Received: 23 May 2022 | Revised: 31 July 2022 | Accepted: 5 August 2022

DOI: 10.1111/ina.13101

ORIGINAL ARTICLE

WILEY

Retrofitting home insulation reduces incidence and severity of chronic respiratory disease

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Funding information
Ministry of Health

Abstract

To assess whether retrofitting home insulation can reduce the risk of respiratory disease incidence and exacerbation, a retrospective cohort study was undertaken using linked data from a national intervention program. The study population was made up of 1 004 795 residents from 205 001 New Zealand houses that received an insulation subsidy though a national Energy Efficiency and Conservation Authority program. A difference-in-difference model compared changes in the number of prescriptions dispensed for respiratory illness post- insulation to a control population over the same timeframe. New prescribing of chronic respiratory disease medication at follow-up was used to compare incidence risk ratios between intervention and control groups. Chronic respiratory disease incidence was significantly lower in the intervention group at follow-up: odds ratio 0.90 (95% CI: 0.86–0.94). There was also a 4% reduction in medication dispensed for treating exacerbations of chronic respiratory disease symptoms in the intervention group compared with the control group: relative rate ratio (RRR) 0.96 (95% CI: 0.96–0.97). There was no change in medication dispensed to prevent symptoms of chronic respiratory disease RRR: 1,00 (95% CI: 0.99–1.00). These findings support home insulation interventions as a means of improving respiratory health outcomes.

KEYWORDS
cold, damp, health, housing, mold, respiratory disease

1 | INTRODUCTION

As acknowledged in several international reports,[1–3] cold housing increases the risk of respiratory disease associated with indoor dampness and mold, with strong evidence for asthma exacerbations and respiratory infections[4,5] and limited evidence for asthma development.[6,7]

Breathing cold air is also a strong and direct trigger for wheezing amongst those with asthma,[8,9] and we have previously shown that cold domestic environments are associated with small decrements in lung function in children with asthma.[10] In contrast, at a population level, warmer climates are associated with a greater prevalence of asthma.[8,11]

Cold indoor temperatures are a consequence of the interaction between cold outdoor temperatures and structural deficiencies of housing, such as air tightness, inadequate heating, and lack of insulation.[12] Most homes in New Zealand are cold by international

standards and do not meet the World Health Organization's recommended minimum indoor temperature of 18°C.[12] The housing stock is dominated by timber framed, detached houses with predominantly weatherboard, brick, or fiber cement cladding, built between 1950 and 2000.[13] Before a 1977 amendment to the building code (NZS 421P), there was no requirement to insulate homes. The amendment only applied to new homes, so retrofitting insulation into existing homes remained at the discretion of the homeowner. In 2005, an estimated 60% of houses built before 1979 lacked any form of ceiling insulation, and 68% were without underfloor insulation.[14]

Retrofitting insulation has been associated with significant improvements in respiratory health.[3,4] For example, a community randomized controlled trial in 1350 households showed a reduction in wheezing, fewer GP visits, and fewer days off work and school.[15]

In 2009, the New Zealand Energy Efficiency and Conservation Authority (EECA) launched a five-year insulation and heater subsidy programme for existing homes, Warm-up New Zealand: Heat Smart (WUNZ). The aim of WUNZ was to bring the thermal efficiency of older houses up to date—to the insulation thermal resistance standard (NZBC clause H1/AS1) set in 2007.[16] Previous analyses of the effects of WUNZ on hospitalizations, involving 994 317 residents of 204 405 houses, found a relative reduction in acute hospitalizations of 11%; while hospitalizations for respiratory disease were 15% lower, and hospitalizations for asthma 20% lower.[17]

In the current linkage study, prescriptions dispensed to treat respiratory disease were used to determine whether improving thermal efficiency is associated with fewer symptoms and reduced incidence of respiratory disease.

Practical implications

- This study supports the use of subsidized home insulation as a means of improving respiratory health.
- This study suggests that subsidizing the cost of a clean, energy efficient heater can be used to further improve health outcomes.
- The study supports further investigation of the impact of improved thermal efficiency in preventing onset of chronic respiratory disease being undertaken.

2 | METHOD

A quasi-experimental retrospective cohort study was conducted using data linkage. As previously described,[17] the study cohort was determined by linking residents of houses insulated through the WUNZ subsidy program between July 2009 and June 2014 to primary health organization (PHO) records by their address. PHO records include everybody registered with a general practitioner and are updated every quarter. Person years contributed were calculated by the number of quarter years an individual lived in a WUNZ house (person-house pair). If a person moved from one WUNZ house to another, a new person-house pair was created. We also identified a *6-year continual-occupancy nested cohort* made up of people who remained in the same WUNZ house for the duration of the study.[17] The area level deprivation and climate zone for each WUNZ house were identified using the matched address and added to the joined dataset.

Personal (age, sex, and ethnicity) and health (prescriptions dispensed, hospital discharges, and mortality) information were retrieved from New Zealand Ministry of Health datasets for residents we identified as having lived in a WUNZ house during the study period. These were matched to each person-house linked record using the resident's national health index number.

A difference-in-difference approach was used to compare the before and after intervention change in pharmaceuticals dispensed to an intervention group with pharmaceuticals dispensed to a control group over the same period. The difference-in difference approach was adapted from an earlier study[18] and chosen as it allowed both differences between the intervention and control groups and changes over time within each group to be controlled for.[19] The intervention group included residents of WUNZ houses that had their homes insulated between July 2009 and December 2011. They were followed for 3 years before and 3 years after the insulation intervention. To ensure that a control group is similar to an intervention group, it is recommended that they are selected from the same or similar population.[20] The control group therefore included all residents of WUNZ houses insulated between January 1, 2012, and June 30, 2014, and were followed for 6 years prior to the insulation intervention.

The details of address matching, data linkage, and baseline and follow-up timeframes from the joined records have been previously described[17] and are summarized in Figure 1.

2.1 | Exclusions

We excluded some records from further analysis where: participant's age was less than or equal to zero years, greater than or equal to 90 years, or when key demographic information (sex, ethnicity, and deprivation decile) was missing. We also excluded records where there was a gap in residence of more than 6 months, as this brought into question whether the address listed was a permanent residence.

2.2 | Definition of medication to treat cold-associated respiratory disease

We compiled a list of medication commonly used to treat cold-associated respiratory disease in consultation with a Public Health physician, a Ministry of Health information analyst, a pharmacist, and a physician specializing in respiratory disease. A dataset of prescriptions dispensed for these pharmaceuticals was retrieved from

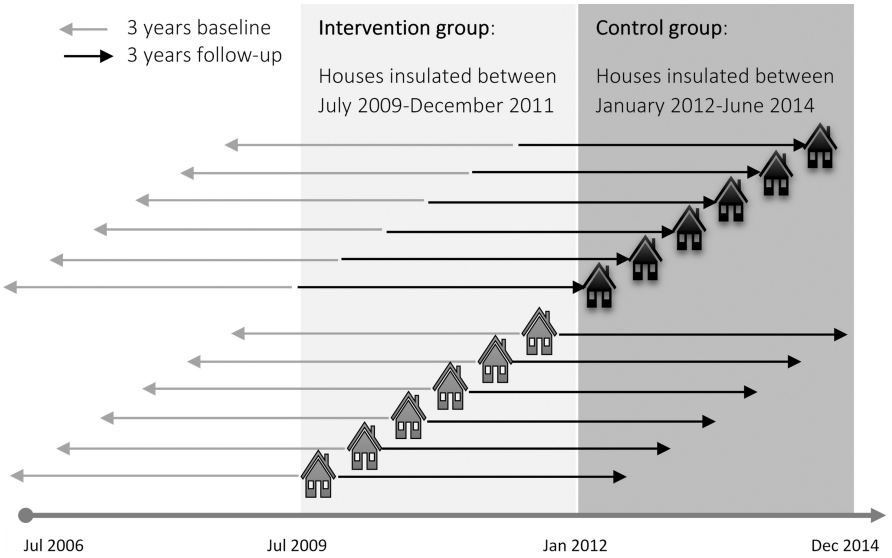

FIGURE 1 Distribution of baseline and follow-up between intervention and control houses

the Ministry of Health "Pharmaceutical Collections" and linked to the WUNZ cohort using an encrypted unique identifier. A second step compared the date dispensed to the start and end date for participation in the study.

Cold-associated respiratory disease medications fell in to one of three broad groups; Table S1 lists formulations that were included in the analysis of each group.

1. Antibiotic medications such as penicillin and macrolides prescribed for infectious respiratory disease.
2. Mast-cell stabilizers, inhaled corticosteroids, and long-acting beta-adrenoceptor agonists (LABA) prescribed to prevent chronic respiratory disease symptoms.
3. Anticholinergics and short-acting beta-adrenoceptor agonists (SABA) prescribed to treat exacerbation of chronic respiratory disease symptoms (exacerbation sensitive medication). An oral corticosteroid, prednisone, was also included as a marker of severe asthma or COPD exacerbation.

2.3 | Determining incidence of respiratory disease

We defined chronic respiratory disease incidence as the number of people for whom prescription medication was dispensed for chronic respiratory disease at follow-up, and who had not had prescriptions dispensed at baseline. We made a direct comparison between the intervention and control group post-intervention to assess whether improving thermal efficiency reduced respiratory disease incidence. We only used the 6-year continual occupancy nested cohort for this analysis as a full baseline history was needed.

We calculated chronic respiratory disease incidence by the number of prescriptions per individual in the study population at baseline that was required to match the age-specific rates for chronic respiratory disease prevalence in New Zealand at the time of the study, see Table 1, similar to what had been done in earlier study.[21] We used two measures of disease incidence:

1. Number of individuals with at least one prescription for medication to prevent symptoms (Table 1) at follow-up, who had not been prescribed the medication at baseline.
2. Number of individuals with at least three prescriptions (including repeat prescriptions) for exacerbation-sensitive medication (Table 1) at follow-up who had not had the medication prescribed at baseline.

2.4 | Data analysis

All data analyses were conducted using SAS 9.4.

We used Poisson regression analysis to calculate baseline and follow-up pharmaceutical dispensing rates (number of pharmaceuticals dispensed/number of person years), rate ratios for the intervention and control groups (pharmaceutical dispensing rate at follow-up/pharmaceutical dispensing rate at baseline), and a relative rate ratio comparing the intervention rate ratio with the control rate ratio. Socio-demographic and environmental factors—age, sex, ethnicity, area level deprivation climate zone, and intervention type—were included as co-variates to control for confounding using a generalized linear model.

Odds ratios for respiratory disease were calculated in the 6-year continual occupancy nested cohort using a logistic regression model as we were making a direct comparison between cases and controls post-intervention, rather than a change over time. Socio-demographic and environmental factors were included as co-variates to control for confounding in the general analysis. We also analyzed subgroups of the population defined by age, sex, ethnicity, area level deprivation, climate zone, and type of insulation installed to determine variations in outcome within these groups.

3 | RESULTS

The study cohort was made up of 1 004 795 people who had lived in one or more of 205 001 WUNZ houses, for all, or part of the six-year

TABLE 1 Definition of respiratory disease based on pharmaceutical use

Age group and condition	New Zealand prevalence rate (95% CI)	Source and year	Medication type	Prescriptions required for match	Prevalence at baseline (study population)
Asthma: <15 years	14.8% (13.5–16.2)	NZHS 2006/07[38]	1 Preventative	≥1 prescription	14.8%
			2 Exacerbation sensitive	≥3 prescriptions (Including repeat)	13.9%
Asthma: ≥15 years	11.2% (10.4–11.9)	NZHS 2006/07[38]	1 Preventative	≥1 prescription	12.7%
			2 Exacerbation sensitive	≥3 prescriptions (Including repeat)	12.8%
COPD: ≥40 years	14.2% (11.0–17.0)	GOLD 2003/04[39]	1 Preventative	≥1 prescription	13.1%
			2 Exacerbation sensitive	≥3 prescriptions (Including repeat)	13.6%

study period. There were 157 338 people and 49 457 houses in the six-year continual occupancy nested cohort, making up 15.7% of the total study population and contributing approximately one third of total person years. A socio-demographic breakdown of the study cohort is given in Table 2.

The 6-year continual occupancy nested cohort had a different population structure to the total population, with fewer Māori (11.39% compared with 18.79%) and Pacific Peoples (5.48% compared with 7.44%), Table 2.

3.1 | Prescriptions dispensed by condition

At baseline and follow-up, the rate of prescriptions dispensed for both infectious disease and for chronic respiratory disease symptom prevention medication was higher in the intervention group compared with the control group. The rate of exacerbation sensitive medication prescriptions dispensed for chronic respiratory disease was greater in the intervention than the control group at baseline, but less at follow-up, Table 3.

3.2 | Influence of the intervention on cold-associated respiratory disease prescriptions

Overall, there was an increase in pharmaceutical prescriptions dispensed between baseline and follow-up for all categories of respiratory disease in both the intervention and control groups. However, there was a weak, but statistically significant, 2% relative reduction in medication prescribed for respiratory infection in the intervention group compared with the control group, with a relative rate ratio (RRR) of 0.98 (95% CI: 0.98–0.99) for the total population, and a RRR of 0.98 (95% CI: 0.97–0.99) for the six-year continual occupancy nested cohort, Table 4. There was no statistically significant relative difference between intervention and control groups in the ratio of symptom prevention medication prescriptions at follow-up compared with baseline, Table 4. There was also a statistically significant 3%–4% reduction in the relative rate of exacerbation sensitive medication for the intervention group: total population, RRR 0.96 (95% CI: 0.96–0.97); 6-year continual occupancy nested cohort, RRR 0.97 (95% CI: 0.96–0.98).

There was also a statistically significant reduction in the relative rate of exacerbation sensitive medication prescribed in most population subgroups. Greatest relative reductions were identified for Pacific Peoples RRR 0.90 (95% CI: 0.88–0.93) in the total population, RRR 0.86 (95% CI: 0.82–0.91) in the 6-year continual occupancy nested cohort; and "other" ethnicity RRR 0.92 (95% CI: 0.89–0.94) in the total population, 0.92 (95% CI: 0.88–0.96) in the 6-year continual occupancy nested cohort. Greater relative reductions were also noted where a low-emmission, energy efficient heater was installed alongside insulation: RRR 0.93 (95% CI: 0.91–0.95) for the total population and RRR 0.93 (95% CI: 0.90–0.98) for the 6-year continual occupancy nested cohort. There was no statistically significant reduction in comparative rates of medication prescribed for Māori, or those living in the most deprived areas (deprivation quintile five).

3.3 | Chronic respiratory disease incidence

Chronic respiratory disease incidence was significantly lower in the intervention group at follow-up with an odds ratio (OR) of 0.90 (95% CI: 0.86–0.94) for measure two, exacerbation sensitive medication. The same trend was observed but softened when measure one, preventative medication, was considered. This trend remained evident when the population was disaggregated by demographic characteristics. The greatest differences were found, using measure two, for young people (<15 years), OR 0.85 (95% CI: 0.75–0.98); people of European ethnicity, OR 0.87 (95% CI: 0.82–0.92); people in deprivation quintile one (least deprived), OR 0.80 (95% CI: 0.70–0.90), four, OR 0.86 (95% CI: 0.77–0.95), and five most deprived OR 0.88 (95% CI: 0.80–0.97); and those who had underfloor insulation, OR 0.82 (95% CI: 0.72–0.94), and whole house insulation, OR 0.86 (95% CI: 0.80–0.91), Table 5.

TABLE 2 Demographic characteristics of the intervention and control groups

	Total population					Six-year continual occupancy nested cohort				
	Intervention group		Control group		All	Intervention group		Control group		All
Characteristic	Number	Percent	Number	Percent	Percent	Number	Percent	Number	Percent	Percent
People	495 864		508 931			83 482		73 856		
Ethnicity										
Māori	85 697	17.28	103 101	20.26	18.79	9017	10.80	8899	12.05	11.39
Pacific peoples	31 024	6.26	43 740	8.59	7.44	3868	4.63	4749	6.43	5.48
European	321 131	64.76	305 031	59.94	62.32	62 046	74.32	53 054	71.83	73.15
Other	58 012	11.7	57 059	11.21	11.45	8551	10.24	7154	9.69	9.98
Sex										0.00
Male	233 801	47.15	241 538	47.46	47.31	36 972	44.29	33 462	45.31	44.77
Female	262 063	52.85	267 393	52.54	52.69	46 510	55.71	40 394	54.69	55.23
Age at start of study										
0–4	66 634	13.44	58 649	11.52	12.47	5308	6.36	1423	1.93	4.28
11–14	66 392	13.39	72 815	14.31	13.85	10 201	12.22	9694	13.13	12.64
15–24	68 947	13.9	79 335	15.59	14.76	4590	5.5	6350	8.6	6.95
25–34	76 106	15.35	76 605	15.05	15.20	5763	6.9	3771	5.11	6.06
35–44	71 114	14.34	70 157	13.79	14.06	11 339	13.58	8493	11.5	12.60
45–54	52 237	10.53	55 994	11	10.77	12 851	15.39	12 333	16.7	16.01
55–64	40 911	8.25	42 495	8.35	8.30	14 039	16.82	16 829	22.79	19.62
65–74	31 415	6.34	29 625	5.82	6.07	12 820	15.36	7540	10.21	12.94
75–84	17 756	3.58	17 843	3.51	3.54	5960	7.14	6335	8.58	7.81
85+	4352	0.88	5413	1.06	0.97	611	0.73	1088	1.47	1.08
Houses	103 087		101 914			26 754		22 703		
NZDep2013 quintile										
Quintile 1: (least deprived)	16 129	15.65	14 909	14.63	15.14	4729	17.68	3976	17.51	17.60
Quintile 2:	19 525	18.94	17 925	17.59	18.27	5274	19.71	4223	18.6	19.20
Quintile 3:	21 925	21.27	20 456	20.07	20.67	5699	21.3	4658	20.52	20.94
Quintile 4:	24 302	23.57	24 152	23.7	23.64	6058	22.64	5208	22.94	22.78
Quintile 5: (most deprived)	21 206	20.57	24 472	24.01	22.28	4994	18.67	4638	20.43	19.48
Climate zone										
CZ1: Far North, Auckland and Coromandel Peninsula	25 486	24.72	28 304	27.77	26.24	5639	21.08	5436	23.94	22.39
CZ2: Rest of North Island (excluding Central Plateau)	51 676	50.13	54 895	53.86	51.99	13 307	49.74	11 862	52.25	50.89
CZ3: South Island and Central Plateau	25 925	25.15	18 715	18.36	21.78	7808	29.18	5405	23.81	26.72
Intervention										
Insulation and heater:	18 932	18.37	5222	5.12	11.78	4502	16.83	988	4.35	11.10
Whole house insulation (ceiling and underfloor)	50 588	49.07	57 637	56.55	52.79	13 069	48.85	12 548	55.27	51.80

(Continues)

TABLE 2 (Continued)

Characteristic	Total population					Six-year continual occupancy nested cohort				
	Intervention group		Control group		All	Intervention group		Control group		All
	Number	Percent	Number	Percent	Percent	Number	Percent	Number	Percent	Percent
Ceiling insulation	19 670	19.08	20 277	19.9	19.49	5444	20.35	4828	21.27	20.77
Underfloor insulation	13 159	12.76	16 793	16.48	14.61	3486	13.03	3779	16.65	14.69
Insulation tops up	738	0.72	2061	2.02	1.37	253	0.95	560	2.47	1.64

4 | DISCUSSION

There was a lower risk of incidence of chronic respiratory disease in the intervention group (when compared with the control group). The risk was reduced by 10% when the exacerbation sensitive medication was used (measure two) and 6% when preventative medication (measure one) was used. There was also a reduction in the intervention group, compared with the control group, in the rate of prescriptions for exacerbation sensitive medication dispensed following the intervention, with the effect size increasing when a low-emission, energy efficient heater was installed alongside insulation. No significant reduction in prescriptions for preventative medication was found, however, there was a small but statistically significant reduction in medicines dispensed for infectious respiratory disease in the intervention group, compared with the control group,

The prevention of chronic respiratory disease was something an earlier meta-analysis suggested was influenced by the length of prior exposure to cold and damp.[22] This was supported in our study where the reduction in incidence risk (using the exacerbation sensitive medication measure) was 15% for children and decreased progressively with age, falling to 10% amongst older people. Results from prior studies have, however, been mixed. An analysis of housing improvements on a range of health outcomes in Glasgow, Scotland, identified improved management of symptoms but not prevention of, or recovery from, chronic illness.[5]

Links between reduction in symptoms and improvements in self-reported health including reductions in wheeze and dry cough in children with asthma have also been reported in other studies.[15,22–24] An economic evaluation of the first year of the WUNZ programme found a small, but highly statistically significant reduction in monthly pharmaceutical costs following the retrofitting of insulation.[18]

The strongest relative reduction in rates of prescriptions dispensed following the intervention was for exacerbation sensitive medication. Results from an earlier analysis of hospitalizations in the WUNZ cohort identified reductions in relative rates of hospitalization following insulation being retrofitted, becoming stronger when more specific chronic respiratory conditions, such as COPD and asthma, were examined.[17] Taken together, these findings support an assertion by the UK National Institute for Clinical Excellence (NICE) of home energy efficiency and heating improvements on asthma being a "sufficiently justified means of managing the condition."[3]

Reductions in the use of exacerbation sensitive medication and hospitalizations, as shown in the current and a previous study, respectively, are more likely linked to the current indoor environment whilst reductions in the need for preventative medication also reflect prior exposure. This could explain why the effect of insulation on prescriptions dispensed for preventative medication was weaker than that found for exacerbation sensitive medication.

4.1 | Dampness and mold

Cold housing has been associated with dampness and mold[2,25,26] and prior studies have found increased odds of new-onset wheeze amongst children living in houses with visible mold and mold odor.[7,27,28] Dampness and mold may therefore have played a role in the observed associations between insulation and lower incidence of chronic respiratory disease and reduction in prescriptions for exacerbation sensitive medications dispensed amongst the intervention group. Indeed, a reduction of damp and mold following improvements in insulating and heating has been reported by residents in evaluations of interventions similar to WUNZ.[29,30]

4.2 | Socio-demographic differences

Reduction in incidence risk differed between subgroups depending on the outcome measure used. For example, the greatest reduction in incidence risk was found amongst adults when the prevention of symptoms medication measure was used, whilst young people (<15 years) demonstrated the greatest reduction in incidence risk when the exacerbation sensitive medications measure was used. There was also lower incidence risk observed for more marginalized groups—such as those in deprivation quintile four and five (most deprived)—when the exacerbation sensitive medications measure was used. These differences might have arisen from differences in prescribing patterns between high-income and low-income households. For example, where compliance in taking preventative medication regularly is assumed to be lower in low-income groups, there may be a tendency to only prescribe exacerbation sensitive medication.[31]

Pacific Peoples benefited most from the intervention in terms of the management of chronic respiratory disease. This could have

TABLE 3 Prescriptions dispensed by population, group, timeframe, and condition being treated. Rate per 100 person years, adjusted for: age, ethnicity, sex, NZDep2013 deprivation quintile, climate zone, and type of insulation installed

			Infectious respiratory disease medication		1 Chronic respiratory disease: prevention medication		2 Chronic respiratory disease: exacerbation sensitive medication	
Population	Group	Timeframe	Number	Adjusted rate	Number	Adjusted rate	Number	Adjusted rate
Total population	Intervention group	Baseline	408 782	53.92	290 666	34.20	373 374	45.99
		Follow-up	467 940	57.80	317 670	35.65	397 999	46.39
	Control group	Baseline	388 935	52.25	265 038	33.29	3460.47	45.41
		Follow-up	435 871	56.60	286 946	34.76	378 061	47.53
Six-year continual occupancy nested cohort	Intervention group	Baseline	150 889	55.21	130 401	37.65	146 087	44.56
		Follow-up	156 361	59.00	148 640	40.83	173 013	49.54
	Control group	Baseline	129 117	53.37	108 256	36.57	122 964	43.99
		Follow-up	136 385	58.11	123 530	39.62	149 903	50.29

been due to higher baseline prevalence of respiratory disease amongst Pacific Peoples in New Zealand[32] as previous studies found that the greatest health benefits from an insulation intervention were observed in those with a pre-existing respiratory condition.[24] However, despite Māori also having a higher prevalence of baseline respiratory disease,[32] no reduced risks were observed in this group, which is of concern and requires further investigation. One reason why Māori may not have received the same benefits could be the structure of the WUNZ programme, which was directed at individual homeowners, whereas a community-based response might be more suited to the Māori collective custodianship model for land.[33] An earlier observation showing significant improvements in self-reported health amongst Māori participating in a cluster randomized trial, involving a community-based rather than individual approach appears to support this.[15]

The difference in incidence risk between socio-demographic groups may reflect the influence of other factors on disease onset in the non-European population, such as higher rates of household crowding[34] or a greater level of prior exposure to cold, damp housing.[22]

4.3 | Differences between intervention types

A greater reduction in risk for chronic respiratory disease incidence was found where underfloor insulation was installed. This may be due to it acting as a barrier between the house and the sub-floor environment, thus preventing rising damp as well as improving the thermal envelope.[28]

The greater improvement in symptoms of chronic respiratory disease where a low-emission energy efficient heater was installed alongside insulation, was likely due to the heater increasing indoor temperature, whilst the insulation helped maintain heat within the house, something that has been shown in other studies that included an energy efficient heater as part of the intervention.[5,29,30,35,36]

4.4 | Limitations

The quasi-experimental design that we adopted has several limitations, including increased risk of bias due to non-randomization of the study population and an inability to match intervention and control houses.[20] In addition to controlling for confounding factors, these risks were managed by using the difference-in-difference model.[19]

We used a direct comparison between the intervention and control group to measure chronic respiratory disease incidence. In this case, unidentified differences between the two groups could have influenced results. However, this risk should have been reduced by sourcing the intervention and control populations from the same program and controlling for confounding factors.[37]

Group size was reduced when the cohorts were disaggregated, for example, the large reduction in risk of chronic disease incidence

TABLE 4 Poisson regression model showing difference-in-difference (relative rate ratio)—for prescriptions dispensed by disease type and chronic disease relief of symptoms population subgroups

Population groups	Total population			Six-year continual occupancy nested cohort		
Measures	Rate ratios (follow up: baseline)		Relative rate ratio: 95% CI in brackets	Rate ratios (follow up: baseline)		Relative rate ratio 95% CI in brackets
Disease types and sub-groups	Intervention group	Control group	RR Intervention group, RR Control group	Intervention group	Control group	RR Intervention group, RR Control group
Infectious disease	1.07	1.08	**0.98 (0.98–0.99)**	**1.07**	**1.08**	**0.98 (0.97–0.99)**
Prevention of symptoms	1.04	1.04	1.00 (0.99–1.00)	1.09	1.08	1.01 (0.99–1.02)
Exacerbation sensitive medication	1.01	1.05	**0.96 (0.96–0.97)**	1.11	1.15	**0.97 (0.96–0.98)**
Age category						
Young person: ≤15 years	1.02	1.04	0.98 (0.96–1.00)	0.96	0.96	**0.97 (0.96–0.99)**
Adult: 15–64 years	0.97	1.02	**0.95 (0.94–0.96)**	1.00	1.07	**0.94 (0.93–0.96)**
Old person: ≥65 years	1.04	1.08	**0.97 (0.96–0.98)**	1.23	1.28	**0.96 (0.95–0.98)**
Sex						
Female	1.00	1.04	**0.97 (0.96–0.98)**	1.11	1.10	0.98 (0.97–1.00)
Male	1.01	1.06	**0.96 (0.95–0.97)**	1.11	1.13	**0.95 (0.93–0.96)**
Ethnicity						
Māori	1.04	1.04	1.00 (0.99–1.02)	1.11	1.12	0.98 (0.95–1.01)
Pacific peoples	0.98	1.08	**0.90 (0.88–0.93)**	0.98	1.12	**0.86 (0.82–0.91)**
European	1.00	1.04	**0.96 (0.96–0.97)**	1.12	1.15	**0.97 (0.96–0.99)**
Other	0.99	1.08	**0.92 (0.89–0.94)**	1.05	1.15	**0.92 (0.88–0.96)**
NZDep2013 quintile						
Quintile 1 (least deprived)	0.97	1.03	**0.94 (0.93–0.95)**	1.05	1.14	**0.94 (0.91–0.97)**
Quintile 2	0.97	1.03	**0.94 (0.93–0.95)**	1.07	1.08	0.99 (0.96–1.02)
Quintile 3	0.98	1.07	**0.92 (0.91–0.93)**	1.11	1.18	**0.94 (0.92–0.96)**
Quintile 4	1.03	1.05	**0.98 (0.97–0.99)**	1.13	1.17	0.97 (0.95–0.99)
Quintile 5 (most deprived)	1.05	1.13	1.00 (0.99–1.01)	1.14	1.15	0.98 (0.96–1.00)
Climate zone						
CZ1 Far North, Auckland and Coromandel Peninsula	1.01	1.04	**0.97 (0.96–0.98)**	1.07	1.11	0.97 (0.95–0.99)
CZ2 Rest of North Island (excluding Central Plateau)	1.00	1.04	**0.96 (0.95–0.97)**	1.11	1.14	**0.97 (0.96–0.99)**
CZ3 South Island and Central Plateau	1.02	1.07	**0.95 (0.94–0.97)**	1.13	1.21	**0.94 (0.92–0.96)**
Intervention						
Insulation and heater:	1.02	1.10	**0.93 (0.91–0.95)**	1.13	1.21	**0.93 (0.90–0.98)**
Whole house insulation (ceiling and underfloor)	1.01	1.06	**0.95 (0.94–0.96)**	1.10	1.14	**0.96 (0.95–0.98)**
Ceiling insulation	1.01	1.04	**0.97 (0.95–0.98)**	1.01	1.14	**0.97 (0.94–0.99)**
Underfloor insulation	1.05	1.03	1.01 (0.96–1.07)	1.21	1.31	0.92 (0.84–1.01)
Insulation top-up	1.00	1.00	1.00 (0.98–1.01)	1.13	1.15	0.98 (0.95–1.01)

Note: Bold indicates $p \leq 0.05$.

in deprivation quintile one (least deprived) using the exacerbation sensitive medication indicator may not be plausible and may instead have resulted from type 1 error inflation.

The use of pharmaceutical prescriptions did not allow for differentiation between some diseases. For example, some exacerbation-sensitive-medications could have been used to address allergies as

TABLE 5 Odds ratio of chronic respiratory disease incidence post-intervention by population subgroup

Incidence measure	1 Prevention of symptoms medication indicator (≥1 prescription)	2 Exacerbation sensitive medication indicator (≥3 prescriptions)
Population sub-groups	Odds ratio: 95% CI in brackets	Odds ratio: 95% CI in brackets
All (unadjusted)	0.94 (0.90–0.99)	0.90 (0.86–0.94)
All (adjusted)	0.94 (0.90–0.99)	0.90 (0.86–0.94)
Age category		
Young person: <15 years	0.99 (0.87–1.13)	**0.85 (0.75–0.98)**
Adult: 15–64 years	**0.91 (0.85–0.98)**	**0.87 (0.81–0.93)**
Old person: ≥65 years	0.92 (0.85–1.01)	**0.90 (0.83–0.97)**
Sex		
Female	**0.90 (0.84–0.96)**	**0.88 (0.83–0.94)**
Male	0.97 (0.90–1.05)	**0.87 (0.81–0.94)**
Ethnicity		
Māori	0.93 (0.81–1.07)	0.92 (0.82–1.06)
Pacific peoples	s	0.91 (0.74–1.11)
European	**0.91 (0.86–0.97)**	**0.87 (0.82–0.92)**
Other	0.95 (0.81–1.12)	0.88 (0.74–1.04)
NZDep2013 quintile		
Quintile 1: (least deprived)	**0.85 (0.75–0.96)**	**0.80 (0.70–0.90)**
Quintile 2:	1.06 (0.93–1.19)	0.89 (0.79–1.00)
Quintile 3:	0.91 (0.81–1.01)	0.96 (0.86–1.07)
Quintile 4:	0.93 (0.84–1.04)	**0.86 (0.77–0.95)**
Quintile 5: (most deprived)	0.91 (0.81–1.01)	**0.88 (0.80–0.97)**
Climate zone		
CZ1: Far North, Auckland and Coromandel Peninsula	0.96 (0.88–1.06)	**0.86 (0.79–0.95)**
CZ2: Rest of North Island (excluding Central Plateau)	**0.87 (0.79–0.97)**	**0.87 (0.79–0.96)**
CZ3: South Island and Central Plateau	0.94 (0.87–1.01)	**0.89 (0.83–0.95)**
Intervention		
Insulation and heating	1.07 (0.89–1.30)	0.97 (0.81–1.15)
Whole house insulation (ceiling and underfloor)	**0.90 (0.84–0.96)**	**0.86 (0.80–0.91)**
Ceiling insulation	0.97 (0.87–1.09)	0.93 (0.83–1.03)
Underfloor insulation	0.89 (0.78–1.02)	**0.82 (0.72–0.94)**
Ceiling insulation top-up	s	s

Note: Bold indicates statistical significance $p \leq 0.05$. "s" indicates outcome suppressed due to insufficient power.

well as asthma. Medications were selected as being *primarily* used in the treatment of respiratory disease in the opinion of the four health and data professionals consulted. Whilst this risked some prescriptions being misclassified, in principle any such misclassification would have been randomly distributed between the intervention and control groups.

The measures used to indicate disease incidence were not as reliable as a formal diagnosis. They assumed that the prevalence of respiratory disease within the study population at baseline was the same as the prevalence within the New Zealand population. However, the prevalence at baseline using these measures was similar across the study population, suggesting that any difference between the study population and the New Zealand population would have been consistent between the intervention and control groups.

5 | CONCLUSION

There was a statistically significant lower relative risk of chronic respiratory disease incidence for the intervention group. The relative rate ratio for exacerbation sensitive medication prescribed (for relief of chronic respiratory disease symptoms) was also lower in the intervention group. These findings add to an emerging body of evidence suggesting that new onset chronic respiratory disease, as well as exacerbation of pre-existing respiratory disease, could be, at least in part, prevented by retrofitting home insulation.

AUTHOR CONTRIBUTION

Dr Caroline Fyfe conducted the data analysis and wrote the original draft. Dr Lucy Telfar Barnard advised on the data analysis and edited

the paper. Professor Jeroen Douwes advised on the data analysis and edited the paper. Professor Philippa Howden-Chapman advised on data analysis and edited the paper. Professor Julian Crane advised on pharmaceuticals used to treat respiratory disease and edited the paper.

ACKNOWLEDGMENTS

The authors would like to thank the New Zealand Energy Efficiency and Conservation Authority (EECA) for supplying the Warm-Up New Zealand (WUNZ) insulation subsidy data on which this study is based. We would also like to thank the New Zealand Ministry of Health for supply the Public Health Organization and Pharmaceutical records used for data linkage. Open access publishing facilitated by University of Otago, as part of the Wiley - University of Otago agreement via the Council of Australian University Librarians.

CONFLICT OF INTEREST

No conflict of interest declared.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Fyfe C, Barnard LT, Douwes J, Howden-Chapman P, Crane J. Retrofitting home insulation reduces incidence and severity of chronic respiratory disease. *Indoor Air*. 2022;32:e13101. doi: 10.1111/ina.13101