instruments placed in their house than to a qualitative survey or to analysis based on energy records. There is a risk also that household behaviour may change temporarily in the knowledge that these outcomes are being logged; hence any observed 'objective' changes may not be representative of longer term changes when households are no longer being observed. These temporary behaviour changes could also contaminate answers to the second qualitative survey.

One possibility that might be used to indicate (ex post) if temporary behaviour changes are present would be to randomise the third evaluation component so that it applies to half the newly retrofitted houses, enabling a test of whether the qualitative responses differ according to the presence or absence of the measurement devices. On balance, the risks and expense of this third evaluation component make it less compelling than the first and second evaluation components for inclusion in an evaluation of WKH.

CONCLUDING OBSERVATIONS

An evaluation of WKH offers an excellent opportunity to update and extend our knowledge of the impacts of housing retrofits in the New Zealand context. In particular, analysis of time-of-day and day-of-year energy use impacts of various forms of retrofit, the effects of the WEP on energy use, attitudes to warmth and to retrofit programmes, and comfort and mental health effects of retrofits would all contribute new knowledge that would aid future policy development. There is also the opportunity to understand temperature, humidity and noxious gas impacts of retrofits, and to obtain more precise estimates of the impact of clean heat devices based on improved information on prior heating devices in the home.

The three evaluation components outlined above would contribute markedly to an increase in our knowledge in these respects. If only one of the evaluation components were possible (e.g. because of financial constraints), the choice between the first and second component would be finely balanced, and would depend on which research question(s) were given priority. If two could be financed, our judgement is that the first two components should be prioritised. The third component adds further potentially valuable information, but comes at likely greater expense (given the need to obtain and operate the measurement devices) and with greater risks of bias in estimated responses than the first two components.