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Retrofitting houses with insulation to reduce health inequalities: Aims and methods of a clustered, randomised community-based trial

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Abstract

This paper describes the purpose and methods of a single-blinded, clustered and randomised trial of the health impacts of insulating existing houses. The key research question was whether this intervention increased the indoor temperature and lowered the relative humidity, energy consumption and mould growth in the houses, as well as improved the health and well-being of the occupants and thereby lowered their utilisation of health care. Households in which at least one person had symptoms of respiratory disease were recruited from seven predominantly low-income communities in New Zealand. These households were then randomised within communities to receive retrofitted insulation either during or after the study. Measures at baseline (2001) and follow-up (2002) included subjective measures of health, comfort and well-being and objective measures of house condition, temperature, relative humidity, mould (speciation and mass), endotoxin, beta glucans, house dust mite allergens, general practitioner and hospital visits, and energy or fuel usage. All measurements referred to the three coldest winter months, June, July and August.

From the 1352 households that were initially recruited, baseline information was obtained from 1310 households and 4413 people. At follow-up, 3312 people and 1110 households remained, an 84% household retention rate and a 75% individual retention rate. Final outcome results will be reported in a subsequent paper. The study showed that large trials of complex environmental interventions can be conducted in a robust manner with high participation rates. Critical success factors are effective community involvement and an intervention that is valued by the participants.

Keywords: Housing; Health; Insulation; Randomised community trial; New Zealand

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Introduction

Despite the fact that we spend around 90% of our lives inside, we still know surprisingly little about the specific health effects of the indoor environment in our dwellings (Howden-Chapman, 2004). It is clear that warm, dry housing is a fundamental human need. Poorly constructed or older houses are more difficult and expensive to heat, which can have health consequences for the occupants. Colder houses place more physiological stress on older people, babies and the sick, all of whom spend more time inside (Howden-Chapman, Signal, & Crane, 1999). Houses that are cold are also likely to be damp and this can lead to mould growth, which can cause respiratory symptoms (Tobin et al., 1987). The link between damp, cold, crowded housing conditions and health has been highlighted recently in a number of international reports (Department of Health, 1998; Independent Inquiry into Inequalities and Health Report, 1998; Bonnefoy, Braubach, Moissonnier, Monolbaev, & Robbel, 2003; Howden-Chapman & Tobias, 2000).

This study is one of only a small number of randomised trials that are directed to evaluating social interventions in general, and housing interventions in particular (Oakley, 1998; Thomson et al., 2004; Thomson, Petticrew, & Morrison, 2001). Several recent reviews of the housing and health literature have concluded that there is a pressing need for trials of housing interventions, designed to improve health, that provide sufficient methodological detail to draw causal inferences.

In this paper, we describe a study where houses were the unit of randomisation. Intervening by installing insulation in existing houses, rather than intervening at the level of the individual, for example by providing more clothes for individuals or a small heater, seems a potentially a cost-effective and practical way of improving health through increasing the indoor temperature and lowering relative humidity. The focus on houses as the main unit of analysis is thus intended to enhance the utility of the trial for the formulation of public policy, which depends on evidence of the cost-effectiveness of interventions.

Housing in New Zealand

Housing in New Zealand, compared to other countries of the Organisation for Economic Cooperation and Development, is more commonly timber frame, inadequately heated and colder than is recommended by the World Health Organisation (WHO). New Zealand households use less energy for home heating, compared to households in other developed countries, although the percentage of the household budget spent on energy is similar (Isaacs, Amitrano, Camilleri, Pollard, & Stoecklein, 2002).

Three-quarters of the current permanent dwellings in New Zealand were built before 1978 when the Building Code introduced minimum insulation standards. Consequently, in 2001 about half of all dwellings still lacked some insulation. In addition, heating practices in New Zealand tend to contribute to lower internal temperatures. According to the 2001 New Zealand Census, 3% of people used no heating.[1] Another study of energy usage in New Zealand showed few households heated the whole house during winter and almost a third of households had an average winter temperature below the WHO recommended minimum of 16 °C (World Health Organisation, 1987).[2] High humidity, poor insulation, poor maintenance practices, relatively low levels of heating, and a tendency for some newer, low cost homes to be very airtight mean that many New Zealand households live in damp and cold conditions. A third of New Zealand households report that their homes have mould (Howden-Chapman, Saville-Smith, Crane, & Wilson, in press) compared for example to only one-eighth of homes in a recent WHO European survey (Bonnefoy et al., 2003). Winter excess mortality for people over 65 years of age is greater in New Zealand than in Northern Europe (Isaacs & Donn, 1993) and this may reflect differences in the quality of housing.

Large-scale research on housing requires large capital outlays and consequently is rarely carried out, but in New Zealand an opportunity has arisen to carry out a community-based trial of installing insulation in older houses. Successive New Zealand governments have provided loans to insulate houses in order to increase their energy efficiency. Community organisations have received employment subsidies in order to train teams to carry out standard housing retrofits. The availability of standardised insulation retrofits, subsidised or free to householders, and trained community retrofit teams able to retrofit houses to the common standard, provided the environment in which it was possible to carry out a community-based, clustered, randomised trial.

Contribution of housing to health inequalities

Like most health risks, those associated with poor housing are not evenly spread across the population. New housing is more likely to be owner-occupied, while older, uninsulated housing, in a poorer state of repair, is more likely to be rented. Those who rent, rather than

[1] http://www.stats.govt.nz/domino/external/pasfull/passfull.nsf/0/4c2567ef00247c6acc256c2f0012396b/$FILE/Table%2021.xls.

[2] http://www.eeca.govt.nz/Content/EW_Homes/EW_Information/heep3.pdf.

own their houses, are more likely to be of lower socio-economic status, compounding the impact of inadequate housing on their health, particularly for more vulnerable groups such as those with chronic respiratory conditions, children and older people.

In New Zealand, indigenous Maori and Pacific migrants and their descendents, compared to the majority European (*Pakeha*) population, are more socially and economically deprived. These inequalities in the determinants of health contribute to Maori living on average 10 years less than Europeans; and Pacific people live on average 7 years less than non-Pacific people (Howden-Chapman & Tobias, 2000; Ajwani, Blakely, Robson, Tobias, & Bonne, 2003). Poor housing, along with other socio-economic-related factors, is likely to be part of the explanation for this critical disparity, which has profound social, health and economic implications.

Furthermore, there is evidence that good quality housing can act as a protection against other socio-economic stress factors, such as low income, lack of wealth and unemployment (Howden-Chapman, 2004). The provision of affordable, warm housing may be an important part of reducing inequalities in health, *if* it can be demonstrated that improved housing conditions contribute to improved health outcomes, especially for those on lower incomes. Housing and heating of the indoor environment are thus potentially key policy areas for intervening to reduce health inequalities.

To plan effective housing and health interventions, it is important to disentangle the effect of housing from that of other, possibly related, socio-economic variables (Davey-Smith & Phillips, 1992). Research that leads to robust policy intervention needs to clarify both the direct and indirect effects of improved housing. Policies, implemented with worthy intent, may have no impact on housing conditions and health, or may, perversely, increase health inequalities, because higher income groups are disproportionately advantaged (Victora, Vaughan, Barros, Silva, & Tomasi, 2000).

Housing and health trials

Despite the strong arguments that can be made *for* experimentation and social interventions, there are very few randomised community trials and even fewer that explicitly try to reduce inequalities in the determinants of health (Oakley, 1998). There is a perception among some researchers and policymakers that such randomised trials are not only unethical, but logistically impractical (Somerville, Mackenzie, Owen, & Miles, 2000).

There is a particular paucity of trials in the area of housing and health (Somerville et al., 2000; Thomson et al., 2001; Thomson, Petticrew, & Douglas, 2003). There is an ongoing randomised trial of re-housing families in public housing into private housing in low-poverty areas, although less than half the families assigned the housing vouchers took up the option of moving to new neighbourhoods (Katz, Kling, & Liebman, 2001; Leventhal & Brooks-Gunn, 2003). We know of only one randomised trial underway that is looking at the impact of cost-effective housing interventions designed to make older houses warmer and drier (Sommerville et al., 2002).

Hopton and Hunt described an important longitudinal study designed to evaluate the effects of an improved heating system on symptoms reported by children living in a socio-economically deprived housing estate, where the results suggested the elimination of dampness and mould prevented a further deterioration in health, rather than an improvement (Hopton & Hunt, 1996). Somerville and colleagues showed children's asthma symptoms improved when central heating was installed in their houses (Somerville et al., 2000). Neither of these studies, however, had a control group so it is not possible to draw definitive causal conclusions.[3]

The remainder of this paper outlines the research methods, recruitment, retention and intended analyses of this large-scale randomised trial of retrofitting houses with insulation. The complexity and scale of the study justifies description, as it is an example of a structural public health intervention, which has been successfully implemented, while adhering to a demanding study design. In doing so, we are complying with CONSORT (Consolidated Standards of Reporting Trials) standards to report all intended study analyses and methods in advance of the substantive analyses (Moher, Schulz, Altman, & Group, 2001; Campbell, Elbourne, Altman, G for the CONSORT Group, 2004).

Method

Participants

There were 1352 houses in the Housing Insulation and Health Study. In these households there were 4413 people, half of whom (49%) were Maori, the indigenous people of New Zealand and 25% of whom were Pacific people, from Samoa, Tonga and other smaller island states, who include new migrants and their usually first and second generation descendants (Table 1). The proportion of Maori and Pacific people in the sample was higher than that in the national population. In the

[3]One trial on a single house exists in which the detailed improvement in indoor climate, microclimate, and energy use were examined closely before and after retrofitting insulation to different levels, but cost-effectiveness was not discussed (Cunningham, Roberts, & Hearfield, 2001).

Table 1
Baseline information for each group

	Control group	Intervention group
Household factors at baseline		
Number recruited	672	680
Number returned questionnaire	652	658
Dwelling reported in "poor" or "very poor" condition (%)	116/644 (18)	118/653 (18)
Condensation reported (%)	566/633 (89)	577/640 (90)
Non-condensation dampness reported (%)	413/613 (66)	437/641 (68)
Mould reported (%)	481/643 (75)	490/651 (75)
Dwelling cold "always" or "most of the time" (%)	452/647 (70)	473/651 (73)
Individual factors at baseline		
Number	2152	2261
Female (%)	1115/2152 (52)	1187/2261 (53)
Ethnicity		
NZE (%)	794/2121 (37)	835/2231 (37)
Maori (%)	1005/2121 (47)	1109/2231 (50)
Pacific (%)	578/2121 (27)	501/2231 (22)
Age		
0–4 (%)	249/2152 (12)	294/2261 (13)
5–14 (%)	524/2152 (24)	566/2261 (25)
15–24 (%)	237/2152 (11)	229/2261 (10)
25–44 (%)	592/2152 (28)	594/2261 (26)
45–64 (%)	362/2152 (17)	391/2261 (17)
65+ (%)	188/2152 (9)	187/2261 (8)
Health rated "fair" or "poor" (%)	438/2138 (20)	445/2242 (20)

2001 Census these fractions were 14.7% and 6.5% respectively.

Insulation intervention

The randomly allocated intervention was the insulation of houses by previously trained community retrofit teams, in all but one rural community, where a local builder was employed to do this work. The insulation package was the standard New Zealand Energy Efficiency and Conservation Authority package, which consists of insulation in the ceiling, draught-stopping around the windows and doors, sisalated paper (insulated foil) strapped under the floor joists and a polyethylene covering over the ground.

Not every house received the full insulation package for a variety of reasons. A standard New Zealand house is often built of weatherboards and placed on piles dug into the ground. If paint on window or door-frames was peeling badly the draught-stopping could not be done; conversely if aluminium window-frames had been installed, the tight seal meant that there was no need for weather-stripping. Under-floor insulation could not always be installed, for example, if the crawlspace under the house was not accessible because the householders had not cleared rubbish as previously agreed, or if the house had been built directly on a concrete pad. Occasionally, inadequate space or rubbish in the roof-space prevented the installation of the ceiling insulation. Overall, in the intervention group, 617 houses were given ceiling insulation, 517 at least one of the under-floor interventions and 466 some draught-stopping—180 houses received all the measures.

Households allocated to the intervention group had their houses insulated after the baseline measures were taken, those in the control group were insulated *after* the study had finished. The intervention was free to householders, because additional funds were raised by the researcher to cover the costs of labour and materials.

Research question

The key research question was whether retrofitting houses with insulation increased the indoor temperature and lowered the relative humidity, energy consumption and mould growth in the houses, as well as improved the health and well-being of the occupants and thereby lowered their utilisation of health care.

Ethics

We initially gained ethics approval to test the feasibility of the experimental design in two pilot studies; the first in urban pensioner housing and the second in a rural community.[4] As a result of these pilots it was decided that to maintain a high retention rate among participants, the households in the control group also needed to be insulated at the end of the study. Also, to avoid those in social housing being stigmatised for having cold houses, we decided in the main study to aim for a range of household tenure-types (e.g. home-ownership, social housing and private renting). We signed memoranda of understanding with organisations that were community-based in each area, to make

[4] In the first pilot study in pensioner units, the drop-out rate was 25% largely due to illness and death, but also due to participants being assigned to the control group (Howden-Chapman et al., 2000).

explicit not only the obligations on both sides, but to highlight the need for everyone to benefit from the research. We successfully sought ethical approval for the study.

Design

The Housing Insulation and Health Study was a clustered randomised community trial, where houses rather than individuals were randomly assigned to the study groups. As the intervention was insulating uninsulated houses, clustering by houses and thus households (rather than individuals) was the only feasible way of carrying out the trial. The trial was single-blinded; that is the households knew whether their house had been insulated, but the baseline interviews and subsequent analyses were carried out with the interviewers and the researchers not knowing which households had been assigned to each group.

We also adopted a partnership research model and collected data to explore more closely the implementation of the study.

Setting

The study was setup in seven geographical areas, three urban and four rural. This was done in partnership with diverse local organisations, all of whom had an interest in housing and health and supporting people in their local area. These organisations included the local branch of the Maori Women's Welfare League, a housing trust, and a local government public health provider. To get both a demographic and climatic spread, five communities were in the North Island and two were in the South Island of New Zealand. Fig. 1 illustrates the geographical spread of the communities. Memoranda of understanding were negotiated and signed with locally based organisations. These organisations then worked closely with the research team in a number of ways: organising the initial community meetings, where the researchers described the study design to the potential participants; responding to their local community concerns; employing local interviewers, who were trained by the researchers, liaising with the local insulation retrofit teams, and organising community meetings to disseminate the preliminary results.

Recruitment

Each organisation established a team of local health workers to select 200 households in their community, in line with the research protocol criteria. The inclusion criteria were: the house had to be uninsulated; at least one person in each household had to suffer currently from some respiratory disease, most commonly asthma, or chronic bronchitis and emphysema with preference being given to households with severe symptoms; and households had to be planning to stay in their house for

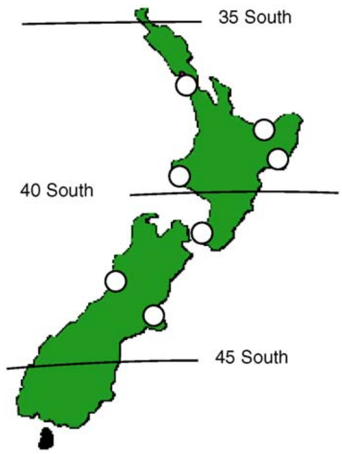

Fig. 1. New Zealand, and the latitude of the participating communities.

the next two winters. The study design was explicitly described to community leaders and individual participants, by face-to-face meetings and written material.

The research was advertised in local papers, on radio and by word of mouth and invited potential participants to fill in application forms. Enrolment continued until 200 households in each community, who met the research criteria for inclusion were selected. If more than 200 applications were received then the community team, using their local knowledge, selected the participants in most need. After the selected householders agreed to participate, their houses were audited by builders and the retrofit teams to check that they were indeed uninsulated before they were finally included in the study. Members of the households gave informed consent on the basis that their house would be insulated eventually, but that the timing (first or second year) would be random. Like the researchers, the organisations who recruited the households into the study were unaware of the subsequent allocation of the household until *after* the baseline measures were collected. See Fig. 2 for a flow diagram showing the number of households and individuals in the study.

Sample population

The houses in the study were largely single storey, stand-alone houses. The tenure patterns showed some divergence from the 2001 New Zealand Census: 24% of houses in the study were rented as against 32% nationally (approximately half the rentals were from public landlords, as against approximately one fifth nationally); and 76% of the houses were owner occupied, as against 68% for NZ as a whole. Overall, about one-third of the houses were in the lowest socio-economic decile of small areas, and two-thirds were in

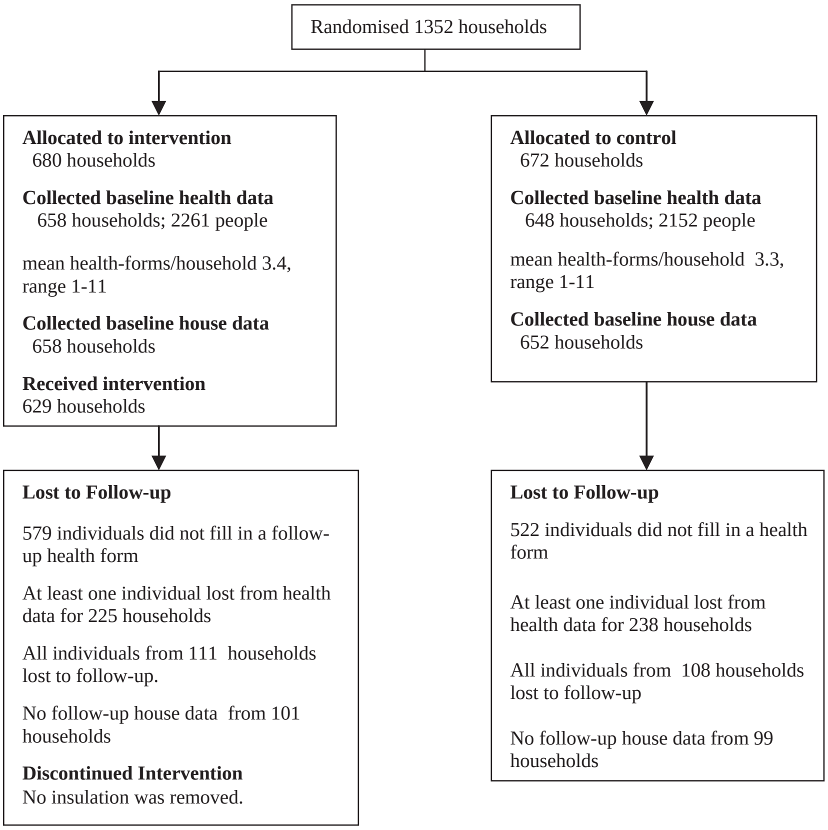

Fig. 2. Flow of individuals and households through the study.

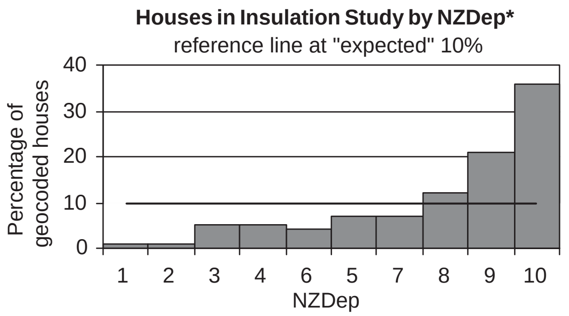

Fig. 3. Socio-economic deprivation of the study areas. *NZDep is a census-based measure that reflects eight dimensions of material and social deprivation such as unemployment, receipt of a means tested benefit and lack of access to a car. It ranks areas (containing approximately 90 people) into deciles, with a higher score indicating a more deprived area (Crampton, Salmond, Kirkpatrick, Scarborough, & Skelly, 2000).

the bottom three deciles (see Fig. 3). That is, the sample population selected was more vulnerable to illhealth due to the social and economic pattern of the area in which they lived. As they were also living in houses with inadequate insulation, the participants represented an especially high risk sub-group of the New Zealand population.

Sample size calculations

As we could find no previous published trials that had attempted to improve health by retrofitting insulation in houses, proxy sample size calculations were based on the number of individuals whose health status could be expected to improve on a generalised health question. To increase the power of the study, we selected a population with pre-existing respiratory conditions, on the assumption that the intervention would have a greater effect in this group.

The main power calculations considered the percentage of people in the lowest income category reporting "fair" or "poor" health, compared with those in the next lowest income category (Ministry of Health, 1999). Sample size estimates were based on the frequency of "fair" or "poor" health in the control group being similar to those of the lowest income category and the frequency in the intervention group being similar to those in the next lowest income category. With a 0.05 level of significance, a sample size of 323 per group would have an 80% chance of correctly concluding there was a significant difference in reported health status. As there was no knowledge of the likely intra-cluster correlation coefficients for either household or the regions; and because the household compositions would vary (from single parents, through both nuclear and large, extended families, to lone senior citizens); and because of the high drop-out rates in the pilot studies, due to mobility of the population, the sample size was doubled and the trial aimed to recruit a total of 1400 households.

Outcome measures

This study used a number of subjective and objective tools to measure the environmental characteristics of houses and occupants (see Table 2). Measures were recorded over the three coldest winter months, June, July and August.

During the three winter months of 2001, households recorded their subjective feelings of warmth (by placing a pink, green or blue sticker on a chart located on the refrigerator to denote being 'warm', 'OK' or 'cold' respectively that day) before their evening meal. In spring, the person designated as the head of the household was interviewed by a local community interviewer, about the demographics of the household occupants, the type of heating used in the house, their economic preferences for heating as against disposable income, and their perception of the surrounding neighbourhood. The interviewer also brought all members of the households a questionnaire about their health, their smoking patterns, and their absences from their normal activities over the preceding winter due to sickness; adults in the households filled the health forms in for babies and children under twelve. The health questionnaires were either completed during the interviewer's visit or left behind and subsequently collected. Occasionally the interviewer, if requested, helped the participant to complete the health questionnaire.

In addition to these subjective measures of warmth, in a randomly selected 140 (11%) of the houses, objective measures of temperature and relative humidity were recorded by 'data-loggers', that were located by interviewers in the main bedroom. A sub-sample was used due to cost considerations. Further, in each of the seven communities, two houses had data loggers installed externally to measure the outside temperature. Independent building inspectors visited this sub-sample of 140 houses and appraised the physical condition of these houses and the degree of damp and mould in the houses. In addition, in 150 houses randomly selected across three communities, samples of dust were taken from the main bedrooms and analysed for allergens, endotoxin and beta glucans. Mould populations actively associated with dust particles were also extracted from dust samples by standard microbiological isolation methods to provide both an estimate of total culturable biomass as well as to enumerate species diversity present (Samson et al., 2000).

Table 2
Outcome measures

Level	Outcome	Measure
Individual	Self-reported health	SF36 scales
		Respiratory symptoms
		Days off work and school
		Variety of health care utilisation questions
	Objective health care utilisation	Number of GP visits
		Hospital visits—number and length
Household	Energy measures	Self-reported fuel usage
		Electric and gas company bills
	Warmth/dampness	Objective temperature and relative humidity
		Comfort charts
		Self reported dampness
	Subjective fungal activity	Musty smell
		Observed mould
	Objective fungal activity	Mould speciation
		Mould mass
		Endotoxins
		Beta-glucans
	Self-reported behaviour	Opening windows etc
	Environmental tobacco smoke	Smoking behaviour
	Subjective neighbourhood trust	Neighbourhood reciprocity and safety

During the winter of 2002, after the experimental group had received the intervention, all the objective and subjective energy measures were repeated and, as in 2001, immediately following winter the health questionnaires were repeated and further dust samples collected. Once the formal part of the study data collection was completed, the houses in the 'control' group were insulated.

Electricity and gas companies supplied data on the energy consumption of each household. We also collected self-reported consumption data for coal, wood and LPG (used in portable gas heaters).

Participants' general practitioners were contacted to obtain the number of visits each person made to the doctor during the three winter months. Diagnoses made and any prescriptions written could not be obtained, because in most cases medical records are not computerised and thus this would have required the employment of medical staff to check medical records. The number, duration and diagnostic codes for inpatient hospital visits were collected through a data matching process using the unique national patient identifier number. We collected self-reports of any prescription changes.

Sequence generation

Randomisation of households was undertaken using a computer programme, and carried out by an independent researcher using anonymised identifiers. The randomisation was stratified by region; in two geographically dispersed communities further stratification occurred by sub-region. Due to the announcement of the funding decision, the timeline between enrolment and start-up was so short that the randomisation was carried out in three phases, each involving all of the houses that were, at that stage, enrolled. Households randomised to receive additional monitoring were simultaneously assigned to an intervention group. The first phase, carried out before the winter, assigned the data-loggers to households; the second, in early spring, chose the households that dust-samples were to be collected from; and the third in late spring randomised the remaining households to intervention or control groups. Neither the householders nor the main research team were informed which intervention group a house had been assigned to until *after* the baseline data had been collected.

In November (late spring) of 2001, the participants were informed of the allocation of their household by letter, and this letter was followed up by a telephone call from a local interviewer. The insulation for those in the intervention group was installed over the subsequent summer and autumn.

Biases

The study design is not free from biases. Most notably, participants were not blinded to receipt of the intervention. A number of options to achieve blinding were considered as part of the original design, but none of them were feasible. However, the study design offered several strategies to investigate possible bias of the main study findings, detailed below.

Data analysis and methodological issues

Data were double-entered to minimise data entry errors. The analysis will be conducted both on clusters (houses) and individuals and involve several outcomes. The outcome measures are both subjective and objective, allowing internal checks of the recorded number of hospitalisations compared to self-reports of hospitalisation. Likewise, we will compare the objective temperature and relative humidity data with the subjective self-reports of comfort recorded nightly in each house by the nominated householder. We will explore the objective and subjective health data in relation to temperature, RH and measures of dampness from the housing condition survey. Changes in energy consumption as a function of community location, socio-economic level, and house age, type and condition will be examined.

In addition to comparing the subjective and objective responses for various variables described above, we will also conduct "basic sensitivity analyses" of main analyses to explore the possible impact of bias—most notably non-blinding of the intervention (Greenland, 1996). That is, using a range of estimates for the likely degree of response bias in the subjective outcome measures, we will determine how much bias would have been required to produce the observed results (assuming a true null association).

Finally, we will be able to take advantage of an unplanned opportunity to measure the possible 'placebo' effect of home insulation. In one geographically bounded sub-community the builder carrying out the retrofit claimed to have carried out the intervention according to contractual specifications, but failed to do so, until the discrepancies were picked up by the external auditor. This contractor's deception was not detected by the householders. Consequently, in part of one community, subjects incorrectly believed they had received the intervention at the time of reporting results for follow-up. Whilst the statistical precision of results for just one community is limited, it does allow us the opportunity to explore placebo effects in regard to self-reported measures. Conversely, we are unable to include this part of the community in some analyses of the intervention. Similarly sub-analyses will be carried out based on the proportion of the total insulation package that each household actually received.

The quantitative results are presently being prepared for publication. In addition, a qualitative analysis of the process of carrying out the study and the impact of the research on the various community groups is being carried out.

Data analytical issues

Data will initially be explored using simple categorical and stratified analyses. The next stage of analysis will use generalised linear models. In addition, generalised linear mixed models (e.g. multi-level models) will be applied to take account of both individual and cluster effects.

We will analyse the subjective health measures which are the SF36 Role Emotional, Role Physical and Social Functioning scales, along with subsets of other scales, self-rated wheeziness, coughing, and shortness of breath. The specific questions asked depended on the age of the participant. These data will be modelled on the baseline score, and the sex, age and ethnicity of the participants. We will also model the reported days off school and work.

We are using cluster specific methods because houses rather than people were randomised. The analysis will be carried out on the basis of 'intention-to-treat' on the sample as a whole in the first instance. Analyses will also be carried out on the basis of the actual intervention or insulation package households received, based on information from the building auditor's report. The independent variable will be whether the households are in the intervention or control group. The dependent variables will be the household measures of fuel consumption and individual measures of health and well-being. Analyses will also control for the clustering of individuals within households. We have considered the clustering of households within communities as random effects and this clustering will be taken into account for the analysis of energy consumption. The effect of the north south gradient will be included using 'degree days'. Degree days measure how often, and how much, the daily average outdoor temperature is below a given set-point (15 °C).

Discussion of policy implications

The community trial outlined here was carried out with the aim of increasing knowledge of the link between specific aspects of housing condition and health, as well as reducing inequalities in one of the possible environmental determinants of health. We used a partnership research approach in local communities, as well as engaging with a number of national organisations. National information and resources were channelled predominantly to Maori and Pacific people, and others in more difficult social and economic circumstances, so they could strengthen their own community resources.

There is a growing literature on the necessity and importance of understanding the local context in community-based trials, as well as understanding the wider impacts, so that the outcomes of such interventions can be more fully interpreted. At the outset of this trial it was recognised that the process of carrying out the research was critical, both in ensuring we could robustly test the hypothesised outcomes and to inform further work. Several researchers have suggested that examining the process of *how* interventions in community-settings improve health may be just as critical if not more important for understanding how to intervene than evaluating the outcomes of community interventions (Attenza & King, 2002; Saegert, Kllitzman, Freudenberg, Cooperman-Mroczek, & Nassar, 2003; Hawe, Shiell, Riley, & Gold, 2004; Roberts, 2004). The adoption of a partnership research model is increasingly being recognised as a powerful participatory approach to collaboratively studying and acting in complex areas such as reducing health inequalities (Israel, Schulz, Parker, & Becker, 1998; Minkler, Glover Blackwell, Thompson, & Tamir, 2003).

The research has the potential to influence the direction of health and energy policy, as well as community and regional development. The successful implementation of a partnership approach can also generate benefits to the community and provide insight into the way that particular methods may make anticipated outcomes more likely.

Potentially, the study provides an example of sustainable development as it demonstrates successful complementarity between objectives in a number of policy domains, notably health, housing and energy. The study took advantage of an existing policy initiative to test the link between housing conditions and health. It highlights an area of housing policy where considerable public health benefits could result from interventions that can be applied in a range of settings, overcoming common institutional and political obstacles to reach significant portions of low-income populations. It fits into the category of housing interventions, which appear most successful when the technology is effective, cheap, durable and requires little effort to maintain or use.

This trial combines several features designed to increase both the robustness of the conclusions, the promotion of community development and the policy application of the conclusions. As an activity within the community, the research provided wider benefits over and above the anticipated outcomes and sharing of knowledge. We trained and employed local interviewers and the local retrofit teams, in most cases giving preference to long-term unemployed people. This approach was generally very rewarding, but challenging and time-consuming, in terms of fundraising, project management, community coordination and the required level of communication with the communities and funders. A television programme and a short film of the project have provided some immediate recognition for the communities. The evaluation of the research process, a partnership approach in the context of a randomised trial, its contribution to community development and the sustainability of the intervention, will be the subject of a separate paper (Matheson et al., forthcoming).

Preliminary results were reported back to the communities for comment, before final results are submitted for publication. Nine community meetings were organised by the local community organisations and members of the research team travelled to each area and gave short presentations before entering into general discussions with the participants about their ideas for future research. Most meetings were well attended and feedback from the participants was overwhelmingly positive. The research and the meetings were extensively covered by local newspapers.

The study was particularly notable for the wide range of disciplines involved. The inter-relationship between the social, medical and physical sciences formed a key element necessary to undertake this study which successfully linked the social and epidemiological sciences of designing community trials, the physics of heat transfer, the engineering of building design, the natural science of microbiology and the science of respiratory illness.

This study was designed to have direct relevance to the development of policy options for reducing health disparities (Davis & Howden-Chapman, 1996). However, care was taken to explain the study as potentially having both energy efficiency and health implications, in order to elicit support from a number of government agencies. Key government agencies were involved from the inception of the study, so that both senior policy analysts and their ministers have taken a personal interest in the study's progress.

The ‘‘prima facie’’ evidence for the effects of poor housing on health are sufficiently powerful that there is a strong case for housing concerns being an integral and explicit part of health research and policy. This research has shown that housing interventions need broad intersectoral action (involvement of people and agencies across the health, housing, building and community sectors) if they are to be effective and sustainable. Housing issues need to be given prominence in planning and resource allocation decisions at both the national and local level, if policy initiatives based on research are to bring much-needed improvements in the health of vulnerable populations.

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