The effect of energy efficiency improvement on health status of COPD patients

A Report to the Eaga Partnership Charitable Trust

Authors:

Liesl M Osman[1]

Jon G Ayres[2]

Carole Garden[1]

Karen Reglitz[1]

Janice Lyon[3]

J Graham Douglas[4]

Gordon Kyle[5]

Karen Milne[5]

Anne Ludbrook[6]

[1]Department of Medicine & Therapeutics, University of Aberdeen, Foresterhill, Aberdeen, AB25 2ZN

[2]Department of Environmental & Occupational Medicine, University of Aberdeen, Liberty Safe Work Research Centre, Foresterhill Road, Aberdeen, AB25 2ZP

[3]Aberdeen City Council, St Nicholas House, Broad Street, Aberdeen

[4]Chest Clinic, Aberdeen Royal Infirmary, Foresterhill, Aberdeen, AB25 2ZN

[5]Castlehill Housing Association, 11 Waverley Place, Aberdeen, AB10 1XH

[6]Health Economics Research Unit, University of Aberdeen, Foresterhill, Aberdeen, AB25 2ZD

ACKNOWLEDGEMENTS

The authors thank the patients who participated in this study. In addition, thanks are extended to Gordon Kyle, Chief Executive of Castlehill Housing Association, Karen Milne, Project Manager, and Mrs Val Bennett, Energy Surveyor, Aberdeen Care & Repair, Castlehill Housing Association. They thank Dr Gordon Prescott, Senior Lecturer in Medical Statistics and Dr Massoud Boroujerdi, Lecturer in Medical Statistics, at the Department of Public Health, University of Aberdeen, for statistical advice.

CONTENTS

FIGURES AND TABLES

Executive Summary

Remit

This report describes a study which aimed to improve energy efficiency action in homes of patients with Chronic Obstructive Pulmonary Disease (COPD), through referral of participants to the Scottish Executive's Central Heating Programme and Warm Deal scheme (paralleling the English Affordable Warmth programme). This Home Environment and Respiratory Health study (HEARTH) was funded by Eaga Partnership Charitable Trust. Its primary aim was to test, in a randomised trial, whether referral to the Central Heating and Warm Deal programme, and hence improvement of energy efficiency of homes, improves health status in patients with chronic respiratory illness. Secondary aims were to assess changes in indoor environmental factors following referral, and the association of these indoor environment factors with patient health status.

Context

It is known that drops in outdoor temperature below 14^oC are associated with increased hospital admissions and deaths from respiratory and cardiovascular disease. This winter mortality and morbidity is relatively higher in the UK than in Scandinavian and Northern European countries. In the Eurowinter study of six European countries it was shown that average temperatures in living rooms in cold months were associated with differences in national mortality rates, independent of outdoor temperatures, and UK temperatures were cooler than Northern European temperatures.

Housing guidelines recommend that temperatures of 21^oC be maintained in living rooms for at least nine hours per weekday and 16 hours on weekends and in bedrooms 18^oC be similarly maintained. Households which need to spend more than 10% their income to maintain this level of warmth are said to be in fuel poverty.

People with existing chronic respiratory illness are particularly vulnerable to winter mortality and morbidity. Little is known about energy efficiency of their homes, indoor levels of warmth maintained, and the relationship of warmth in the home to exacerbations of their illness.

Investigation

The study was carried out in Aberdeen, in the North East of Scotland between 2004 and 2007. Homes of 178 patients with COPD who had required acute hospital admission within the past two years were surveyed, an Energy Rating established, and possible energy efficiency improvements identified. Of these patients 118 were randomised to Intervention or waiting list Control groups. A further 60 were not willing to be randomised but agreed to be monitored. After baseline indoor environmental measures had been carried out, the Energy Surveyor arranged a further visit to participants in the intervention group to discuss the improvements identified at the initial survey visit, and asked whether they wished to go ahead.

The 178 homes had indoor air quality and temperature monitoring over one week at baseline on entry to the study, and one week at 12 month follow up. Respiratory and general health status was measured at baseline and follow up, and clinical data (lung function and hospital admissions) collected.

Results

Average National Home Energy Rating of the 178 homes on entry was identical to the Scottish national average of 5.4. Average temperature at 5pm in living rooms was 21^{o}C at baseline and follow up, and average temperature in bedroom between 8pm and 8am was 19^{o}C which also did not change between baseline and 12 month follow up.

Higher Estimated Annual Fuel Cost (EAFC) was associated with lower hours of warmth ($r=-0.21$, $p<0.01$) at baseline.

At baseline there was a significant association between measures of warmth (particularly number of days on which a temperature of 21^{o}C was maintained for at least 9 hours) and health status. Symptom and Impact scores on the St George's Respiratory Health Questionnaire and general health scores on the Euroqol VAS were associated with fewer living room hours of 21^{o}C warmth. The association of respiratory and general health status with bedroom warmth was in the same direction but not statistically significant.

Air quality, measured as micrograms per cubic metre of fine particles ($PM_{2.5}$) was also measured in these homes. Maximum values were found to be high (148 $\mu g/m^3$) more than four times the US Environmental Protection Agency (EPA) recommendation for maximum levels over 24 hours (35 $\mu g/m^3$), and were significantly related to respiratory health status. $PM_{2.5}$ level was strongly associated with presence of environmental tobacco smoke in the homes studied.

Participants in the study who were continuing to smoke showed higher adverse effects of lower temperatures and poor air quality on respiratory health than those who had given up smoking.

After baseline measurements the energy efficiency improvements which had been identified for Intervention homes were set in process through the Aberdeen Affordable Warmth Scheme, with referrals being made to the Scottish Executive's Central Heating and Warm Deal programmes as appropriate, for homes in private ownership, or Aberdeen City Council and Castlehill Housing Association for social housing. Over the next 12 months, in spite of agreement to randomisation, more than half of the Intervention homes did not have the recommended energy efficiency action. The main reasons for this were concerns over the cost or disruption of energy efficiency action. Conversely, nine of the 59 Control homes had energy efficiency action carried out independent of the study. This weakened the power of the study to test for differences between the randomised arms. In the follow up evaluation, 12 months after intervention, no difference was found between the Control and Intervention groups in health or energy efficiency outcomes.

An analysis was then carried out which compared health and energy efficiency outcomes between patients in homes which had had energy action, and those which had not, independent of original assignment, and including the group who had been monitored but not randomised.

This post hoc analysis found significant improvement in respiratory symptom scores for those patients who had energy efficiency action. They also had a significant decrease in estimated annual fuel costs to heat homes to recommended levels, and improved home energy efficiency rating. However energy efficiency action was not associated with fewer admissions to hospital in the 12 month follow up. It was also not associated with increase in living room or bedroom hours of warmth, or changes in indoor humidity.

Thomson and Petticrew[1] have discussed this question of how benefits from improving housing are mediated, specifically that change in indoor warmth and humidity does not appear to be essential for benefits to health from energy efficiency action. Richardson and Somerville[2] have suggested that a more even distribution of warmth within the home may be significant in health outcomes. Alternatively, there may be broad psychosocial benefits from reduced fuel costs following home improvement, which impact on health.

Conclusions

- Failure to meet guideline recommendations for at least nine hours a day of indoor hours of warmth at 21^{o}C is associated with poorer respiratory health among patients with Chronic Obstructive Pulmonary Disease.
- Chronically ill respiratory patients are reluctant to take up energy efficiency upgrading, if this is offered to them.
- Those patients who do take energy efficiency action show clinically significant improvement in respiratory symptoms.
- Energy efficiency action is not associated with increase in indoor warmth in homes of average energy efficiency.
- Indoor air quality, reflecting environmental tobacco smoking, is strongly associated with poorer health of these patients, and air quality should be considered when evaluating benefits of energy efficiency improvement.
- Levels of $PM_{2.5}$ in these patients' homes were strikingly higher than levels recommended for outdoor air quality.
- Patients with COPD who continue to smoke show more adverse effects of fewer hours of warmth than those who have given up smoking.

1 INTRODUCTION

Improvement to housing has long been recognised as the obvious arena for public health interventions. In the 19th century, overcrowding and hygiene were common areas for improvement while in recent times attention has turned to the physical characteristics of housing such as building materials used, and the indoor environment including dampness, mould and inadequate heating[3]. Older or poorly constructed homes can be more difficult and thus more expensive to heat, incurring financial hardship and fuel poverty[4;5]. This is defined as the need to spend more than 10% of the household income on fuel. From census data, Rudge and Gilchrist found a significantly higher rate of emergency admissions for respiratory illnesses in winter among those at high fuel poverty risk between 1993 and 1997[6].

Cold and/or damp homes place physiological stress on vulnerable people such as the very young, the elderly and the unwell, and the link between these environmental conditions and ill health has been well evidenced[7-10]. Several studies have found damp housing to be associated with long-standing illness[7], in particular asthma, and demonstrated a dose-response relationship[9;10]. Evans found inability to keep the home warm in winter was strongly associated with the majority of health outcomes in a general population questionnaire study[7].

Although there is agreement that improvements to housing can benefit health, the problem seems to occur in moving beyond associations to identifying causal links[11]. There has been a lack of robust intervention studies which are well enough designed to take account of the range of confounding variables surrounding housing and health[12]. The cumulative effects of life circumstances such as poverty, unemployment and social deprivation create a complex range of influences which make it difficult to reach any clear conclusions regarding the benefits to health of specific housing improvements.

Studies looking at the impact of improved central heating and insulation have shown increased indoor temperatures and higher satisfaction with heating systems following these improvements[13]. Oreszczyn's Warm Front scheme demonstrated appreciable increases in living room and bedroom temperatures in homes that received both central heating and insulation. This was a comprehensive study using direct monitoring of indoor temperatures over two winters, and adjusting for outdoor temperature. Although no measure of health benefit was included, implicit in the findings was the suggestion that improved warmth would in turn lead to improved well being among participants[13].

A systematic review by Thomson looked at eighteen studies that explored the health effects of housing improvements such as refurbishment and renovation programmes, energy efficiency measures, community regeneration and re-housing based on medical need[14]. They found that most studies reported some health gain but the quality of studies was generally poor. Study populations were small, they were not randomised, did not control for potential confounding variables, and only a few had comparison groups.

More recently, other studies have shown this trend towards improved mental health. Allen found a significant improvement in mental health in a group of patients with coronary heart disease after receiving housing improvements in the form of central heating, roofing repairs or shower/bath access[11]. He did not, however, find a physical health improvement in this sample of low income owner occupiers. Allen concluded that the process of implementing the improvements was valued by participants as much as the improvements themselves, as support received from project workers was considered an important factor. This emphasis on support may explain the mental health improvement and suggests that collaborative working can be an effective way of maximising the health benefit of this type of intervention.

Similarly in New Zealand, Howden-Chapman conducted a randomised trial looking at the effect of insulation on health inequality in a community setting[15]. Following baseline measures of indoor environmental variables and self-reported health, households randomly allocated to intervention group had their homes insulated – ceiling, underfloor and draught-proofing. They too reported a large improvement in self-perceived health status, a small improvement in bedroom temperature, and a reduction in days off work.

Exposure to cold and damp induces changes in the respiratory tract, and it is widely accepted that living in cold, damp housing is associated with respiratory illnesses[8;16]. Two multidisciplinary studies of pre-school children in Sweden found that dampness increased the risk of asthma, allergic symptoms and airway infections, although the exact mechanism for the health effects was not identified[17]. Other studies have shown that the relationship between damp housing and ill health may be causal[7;18;19]. Although these are epidemiological studies, they have consistently shown an association between damp homes and health in a number of different populations[7;20], and shown a dose-response relationship between the severity of dampness and health effects[7;9;18;20].

Studies have tended to focus on dampness and mould but less is known about the effects of cold homes, independent of dampness. Evans has suggested that being unable to keep the home warm is more strongly associated with self-reported health as measured by the SF-36 than having a damp home[7]. In a controlled prospective study, Walker found indirect associations between heating use and several health outcomes in the presence of environmental problems such as mould and condensation[21]. Although the data was cross-sectional, Walker found significant associations between the presence of mould/condensation and scores on the SF-36 general health and mental health scales, and reported presence of wheezing. He demonstrated significant associations between self-reported heating use and presence of these environmental problems and concluded that homes with more heat may lead to less mould/condensation and, in turn, improved health outcomes. Caution is needed when drawing conclusions from cross-sectional data but Walker's results indicate that heating use and health outcomes is an area worthy of further investigation.

In a cohort study of the over-55s by Gemmell[22], participants who reported feeling cold 'often' or 'most of the time' in winter were five times more likely to rate their health as fair or poor. In multiple regression analysis, measures of home dampness were not found to be significant[22].

People with existing respiratory illness are vulnerable to effects of outdoor cold, but few studies have explored health and indoor warmth in these groups. In patients with Chronic Obstructive Pulmonary Disease (COPD) Donaldson found lower bedroom temperatures to be almost significantly associated with increased exacerbations and a decline in lung function[23].

Somerville evaluated the effect on health outcomes of installing central heating in the homes of a group of children with asthma who were living in damp housing in Cornwall[24]. They found all respiratory symptoms were significantly reduced after intervention particularly nocturnal cough, and days lost from school due to asthma were reduced. Lack of a comparison group limits this study however, and the extent of benefit gained is likely to have been subject to reporting bias. Somerville did not measure heating use in the homes that were improved.

The Watcombe Housing Study was a three year randomised intervention study with Phase I homes receiving upgrading immediately and Phase II homes one year later[2]. Improvements included central heating, insulation, ventilation and double glazing. This study was a rigorously designed evaluation, using direct measurement of environmental variables in living rooms, bedrooms and outdoors in each of the three years. Energy efficiency levels improved significantly in the upgraded homes. They found a significant difference in bedroom temperature ($p=0.002$) and in surface and wall dampness ($p=0.001$) after one year between upgraded and not upgraded homes. A year later however, dampness in the upgraded homes had returned to previous levels. The authors concluded that improving the energy efficiency of homes produced a more even indoor temperature but further improvement of the indoor environment will still be affected by activities and habits of the occupants.

These studies have all identified a need for more multi-agency interventions to reach a better understanding of the complexity of factors involved in housing and its effect on health and quality of life.

Our current study was a collaborative project involving NHS Grampian, Aberdeen City Council, Communities Scotland and the University of Aberdeen and offered energy efficiency improvement to the homes of patients with COPD in the Aberdeen City area who had been admitted to hospital with an exacerbation within the past two years. Improvements included new or updated central heating systems or boilers, insulation, draught-proofing, and reassessment of benefits. We report here on the lessons to be learned from conducting a multi-agency, real-life study in a particular client group.

2 METHODS

2.1 Time period

The study was carried out from the end of October 2004 to mid May 2007.

2.2 Sample

617 patients who had been admitted to Aberdeen Royal Infirmary for COPD in the previous two years were identified from hospital records, and invited to take part in the study if they lived within the Aberdeen City Council boundaries in their own homes. Patients in nursing homes or sheltered homes, where individual control over the heating system was not possible, were excluded. Those who accepted the invitation were visited by a trained surveyor who carried out an energy survey of the home. This provided a National Home Energy Rating (NHER) (see below for a definition of NHER). Homes were not included in the study if their energy rating was above 6.0 and they were judged by the surveyor to not be able to have energy efficiency improvement.

2.3 Energy efficiency

In Scotland energy efficiency is measured by the National Home Energy Rating (NHER)[25]. NHER is calculated by estimating the energy costs for a property divided by the floor area, using a standard heating pattern of 9 hours heating per day during the week and 16 hours a day at weekends, with the living area calculated to 21^{o}C and the rest of the house to 18^{o}C. The index is adjusted to fit a 0 to 10 scale (Figure 1).

The NHER program also provides an estimated annual fuel cost figure for homes surveyed based on the parameters described above, plus cost for other domestic fuel.

Figure 1: NHER Scale (Adapted from Scottish House Condition Survey 2002)

10	**Very efficient**	**Good energy efficiency**
9+	**2002 Scottish Building Regulations for new build homes**	
7-8	**1999 Scottish Building Regulations for new build homes**	
6-7	**1991 Scottish Building Regulations for new build homes**	**Moderate energy efficiency**
5.4	**Scottish average (2002 SHCS)(Scottish Homes Communities Scotland 2005b)**	
4	**Scottish average (1996 SHCS)(Scottish Homes Communities Scotland 1996)**	
3		
2		**Poor energy efficiency**
1		
0	**Unsatisfactory, very energy inefficient**	

[1]Adapted from Scottish House Condition Survey 2002

Scottish Housing standards require all social housing in Scotland to have NHER of at least 5.0 by 2015. An NHER of 7.4 to 8 has been suggested to be the desirable minimum level for energy efficiency in low income households[26].

2.3.1 Energy efficiency intervention

After baseline measurements, for participants whose homes were identified as suitable for energy efficiency improvements, and who were randomised to the intervention group, the Energy Surveyor arranged a further visit to participants' homes to discuss the improvements identified at the initial survey visit, and whether they wished to go ahead. If they did agree to proceed, action was set in process through the Aberdeen Affordable Warmth Scheme. For homes in private ownership referrals were made to the Scottish Executive's Central Heating and Warm Deal programmes as appropriate. For social housing, to Aberdeen City Council and Castlehill Housing Association

Improvements included replacement and upgrade of central heating systems, installation of loft, underfloor and cavity wall insulation, and reassessment of benefits. In addition, participants were offered low energy light bulbs free of charge. The average time to achieve intervention was nine months, with a minimum of one month and a maximum of 18 months.

For owner occupiers wishing to have energy efficiency improvements, a full financial assessment was carried out by the Energy Surveyor to determine eligibility for local authority and charitable organisation grants. Participants who were not eligible for grants were offered low cost loans to assist with the financing of improvements. Aberdeen Care and Repair sought quotations for the proposed work and reported back to owner occupiers, and liaised with contractors. Financial assessment was not necessary for those living in social housing. After agreeing with participants what improvements were to be done, the Energy Surveyor then contacted the council with her recommendations.

All participants were offered a benefit check to determine whether they were in receipt of the maximum entitlement (Disability Living Allowance or Attendance Allowance depending on the age of the participant). Assistance was given to complete the necessary paperwork to apply for or reassess benefits.

2.4 Environmental data collection

Environmental data (temperature, humidity, air quality $PM_{2.5}$), and endotoxin load were collected from participants' living rooms (LR) and bedrooms (BR) during one week on entry to the study and one week on exit from the study, which was at least 12 months later. Entry and exit monitoring was carried out from the end of October 2004 to mid May 2007.

2.4.1 Temperature and humidity

Temperature and humidity were measured using an Escort iLOG^{TM} datalogger, placed 1-1.5m high (usually on sideboard in LR and bedside table in BR).

Recordings were made at 30-minute intervals. From this data was calculated the average per cent humidity in living room and main bedroom, and number of hours during the week at which LR temperature was above 21^{o}C, and number of hours when BR temperature was above 18^{o}C.

Temperature indices used as outcome measures were

1. LR average temperature at 5pm, over the week studied, as used in the Eurowinter Study.
2. LR hours 21^{o}C: Total hours over observation week when Living room temperature was at or above 21^{o}C.
3. LR days at 21^{o}C for at least 9 hours.
4. BR average temperature between 8pm and 8am, over the week studied.
5. BR Hours 18^{o}C: Total hours over observation week when bedroom temperature at or above 18^{o}C.
6. BR days at 18^{o}C for at least 9 hours.

The UK Meteorological Bureau provided outdoor temperature data for Aberdeen, giving maximum and minimum temperatures for each day monitored.

2.4.2 Indoor air quality monitoring

Particulate data were measured for $PM_{2.5}$ mass in micrograms per metre^3 (µg/m^3). Measurements were taken using a DustTrak Aerosol monitor, a laser photometer calibrated from 0.001 to 100 mg/m^3. The DustTrak was placed in participants' living rooms, usually 1-1.5m high, between 12pm and 5pm and collected the following day between 9am and 12pm.

Outdoor $PM_{2.5}$ readings were collected from a DustTrak monitor at the Department of Environmental and Occupational Medicine which is based approximately three miles from the Aberdeen City centre, in a medium density suburban area. The DustTrak was based inside the laboratory but fitted with a probe to allow external monitoring. Readings were taken every 5 minutes. Monthly averages were calculated from daily averages. Calibration was done after every download (approx every three days). Over the study period monthly median 24-hour outdoor value of $PM_{2.5}$ ranged from 4 to 17µg/m^3.

Endotoxin dust samples were collected using a Morphy Richards 2000 watt vacuum cleaner with HEPA filtration, following the methods used in the US Department of Housing First National Survey of Lead and Allergens in Housing[27]. The endotoxin results are expressed in endotoxin units (EU)/mg (bulk samples).

Indoor NO_2 was measured with passive samplers (Palmes tubes) in living room (LR) and bedroom (BR). Sample tubes were placed away from windows and doors, usually at 1-1.5m height. Samplers were left for one week.

More details of measurement of the indoor environment are given in Appendix D.

2.5 Health Status

The chronic (12 months) version of the St George's Respiratory Questionnaire was used to assess respiratory health status of participants. It has three components:

- **Symptoms:** Frequency and severity of symptoms and exacerbations, over the past 12 months.
- **Activity Limitation:** Summative weighted score of activities limited by breathlessness over the past 12 months.
- **Disease Impact:** Summative weighted score of limitation in social functioning and degree of psychological disturbances over the past 12 months resulting from the airways disease.

Scores are expressed as percentages ranging from 0 to 100. Higher scores represent worse heath status.

The Euroqol[28] health questionnaire EQ VAS was used to assess generic health status. The EQ VAS (Visual Analogue Scale) obtains a self-rating of current health status, using a vertical 20cm. 'thermometer'. The thermometer has endpoints of 100 ('best imaginable health state') and 0 ('worst imaginable health state'). The respondent rates his/her current health state by drawing a line from the box marked 'your own health state today' to the appropriate point on the EQ VAS.

2.6 Perception of warmth

At the end of the twelve month follow up period additional structured questions were included asking participants about their perception of warmth in their home, and influences on heating behaviour.

Questionnaire

A structured questionnaire was designed, asking participants questions such as:

- "Over the past week, was the temperature in your LR/BR always just right, sometimes too warm, or sometimes too cool?"
- "In a normal day, how many hours do you spend in your LR, Kitchen, BR, outdoors?"
- "Is the warmth in your LR/BR influenced by any of the following – heating difficult to adjust, other peoples' preferences, room difficult to heat, or concern over keeping heating costs down?"

The full questionnaire is available as Appendix E.

2.7 Demographic data

Social deprivation was assessed by the Scottish Index of Multiple Deprivation (SIMD). This is the Scottish Executive's official tool for identifying small area concentrations of multiple deprivation presented at data zone level. The SIMD 2006 contains 37 indicators in seven domains: Current Income, Employment, Health, Education Skills and Training, Geographic Access to Services (including public transport travel times for the first time), Housing and a new Crime Domain. The data zones, which have a median population size of 769, are ranked from most deprived to least deprived on the overall SIMD and on each of the individual domains. The result is a comprehensive picture of relative area deprivation across Scotland. Post codes can be used to provide an SIMD decile ranking of deprivation from 1 (least deprived) to 10 (most deprived).

2.8 Clinical data

Data on most recent lung function measurement (FEV_1 and FVC) and hospital admissions for COPD exacerbations in the 12 months before the study were collected from clinical records.

2.9 Smoking status

Continued smoking is a high risk factor for morbidity in patients with COPD. It was important to accurately assess whether participants were still smoking. Cotinine analysis of saliva samples allowed objective measurement indicating current smoking status. Participants were asked to provide a saliva sample by sucking on a dental cotton wool roll. This procedure was witnessed. Samples were refrigerated and then assayed using Salimetrics High Sensitivity Salivary Cotinine Enzyme Immunoassay kit.

3 ANALYSIS

Descriptive statistics are given for results of the environmental monitoring, together with report of intercorrelations among environmental measures. Parametric and non-parametric statistics were used as appropriate. SPSS 15.0 was used for statistical analyses (SPSS V13, SPSS, Inc., Chicago ILL).

3.1 Baseline analysis

An initial analysis was carried out testing for the association of baseline health status with baseline environmental measures. Unadjusted associations between demographic, clinical and temperature measures were calculated for SGRQ Symptom, Activity Limitation and Disease Impact scores and EQ VAS scores. The demographic and clinical variables in analyses included: age, validated smoking status, marital status, SIMD (Scottish Index of Multiple Deprivation), number of prior admissions for COPD and percentage of predicted FEV_1 and FVC. As FEV_1 and FVC were highly correlated ($r=0.61$, $p<0.001$) only predicted FEV_1 was used. Variables with p values of at least 0.10 in the unadjusted analyses were entered into an ordinary least squared multivariate regression analysis. Using Bonferroni correction for multiple testing of intercorrelated outcomes a p value of <0.01 was required for significance.

Data were analysed separately for continuing smokers and for non-smokers.

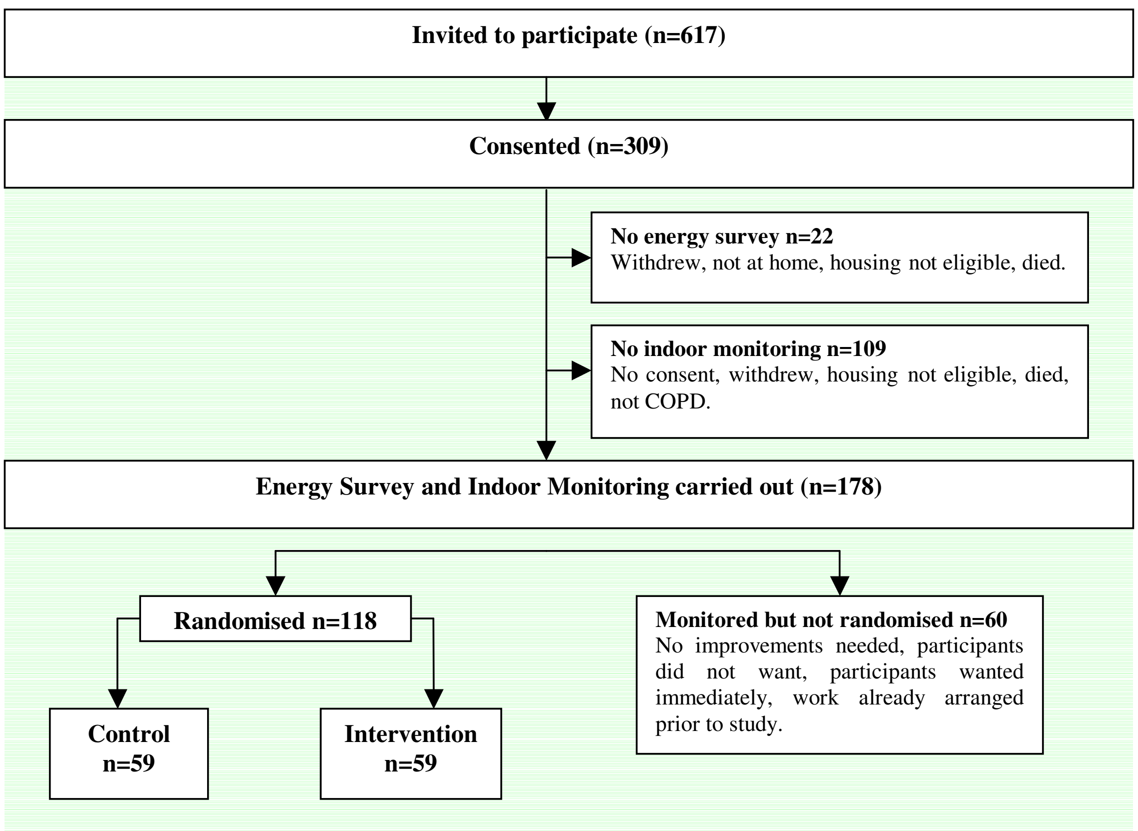
3.2 Follow up analysis

In this analysis multiple regression analysis (or ANCOVA) was used. The outcome measure at twelve month was the dependent variable and the corresponding measure at baseline was the independent variable together with the grouping variable. In multiple regression analysis the coefficient of the groping variable indicate the average difference between the groups following intervention. The average difference can be corrected for potential confounders by including them in the multiple regression as additional independent variables. The multiple regression has the advantage of being unaffected by the baseline differences[29]. We first tested for differences between randomized arms of the study (intention to treat analysis) and then compared homes where action was carried out with homes where no action was implemented. The average differences in health status scores were adjusted for demographic and clinical variables previously identified as significant covariates[30]. These were: age, levels of $PM_{2.5}$ in the home and percentage of predicted FEV_1 and FVC. As FEV_1 and FVC were highly correlated ($r=0.61$, $p<0.001$) only predicted FEV_1 was used.

4 BASELINE RESULTS

Figure 2 shows the selection of participants in the study. Six hundred and seventeen patients were invited to take part in the study. Three hundred and nine initially agreed, of these 287 were surveyed (22 were not surveyed for a variety of reasons including difficulty in contacting to arrange survey, withdrawing from the study, or death). 109 of those surveyed did not go further in the study; these patients had more energy efficient homes. Average difference in energy efficiency ratings of these patients' homes was NHER 1.0, 95% CI 0.6 to 1.3.

Figure 2: Selection of participants into study



Patients who declined to take part in the study (n=439) had higher (worse) SIMD scores, and were therefore more deprived than those who took part (6.3 vs 5.7, p<0.02).

Table 1 shows basic characteristics of homes and participants who went on to take part in the study

Table 1: Demographic and housing characteristics at baseline

Characteristic		Total n=178
Age (m, SD)		70 (8.5)
Male		82 (46%)
Pensioner household		135 (76%)
SIMD decile score (m, SD)		5.7 (2.6)
Social housing/ privately owned*		75 (42%)/103 (58%)
†Property type:		
Detached, semi- or end terrace		77 (43%)
Terraced		31 (17%)
Flat		69 (39%)
Property age:		
Pre 1930s		16 (9%)
1930-1963		89 (50%)
>1964		73 (41%)
Central heating		150 (84%)
Kitchen adjacent to living room		70 (39%)
Floor area sq m (m, SD)		73.5 (31.9)
Energy efficiency (NHER)		5.4
	Poor 0 – 2	23 (13%)
	Moderate 3 - 6	124 (70%)
	Good 7 -10	31(17%)
Estimated Annual Fuel Costs (Median, IQR)		£509 (£415-£635)

*homes were privately rented; †1 mobile home excluded; m = mean; SD = standard deviation; IQR = interquartile range.

The energy efficiency survey showed that mean NHER of patients' homes was 5.4, identical to the Scottish average[31] of 5.4 NHER. Table 1 shows that only a minority (13%) had very poor energy efficiency.

There was no significant difference between privately owned and social housing in NHER. More than half of the homes with low energy efficiency had central heating.

4.1 Indoor temperature and humidity survey

After the initial energy efficiency survey participants had a one week monitoring of indoor temperature between October and the following May of each year in which participants were entered in the study. Temperature and humidity measures are shown in Table 2.

Table 2: Baseline Temperature and Humidity

	Total N=178 Median (IQR)
LR average temp at 5pm (^{o}C)	21 (19.5-22.5)
LR hours above 21^{o}C	48(9-119)
*LR days 9H/21^{o}C (N,%)	
No days	70 (39%)
1 -4 days	30 (17%)
5-7 days	77 (44%)
LR humidity (%)	43.7 (39.1-50.9)
BR lowest temp (^{o}C)	15.6 (13.7 – 17.5)
BR hours above 18^{o}C	126(61-164)
**BR days 9H/18^{o}C (N,%)	
No days	41(23%)
1 -4 days	33(20%)
5-7 days	101(57%)
BR humidity (%)	48.7 (43.2-54.5)

*Missing for 1 participant; **missing for 3 participants; IQR = interquartile range.

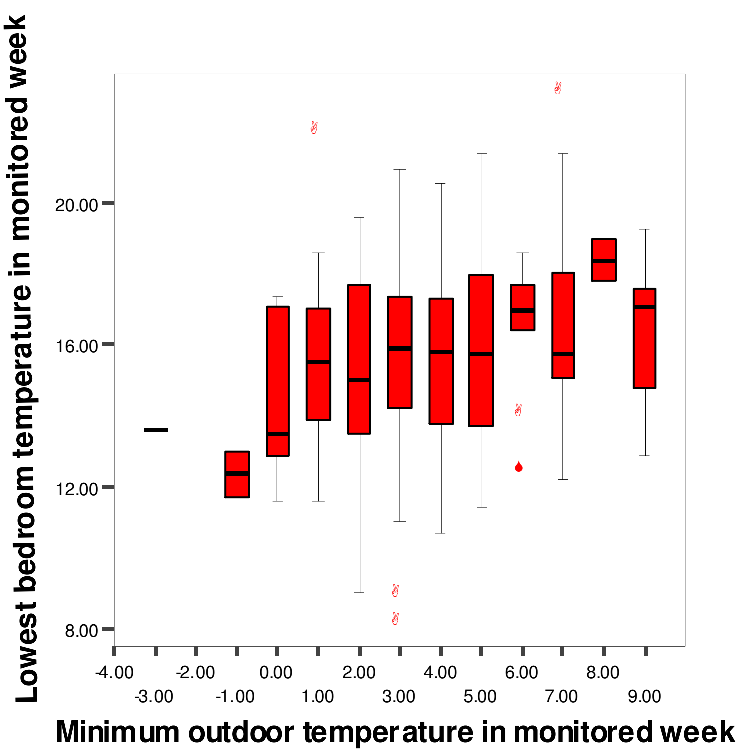
NHER parameters recommend at least 9 hours per day at 21^{o}C in living rooms, and 18^{o}C in bedrooms. Almost half the houses in the study did not reach this recommended level of warmth in the living room over the week in which they were monitored. Bedrooms were more likely to be maintained at recommended levels.

During the observation week five homes in the study had mean living room 5pm temperatures below 16^{o}C.

Hours of warmth in living rooms and bedrooms were higher in more energy efficient homes, but the difference did not reach statistical significance. Living room median temperature was identical in homes of high and low energy efficiency.

Indoor temperatures were not strongly related to outdoor temperatures, although there was a weak relationship between lowest bedroom temperature and outdoor minimum temperature (r=0.2, p<0.01, see Figure 3 below).

Figure 3: Lowest bedroom temperature in monitored week

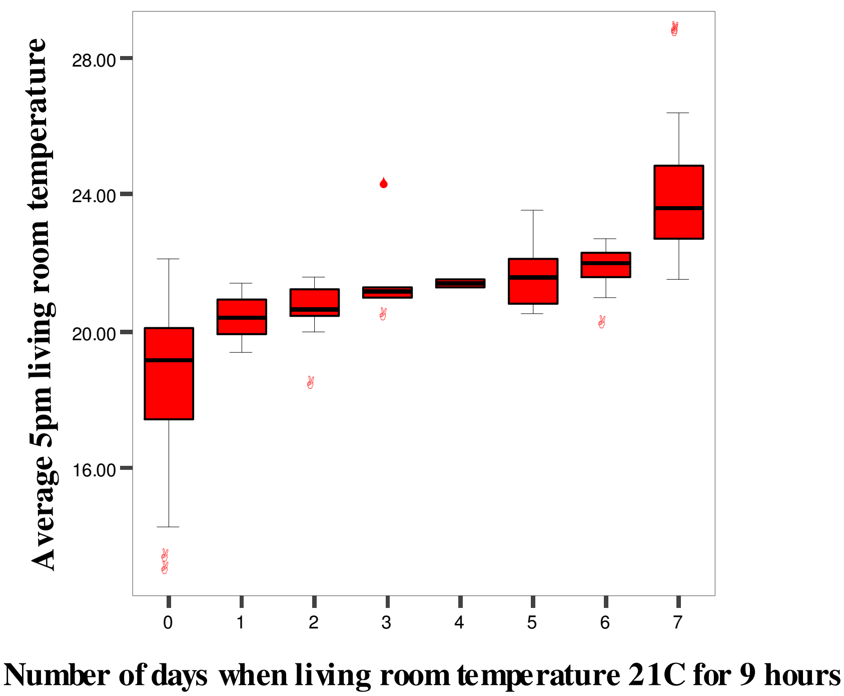


The boxplot shows median values as a heavy black line, interquartile range (IQR) as the boundaries of the box, and indicates extremes by the whiskers extending above and below the box. Outliers are indicated by circles. Asterisks indicate extreme values.

4.2 Indoor temperatures at 5pm and days at which temperature of 21°C was maintained for 9 hours

Figure 4 shows average 5pm temperatures in the monitoring weeks. There was a clear distinction in average living room temperature between the 70 homes which had no days with 21°C for 9 hours and homes which had at least one day with 21°C/9H. In homes with no days of 21°C/9H, minimum 5pm temperatures went down to 12.9°C. In all other groups, minimum 5pm temperature never fell below 18°C.

Figure 4: Living room temperature at 5pm by number of days with 21°C for 9 hours

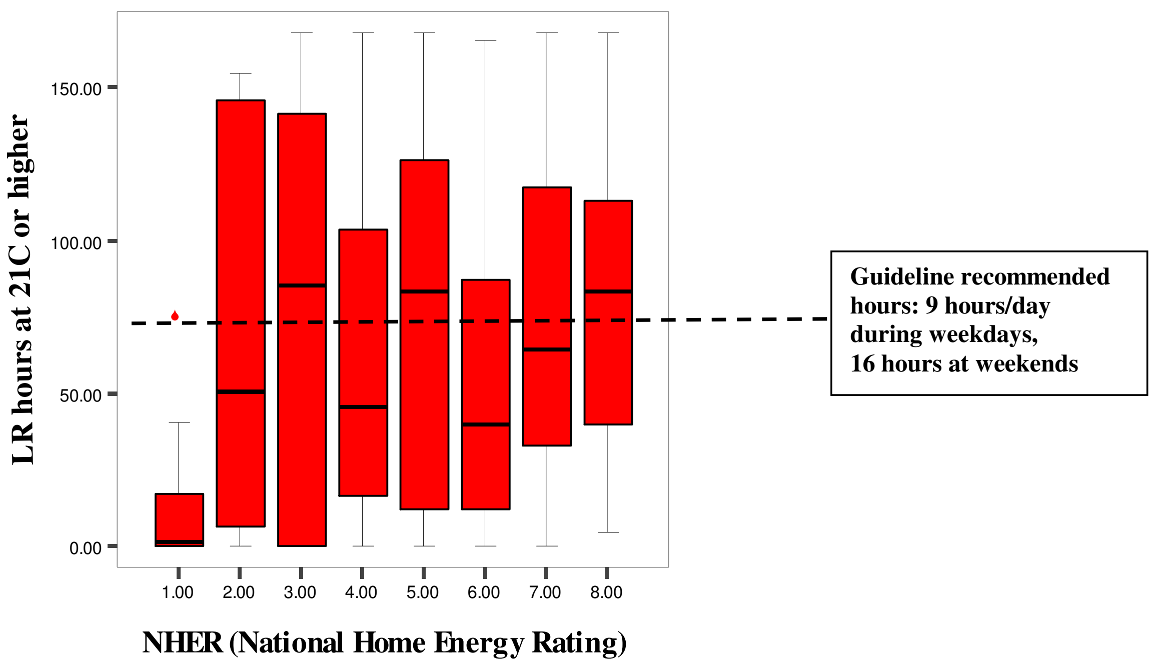


The boxplot shows median values as a heavy black line, interquartile range (IQR) as the boundaries of the box, and indicates extremes by the whiskers extending above and below the box. Outliers are indicated by circles. Asterisks indicate extreme values.

4.3 Energy efficiency and hours of warmth

Figure 5 shows the wide variation in hours of warmth in living rooms in homes at equivalent NHER levels. If homes reached guideline warmth they would have 77 hours per week at 21°c. The graph shows that there was little relationship between higher energy efficiency and hours of warmth, except in the case of the 6 homes with very high energy efficiency (above 8), or very low energy efficiency (the 7 homes with NHER below 2).

Figure 5: NHER and variation in hours of 21^{o}C warmth over the monitoring week



The boxplot shows median values as a heavy black line, interquartile range (IQR) as the boundaries of the box, and indicates extremes by the whiskers extending above and below the box. Outliers are indicated by circles. Asterisks indicate extreme values.

4.4 Estimated annual fuel cost and hours of warmth

Actual fuel costs were not assessed, but from the NHER program potential costs of maintaining homes at recommended warmth levels were calculated. Results showed that homes which were most energy inefficient, with high potential fuel costs, were less likely to be heated to recommended levels, although the correlation of -0.21 ($p<0.001$) was small, explaining only 4% of variation in hours of warmth between homes,

4.5 Health status at baseline and indoor temperatures

An analysis was carried out of the association between baseline temperature and humidity and health status of participants. In this population no association was found between humidity and health status of participants. The association between indoor temperatures and health status measures is shown in Tables 3a and 3b.

In the overall analysis symptomatic health status showed the strongest relationships to warmth indices, specifically to hours of living room warmth. There was a trend for fewer hours of bedroom warmth to be associated with more symptoms, but this did not reach the 0.01 level of significance. Fewer living room hours of warmth were also associated with worse scores on the illness impact scale of the St George's Respiratory Questionnaire. The general health measure (Euroqol VAS) showed effects in the same direction, but these did not reach the 0.01 significance level.

The analysis by smoking status showed that smokers experienced more effect of low warmth on respiratory symptoms than non smokers, for respiratory symptoms, and illness impact. EQ VAS scores showed the same trend but did not reach significance.

Table 3a: Coefficients of regression models for SGRQ health status outcomes with warmth exposures

+SGRQ-Symptoms[1]	B (SE)		p value*	R^2
LR hours 21°C	-0.06	0.02	0.007	0.15
LR 5pm	-0.80	0.48	0.10	0.12
LR days (9H/ 21°C)	-1.34	0.42	0.002	0.16
BR hours 18°C	-0.05	0.02	0.04	0.13
BR low	-0.60	0.51	0.25	0.11
BR days (9H/18°C)	-1.16	0.46	0.02	0.14
+SGRQ-Activity[2]	**B (SE)**		**p value***	**R^2**
LR hours 21°C	-0.02	0.02	0.44	0.11
LR 5pm	-0.25	0.49	0.61	0.11
LR days (9H/ 21°C)	-0.76	0.43	0.08	0.13
BR hours 18°C	0.005	0.02	0.82	0.11
BR lowest	0.54	0.51	0.29	0.12
BRdays (9H/18°C)	0.05	0.47	0.91	0.11
+SGRQ-Impact[3]	**B (SE)**		**p value***	**R^2**
LR hours 21°C	-0.05	0.03	0.06	0.20
LR 5pm	-0.44	0.59	0.45	0.18
LR days (9H/ 21°C)	-1.30	0.90	0.01	0.21
BR hours 18°C	-0.04	0.03	0.16	0.19
BR low	-0.47	0.64	0.46	0.18
BR days (9H/18°C)	-0.94	0.57	0.10	0.19
EQ-VAS[4]	**B (SE)**		**p value***	**R^2**
LR hours 21°C	0.005	0.002	0.04	0.06
LR 5pm	0.096	0.052	0.07	0.06
LR days (9H/ 21°C)	0.10	0.04	0.02	0.08
BR hours 18°C	0.001	0.002	0.92	0.04
BR low	0.06	0.06	0.27	0.04
BR days (9H/18°C)	-1.1	0.45	0.02	0.04

Using Bonferroni correction for multiple testing of inter-correlated outcomes a p value of 0.01 was required for significance.

LR = Living Room; BR = Bedroom; Days (9H/21°C) = Number of days with at least 9 hours at or above 21°C); Days (9H/18°C)= Number of days with at least 9 hours at or above 18°C.
[1]Adjusted for: Age, COPD prior admissions, $PM_{2.5}$ and SIMD
[2]Adjusted for: %PredFEV, COPD prior admissions, SIMD and $PM_{2.5}$
[3]Adjusted for: Age, %PredFEV, COPD prior admissions, marital status, SIMD and $PM_{2.5}$
[4]Adjusted for: %Pred FEV and $PM_{2.5}$

Social and clinical variables which were significant at p<0.10 were entered into the adjusted model for each SGRQ component. Full details of covariates with regression coefficients p<0.10 are shown in Appendix D.

Table 3b: Coefficients of regression models for SGRQ health status outcomes with warmth exposures.

	Non-smokers				Smokers			
+SGRQ-Symptoms[1]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
LR hours 21°C	-0.03	(0.03)	0.11	0.15	-1.00	0.03	0.001	0.33
LR 5pm	-0.13	(0.63)	0.83	0.14	-1.64	(0.75)	0.03	0.25
LR days (9H/ 21°C)	-0.81	(0.56)	0.16	0.16	-1.91	(0.60)	0.003	0.34
BR hours 18°C	-0.04	(0.03)	0.10	0.13	-0.05	(0.03)	0.07	0.26
BR low	-0.26	(0.63)	0.68	0.14	-1.57	(0.87)	0.08	0.26
BR days (9H/18°C)	-1.22	(0.62)	0.05	0.18	-1.1	(0.65)	0.10	0.25
+SGRQ-Activity[2]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
LR hours 21°C	0.02	(0.02)	0.42	0.14	-0.08	(0.05)	0.10	0.19
LR 5pm	0.42	(0.49)	0.39	0.14	-1.4	(1.04)	0.18	0.17
LR days (9H/ 21°C)	0.21	(0.46)	0.61	0.14	-2.31	(0.85)	0.009	0.25
BR hours 18°C	0.01	(0.03)	0.61	0.14	0.005	(0.04)	0.90	0.14
BR low	0.93	(0.50)	0.07	0.17	-0.11	(1.22)	0.93	0.14
BR days (9H/18°C)	0.03	(0.52)	0.87	0.13	0.20	(0.92)	0.83	0.14
+SGRQ-Impact[3]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
LR hours 21°C	0.006	(0.04)	0.88	0.14	-0.11	(0.04)	0.01	0.33
LR 5pm	0.89	(0.75)	0.24	0.15	-1.76	(1.01)	0.09	0.28
LR days (9H/ 21°C)	0.19	(0.70)	0.78	0.14	-2.65	(0.80)	0.002	0.38
BR hours 18°C	-0.01	0.04	0.79	0.14	-0.019	(0.04)	0.64	0.23
BR low	0.35	0.79	0.66	0.14	-0.78	1.21	0.52	0.24
BR days (9H/18°C)	-0.65	0.50	0.42	0.15	-0.36	0.90	0.70	0.23
EQ-VAS[4]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
LR hours 21°C	0.005	(0.003)	0.14	0.04	0.005	(0.003)	0.12	0.24
LR 5pm	0.07	(0.07)	0.27	0.04	0.11	0.08	0.07	0.24
LR days (9H/ 21°C)	0.10	(0.06)	0.08	0.05	0.12	0.06	0.07	0.24
BR hours 18°C	0.001	(0.002)	0.75	0.02	0.001	(0.003)	0.67	0.20
BR low	0.02	0.07	0.74	0.01	0.11	0.09	0.25	0.20
BR days (9H/18°C)	0.04	0.07	0.91	0.02	0.03	0.07	0.61	0.20

Using Bonferroni correction for multiple testing of intercorrelated outcomes a p value of <0.01 was required for significance.

LR = Living Room; BR = Bedroom; ppb = parts per billion; EU/mg = endotoxin units per milligram
[1]Adjusted for: Age, COPD prior admissions, Log$PM_{2.5}$ average and SIMD
[2]Adjusted for: %Pred FEV, COPD prior admissions and SIMD
[3]Adjusted for: Age, %Pred FEV, COPD prior admissions, Marital status, Log$PM_{2.5}$ average and SIMD
[4]Adjusted for: %Pred FEV

+St George's Respiratory Questionnaire

4.6 Health status at baseline and indoor air quality

High levels of $PM_{2.5}$ were recorded in these homes. Table 4 shows that maximum levels were more than four times the US Environmental Protection Agency (EPA) recommendation for maximum levels over 24 hours (35 $\mu g/m^3$) Recent WHO air quality guidelines[32] recommend even lower maximum outdoor air quality levels of $PM_{2.5}$ of 25 $\mu g/m^3$ over 24 hours and an annual mean of 10 $\mu g/m^3$.

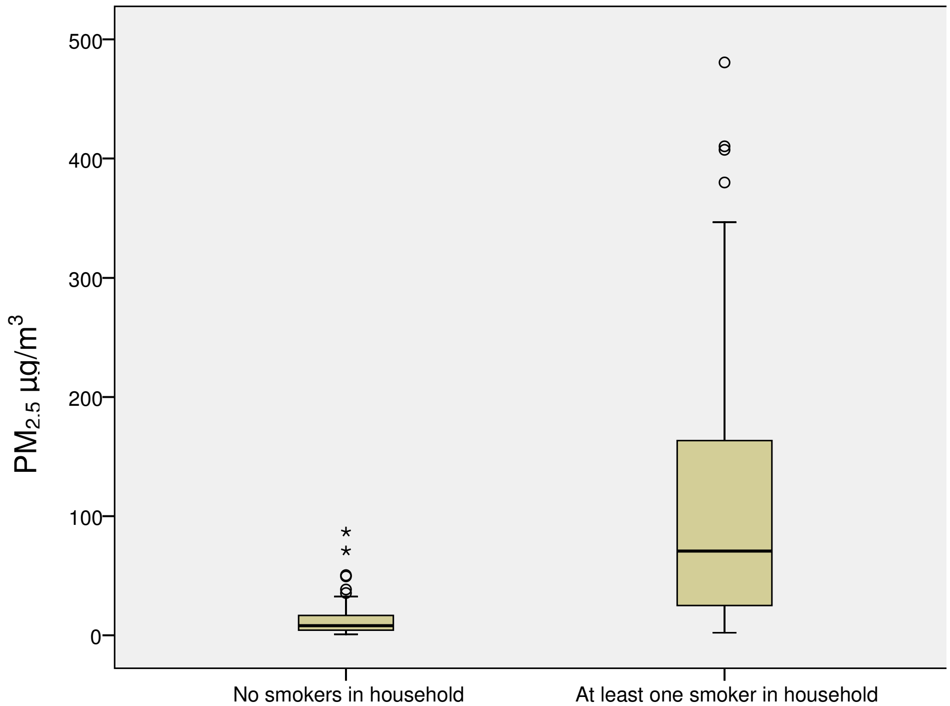
These high levels were associated with presence of smokers in the home.

Table 4: Indoor air quality and household smoking status

Indoor air quality measures	Total N=178 Median (IQR)		Non-smoking household* N=86 Median (IQR)		Smoking Household* N=81 Median (IQR)		P
$PM_{2.5}$ Maximum $\mu g/m^3$ LR	148	(25-454)	43	(13-14)	465	(168-812)	p<0.001
$PM_{2.5}$ Average $\mu g/m^3$ LR	17	(6-71)	7.8	(4.3-16.5)	70	(23-165)	p<0.001
NO_2 ppb LR	7.5	(4.8-11.7)	6.9	(3.6-11.4)	8.6	(6.4-12.5)	p<0.02
NO_2 ppb BR	7.0	(4.1-10.3)	5.8	(3.2-10.3)	7.8	(5.6-10.4)	p<0.02
Endotoxin EU/mg LR	94.4	(62.8-156.1)	92.6	(59.2-150.2)	104.2	(70-167)	p=0.23

*Smoking status not confirmed for 11 participants; IQR = Interquartile range; LR = Living Room; BR = Bedroom; ppb = parts per billion; EU/mg = endotoxin units per milligram

Figure 6: $PM_{2.5}$ in smoking and non-smoking households



Distribution of $PM_{2.5}$ by home smoking status. The lower and upper boundaries of each box indicate the 25th and 75th percentiles. The line within the box shows the median, and whiskers above and below the box indicate the 90th and 10th percentiles. Outliers are values between 1.5 IQRs and 3 IQRs from the end of a box.

Tables 5a shows that higher $PM_{2.5}$ in homes was strongly predictive of increased respiratory symptoms for participants. In the multivariate analysis, adjusting for clinical and demographic variables significant at the p=0.10 level, symptom scores were significantly positively related to Log$PM_{2.5}$ average and maximum levels[1]. The final models explained 15% to 17% of total variation in symptom scores. The coefficients of 5.3 and 6.0 indicate that a one unit reduction in log $PM_{2.5}$ or equivalently a ten fold decrease in $PM_{2.5}$ would reflect a significant decrease of 5.3 or 6.0 SGRQ points respectively (p=0.001). A change of 4 points in SGRQ is regarded as clinically significant.

[1] Alternative regression models with either a square rooted outcome or untransformed $PM_{2.5}$ gave very similar predictions to the model with logarithmically transformed $PM_{2.5}$ except at very low levels of $PM_{2.5}$ (approx 5 µg/m^3) where these models predicted higher (worse) symptom scores.

When the analyses were stratified by smoking status, the results were in the same direction as in the total model, but the size of the coefficients indicated that the effect of $PM_{2.5}$ on symptoms was increased for smokers, and reduced for non-smokers. That is, smokers showed more effect of any increase in $PM_{2.5}$ than in non-smokers. (See Table 5b).

Table 5a: Coefficients of regression models for SGRQ health status outcomes with exposures.

Total			
SGRQ⁺-Symptoms[1]	**B (SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	6.0 (1.9)	0.002	0.17
Log $PM_{2.5}$ Average	5.3 (2.2)	0.002	0.15
Log NO_2 ppb LR	5.7 (4.5)	0.22	0.12
Log NO_2 ppb BR	2.7 (4.8)	0.58	0.10
Log Endotoxin	3.1 (4.4)	0.49	0.09
SGRQ⁺-Activity[2]	**B (SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	2.1 (1.9)	0.26	0.08
Log $PM_{2.5}$ Average	1.7 (2.1)	0.41	0.08
Log NO_2 ppb LR	5.2 (4.5)	0.26	0.08
Log NO_2 ppb BR	4.4 (4.9)	0.37	0.08
Log Endotoxin	5.3 (4.3)	0.22	0.09
SGRQ⁺-Impact[3]	**B (SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	3.6 (2.3)	0.12	0.17
Log $PM_{2.5}$ Average	3.7 (2.6)	0.17	0.17
Log NO_2 ppb LR	8.0 (5.5)	0.15	0.17
Log NO_2 ppb BR	8.3 (5.8)	0.15	0.14
Log Endotoxin	7.4 (5.2)	0.16	0.18

LR = Living Room; BR = Bedroom; ppb = parts per billion; EU/mg = endotoxin units per milligram
[1]Adjusted for: Age and COPD prior admissions
[2]Adjusted for: %Pred FEV and COPD prior admissions
[3]Adjusted for: Age, %Pred FEV, COPD prior admissions and Marital status

Social and clinical variables which were significant at p<0.10 were entered into the adjusted model for each SGRQ component. Full details of covariates with regression coefficients p<0.10 are shown in Appendix D.

⁺St George's Respiratory Questionnaire

Table 5b: Coefficients of regression models for SGRQ health status outcomes with exposures

	Non-smokers				Smokers			
SGRQ[+]-Symptoms[1]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	4.8	(2.5)	0.06	0.15	13.2	(3.4)	<0.001	0.31
Log $PM_{2.5}$ Average	4.9	(3.2)	0.13	0.13	11.1	(3.7)	0.004	0.24
Log NO_2 ppb LR	4.3	(5.3)	0.43	0.12	9.1	(9.7)	0.35	0.13
Log NO_2 ppb BR	0.4	(5.6)	0.95	0.11	11.4	(10.8)	0.30	0.12
Log Endotoxin	-3.0	(6.0)	0.61	0.08	6.4	(5.2)	0.22	0.14
SGRQ[+]-Activity[2]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	3.7	(2.1)	0.07	0.14	6.9	(4.8)	0.16	0.08
Log $PM_{2.5}$ Average	5.1	(2.6)	0.05	0.14	5.9	(4.9)	0.23	0.08
Log NO_2 ppb LR	7.4	(4.2)	0.08	0.13	4.0	11.5	0.75	0.05
Log NO_2 ppb BR	4.0	(4.5)	0.37	0.11	16.2	(14.1)	0.26	0.11
Log Endotoxin	-0.3	(4.6)	0.95	0.10	14.5	(8.2)	0.08	0.13
SGRQ[+]-Impact[3]	**B**	**(SE)**	**p value**	**R^2**	**B**	**(SE)**	**p value**	**R^2**
Log $PM_{2.5}$ Maximum	4.5	(3.1)	0.14	0.18	6.3	(4.7)	0.18	0.21
Log $PM_{2.5}$ Average	5.9	(3.9)	0.14	0.18	6.2	(4.9)	0.21	0.20
Log NO_2 ppb LR	11.2	(6.6)	0.09	0.18	5.5	(11.8)	0.64	0.18
Log NO_2 ppb BR	6.0	(6.8)	0.38	0.14	22.2	(13.1)	0.10	0.18
Log Endotoxin	2.1	(7.0)	0.77	0.16	14.5	(7.8)	0.07	0.24

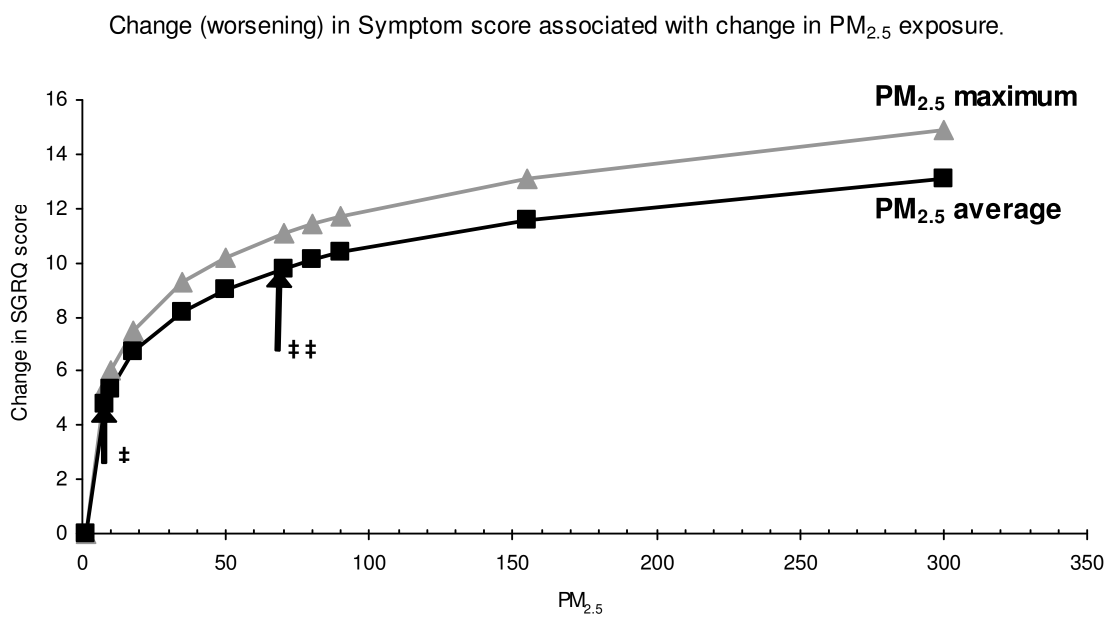
LR = Living Room; BR = Bedroom; ppb = parts per billion; EU/mg = endotoxin units per milligram
[1]Adjusted for: Age and COPD prior admissions
[2]Adjusted for: %Pred FEV and COPD prior admissions
[3]Adjusted for: Age, %Pred FEV, COPD prior admissions and Marital status

Social and clinical variables which were significant at p<0.10 were entered into the adjusted model for each SGRQ component. Full details of covariates with regression coefficients p<0.10 are shown in Appendix D.

[+]St George's Respiratory Questionnaire.

Figure 7 models the change (worsening) in SGRQ associated with increase in exposure levels of $PM_{2.5}$, for the models derived from average and maximum $PM_{2.5}$ levels. It shows that the difference in median exposure levels between smokers and non-smokers is associated with a six point difference in SGRQ Symptom score.

Figure 7: Regression model of change in SGRQ Symptom score associated with change in $PM_{2.5}$ exposure



†$PM_{2.5}$ average in non-smoking household was 8 µg/m^3;
‡‡$PM_{2.5}$ average in smoking household was 71 µg/m^3

6 DISCUSSION OF BASELINE RESULTS

Health status was not significantly related to indoor warmth.

These baseline results find that symptomatic health status of COPD patients is associated with maintaining guideline warmth in their homes during cold months. Patients with fewer days with 21°C for at least 9 hours in their living rooms had significantly worse respiratory Symptom scores. They also showed worse respiratory Illness Impact and poorer general health on the EQ VAS. BR warmth effects were consistent in the same direction, but did not reach significance. Smokers showed markedly stronger adverse health effect of lesser warmth than non-smokers. Although studies have reported that self perception of living in a cold house is associated with self perceived poor health[21;22;33;34], and indirect association has been found between colder homes and health[21], no previous study has shown direct relationship between objectively measured indoor hours of warmth and respiratory health status.

The significant relationship between hours of warmth and symptomatic health status was not due to the effects of extremely cold temperatures in the homes studied. Homes were somewhat cooler than is recommended, but most were not very cold. Median LR temperature at 5pm in the homes studied was 21°C. Only three homes had average 5pm LR temperatures below 16°C, suggested as a threshold for indoor temperature health effects[35]. The results of the study support the belief that there can be health effects of marginally cold homes. This is a finding which needs further exploration, and increased understanding of the possible physiological mechanisms operating to impact on health in these conditions of cool but not severely cold homes.

There was little relationship of indoor to outdoor temperatures. In particular, hours of LR warmth was not associated with outdoor maximum or minimum temperatures. During the study outdoor temperatures were well below acceptable indoor temperatures, with mean maximum outdoors below 11°C, and mean minimum 3°C. It appears that in very cold periods participants maintain a level of preferred warmth in living areas, which cannot be predicted from outside temperatures. BR hours of warmth did have a significant but weak relationship with outside temperatures. Anecdotally, many of these participants reported a deliberate choice to have lower temperatures in their bedrooms, and a number kept windows open at night even during winter months. Donaldson et al[23] found similar behaviour patterns (keeping windows open, not heating bedrooms) among COPD patients in their London study.

The study was not designed to track the effect of changes in outdoor temperature on COPD health, and indoor LR temperatures were independent of outdoor temperatures during the study. Most of our participants were very house bound as can be seen from their high activity limitation scores.

Air quality was an important additional influence on health of the study participants.

The study has found high levels of airborne $PM_{2.5}$ in the homes of COPD patients. Highest levels of $PM_{2.5}$ were on average four times the maximum recommended by the EPA for 24-hour periods. Levels of $PM_{2.5}$ were strongly associated with presence of smokers in the household. Higher $PM_{2.5}$ levels were related to poorer health status of smoking and non-smoking participants.

Nitrogen dioxide levels were not associated significantly with health. Levels in bedrooms and living rooms were lower than those found by Jarvis et al[36] similarly measured over one week (6 – 7ppb in our study compared to 13ppb in Jarvis' study.)

Settled dust endotoxin levels were associated with airborne levels of $PM_{2.5}$ but did not show an independent association with health status.

It was apparent that the main source of $PM_{2.5}$ in the homes studied was ETS. In other studies in respiratory patients[37;38] reported exposure to cigarette smoke is associated with poorer health status and asthma specific quality of life and with increased risk of hospital admissions and emergency visits. A difference of four points in SGRQ scores is regarded as clinically significant and Figure 7 shows that a change from the median $PM_{2.5}$ exposure in smoking homes (71 μg/m3) to median exposure in non-smoking homes (8 μg/m3) is associated with a six point improvement (reduction) in SGRQ symptom scores.

Smokers are found to be more sensitive to effects of indoor temperature and ETS.

The stratified analysis showed that exposure effects were consistent between smokers and non-smokers, but that the effect on symptom score of an increase in $PM_{2.5}$ was greater for smokers than for non-smokers. Almost half the participants in the present study lived in ‘smoking environments’. Thirty-one per cent of smokers and 17% of non-smokers lived in households where another member smoked. In addition, individual monitoring results showed that even in non-smoking households short-lived high values of $PM_{2.5}$ were recorded, probably associated with visits to the home by smokers. In any study of health and housing ETS should be considered as an important independent influence on health of participants.

In addition to the greater effects of air quality on health of smokers, they also showed more effects of lower indoor temperatures on symptoms than non-smokers. As a post hoc analysis these results must be treated with caution, but the associations were large, significant at less than alpha=0.001 and consistent across the respiratory outcome measures. There is evidence that smokers have heightened vascular response to drops in temperature. Plasma fibrinogen levels and blood coagulation factors are higher in smokers, and are also higher in cold months[39-42]. This suggests that patients with COPD who smoke will have an added health load during winter and are likely to be more vulnerable to low temperatures within the home.

The patients taking part in the study were representative in age, sex and deprivation of patients living in the North east of Scotland who have had a hospital admission as a consequence of COPD exacerbation, but we do not know if results can be generalized to COPD patients in the UK community who have not had a hospital admission. Behaviour such as sleeping with windows open may also not be generalisable to patients in other UK areas, or outside the UK.

A limitation of the study was that health status was related to indoor hours of warmth over one week only. Although we know that variation in hours of warmth between homes in the UK can be large[13], we know little about expected variation within a home over winter months. However, this variability will tend to weaken associations with health status measured at one point in time, and in the present study the association between health status outcomes and hours of warmth was consistent across the SGRQ subscales, and with the generic EQ-VAS measure.

We did not assess outdoor behaviour in cold temperatures, which will have contributed to health status, but the Eurowinter study showed that indoor temperatures have an effect independent of outdoor temperatures, which this study confirms. Outdoor pollution will have contributed to indoor levels of $PM_{2.5}$. However, since average monthly outdoor $PM_{2.5}$ level over the study period varied between 4 and 17μg/m^3, well below averages found in smoking households, the main contributor to high indoor levels of $PM_{2.5}$ must be personal behaviour within the home, particularly cigarette smoking, and it is these very high levels which are associated with poorer health status.

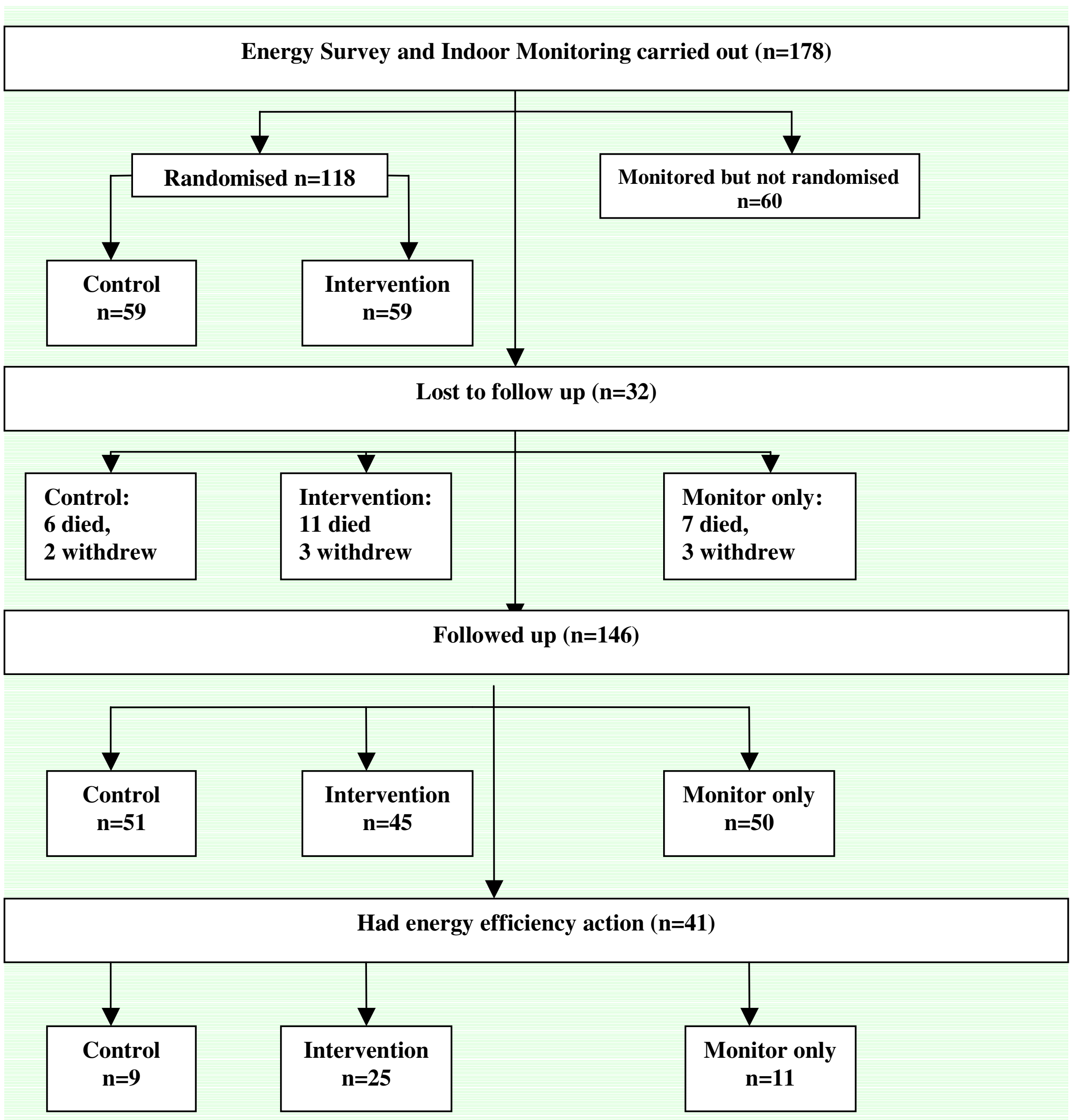
Conclusion

The results of the study suggest that home indoor warmth influences respiratory health status, and that the 21^{o}C for 9 hours index is a useful indicator of whether indoor warmth is sufficient for health. This is a potentially important finding. It supports the emphasis of current UK government policy on funding interventions to achieve affordable warmth for UK homes and hence improve health. Results also support the likelihood of health benefits from liaison programmes between health workers and local Central Heating Programme and Warm Deal workers, where patients' home living conditions can be professionally assessed, and patients referred to local improvement schemes where need is observed. The study provides information which could be helpful to patients and their families in reinforcing attempts to stop smoking. Finally, the study raises the question of the effect of indoor air pollution, primarily from ETS, in interaction with indoor temperature, and makes clear the importance of measuring indoor air quality when evaluating health outcomes of home energy action.

7 FOLLOW UP RESULTS

Figure 8 shows the progress of participants from baseline entry to the study through to follow up. One hundred and forty-six participants (82%) completed the study. The other 32 were lost to follow up: 24 died and 8 did not wish to continue in the study.

Figure 8: Flow of participants through study



7.1 Demographic characteristics

Table 6 shows the baseline demographic characteristics of the participant who completed the study. There were no significant differences in any demographic characteristic between the baseline participants and those who continued to follow up twelve months later.

Table 6: Demographic characteristics of participants completing study

Demographic		Follow up N % (n=146)
Age (m, SD)		68.5 (7.9)
Male		65 (45%)
Marital status:	Never married	9 (6%)
	Married	88 (60%)
	Widowed/divorced	49 (34%)
Lives alone		50 (34%)
SIMD decile score (m, SD)		5.9 (2.6)
Smoker		58 (42%)
Smoking household		72 (49%)

7.2 Characteristics of homes in the study

Table 7 shows the housing characteristics both at baseline and follow up.

Table 7: Housing characteristics at baseline and follow up

Housing characteristic		Follow up N(%) (n=146)
Social housing/privately owned housing		66 (45%)/80 (55%)
Property type:		
Detached, semi- or end terrace		62 (43%)
Terraced		26 (18%)
Flat		58 (40%)
Property age:		
Pre 1930s		11 (8%)
1930-1963		78 (53%)
>1964		57 (39%)
Central heating		124 (85%)
Floor area sq m (M, SD)		69.4 (26.6)
Kitchen adjacent to living room		57 (39%)
Initial Energy efficiency (NHER)	Poor 0 – 2	18 (12%)
	Moderate 3 – 6	103 (71%)
	Good 7 -10	25 (17%)
Initial Estimated Annual Fuel Costs (Median, IQR)		£481 (£408-£599)

Moderate energy efficiency is indicated by an NHER score between 3 and 6. 71% of homes that remained in the study fell in this range in which is the same as in Scotland as a whole. 17% of homes had NHER of 7 or above, compared to 21% in Scotland. 18 homes (12%) were initially rated as being below 3 in the NHER scale, regarded as unsatisfactory[34]. This proportion of poor housing exactly matches that found in the National Scottish Homes Survey in 2002[34]. The homes with initial unsatisfactory energy efficiency were slightly larger (76m^2 vs 68m^2) and their occupiers had lower (better) SIMD deprivation scores. 72% were private owners, compared to 52% in homes with higher NHER.

Homes built prior to 1930 consisted of seven detached properties and nine flats. Six of these properties had poor energy efficiency (NHER <3). Five out of these six homes had energy efficiency action, although only two of them had recorded indoor temperatures at baseline that were outwith recommended levels of warmth. The one home built prior to 1930 where nothing was done had recorded temperatures well above 21^{o}C in the living room and 18^{o}C in the bedroom, and the owners chose not to have energy efficiency action

7.3 Indoor Temperature and Humidity

Follow up indoor temperature and humidity monitoring was carried out as far as possible on date matched weeks 12 months after the baseline measurements were taken. Table 8 shows the results for the participants who remained in the study at follow up.

Table 8: Temperature and Humidity at Follow up

	Median (IQR) n=146
LR average temp at 5pm ^{o}C	20.8 (19.6-22.6)
LR hours above 21^{o}C	45.5 (8.5-124)
LR days 9H/21^{o}C (N,%)	
No days	56 (38%)
1 -4 days	27 (19%)
5-7 days	62 (43%)
LR humidity %	43.6 (39.3-48.5)
BR lowest temp ^{o}C	16.6 (14.9-17.7)
BR hours above 18^{o}C	133 (60.9-166.6)
BR days 9H/18^{o}C (N,%)	
No days	22 (16%)
1 -4 days	23 (16%)
5-7 days	97 (68%)
BR humidity %	47.4 (42.6-54.3)

IQR = Interquartile range

7.4 Achieving energy efficiency action

60 participants were willing to be monitored but did not want energy efficiency improvements. Concerns over cost were expressed by some participants, despite being offered incentives of grants to cover the cost of the work, or low-cost loans set up to be repaid out of the savings made on fuel bills. Others considered that the work would be too disruptive, eg underfloor insulation would require the lifting of laminate flooring or carpeting, while loft insulation required the loft space to be cleared. Several were waiting for re-housing by the council to sheltered accommodation and did not want to jeopardise their chances of being allocated a new home. It was found however that 11 of the 60 initiated independent energy action during the study period.

In the Intervention arm, after initial agreement to energy efficiency action and monitoring, 34 ultimately did not have improvements for similar reasons to those given above. Improvements carried out in 25 intervention homes were upgrading of central heating boilers, loft or underfloor insulation, or both. In the Control arm, after agreeing to being placed on the waiting list for 12 months, 9 participants had improvements carried out during the study. Some of these were due to homes being in the catchment area for council heating upgrade schemes while others were due to participants taking independent action. Ethical approval had been given for the study on condition that all participants were given information on how to access home improvement support.

Reasons for not having energy efficiency action were as follows:

- Client did not want 15
- Client deceased 5
- No gain 4
- Outwith study timescale 3
- Work not possible 3
- Client moved house 2
- Outwith council control 1
- Privately rented 1

Homes of patients where energy efficiency action was achieved differed from those who did not want action, or who initially agreed to action and then changed their minds. They had lower baseline NHER (5.0 vs 5.6, $p=0.04$) and fewer baseline hours of warmth above 21^{o}C in living rooms in the monitored week (49 hours vs 70 hours, $p=0.04$).

7.5 Time to energy efficiency action

Average time to achieving energy efficiency action was nine months, with a range of between one and 18 months. One reason for delay in achieving energy efficiency action was due to personal decisions by participants who wanted to schedule the work at a date convenient to them. This sometimes meant waiting until after a period of illness had elapsed. Some insulation work was held up during the study as the council were renegotiating the contract for the installation of insulation through the Warm Deal programme. A few participants did not get their energy efficiency action done before the study ended in May 2007 because of this.

7.6 Benefit reassessment

Participants were made aware of any benefits they were entitled to and offered help in making application for either Attendance Allowance or Disability Living Allowance. It was found during the study that very few participants were not already in receipt of maximum benefit entitlement. Clearly this chronically ill group had been previously informed about benefits available to them and had accessed these at an earlier time. Only three participants were able to increase benefits through reassessment; a further four were considered eligible for benefit reassessment, two of whom died during the study and two were not documented as receiving increase.

7.7 Health outcomes and energy efficiency action

Tables 9 and 10 show multivariate models of the relationship of health status to randomisation (intention to treat analysis) and by pragmatic analysis whether or not energy action was achieved.

7.7.1 Randomised comparison

The only outcome variable significantly associated with the randomisation to action arm was hours of bedroom warmth, which in follow up was higher in homes assigned to the energy action arm. Symptom scores were lower (better) in those in the action arm, but the difference was not significant. Results are shown in Table 9.

7.7.2 Pragmatic comparison

In the analysis comparing the 41 patients who had action with the 105 who did not, independent of randomisation status, a number of significant differences were observed. Action homes had increased by 1.1 points on the 10 point NHER scale, and estimated annual fuel cost had decreased by approximately 10%. Symptom scores had improved by more than 8 points. A change in score of 4 points is considered clinically significant. There was no change in hours of indoor warmth in living room or bedroom, or indoor humidity levels, or in scores for illness impact or activity limitation. Results are shown in Table 10.

Table 9: Outcomes measures – intention to treat analysis

	At study entry		12 months after intervention		Difference (95% CI)	
Outcome	Intervention Group	Control Group	Intervention Group	Control Group	Unadjusted	Adjusted for baseline score
National Home Energy Rating	5.1	5.5	5.5	5.7	0.2 (-0.5, 0.9)	0.2 (-0.1, 0.6)
Estimated Annual Fuel Costs (£)	696	533	647	580	-66.9 (-250.2, 116.4)	-12.1 (-52.4, 28.7)
LR hours at 21°C	55.9	73.1	59.4	64.0	4.6 (-19.2, 28.3)	7.4 (-11.0, 25.8)
BR hours at 18°C	100.2	109.5	111.9	102.2	-9.7 (-36.4, 17.0)	22.4 (1.6, 43.4)
LR average humidity	46.4	60.0	43.8	43.0	-0.9 (-4.8, 3.0)	-1.7 (-4.9, 1.6)
BR average humidity	50.0	65.4	49.5	48.7	-0.8 (-4.3, 2.7)	-0.8 (-3.5, 1.9)
COPD admissions	1.1	1.1	1.5	1.1	-0.4 (-1.2, 0.4)	-0.1 (-0.8, 0.68)
Symptom score*	73.8	76.5	73.2	77.1	-3.8 (-12.4, 4.8)	-4.0 (-11.4, 3.3)†
Impact score*	56.7	57.1	61.0	58.8	2.1 (-6.8, 11.0)	-3.5 (-10.1, 3.2)†
Activities score*	85.5	83.0	83.5	82.6	0.9 (-6.9, 8.7)	0.6 (-5.5, 6.6)†
VAS score††	50.3	47.1	48.5	48.5	0.0 (-1.0, 1.0)	0.1 (-0.8, 1.0)†

*St George's Respiratory Questionnaire; ††Visual Analogue Scale; †Adjusted for baseline score, age, %predFEV_1 and $PM_{2.5}$.

Table 10: Outcomes measures – action versus no action

	Before action		12 months after action		Difference (95% CI)	
Outcome	Action Group	No action Group	Action Group	No action Group	Unadjusted	Adjusted for baseline score
National Home Energy Rating	4.8	5.6	6.0	5.7	0.3 (-0.3, 0.9)	1.1 (0.8, 1.4)
Estimated Annual Fuel Costs (£)	£705	£557	£612	£576	-36.5 (-105.7, 81.8)	-67.1 (-34.8,- 99.3)
LR hours at 21^{o}C	47.9	69.0	54.1	69.2	15.2 (-6.1, 36.4)	1.9 (-15.0, 18.8)
BR hours at 18^{o}C	104.5	114.8	110.5	112.0	1.5 (-21.1, 24.0)	0.8 (-22.8, 21.3)
LR average humidity	46.6	51.8	44.7	43.6	-1.1 (-4.4, 2.2)	0.4 (-2.4, 3.2)
BR average humidity	49.5	56.2	49.7	48.2	-1.4 (-4.5, 1.6)	-0.6 (-2.9, 1.7)
COPD admissions	0.9	1.2	0.8	1.4	0.5 (-0.2, 1.2)	0.4 (-0.2, 1.0)
Symptom score*	72.4	77.0	66.0	77.7	11.7 (4.1, 19.2)	-8.9 (-14.9,-2.8,)†
Impact score*	58.3	55.4	58.8	59.6	0.9 (-7.2, 8.9)	-3.7 (-8.7, 1.3,)†
Activities score*	86.3	82.4	83.2	83.8	0.6 (-6.8, 8.0)	-4.1 (-10.1, 1.9,)†
VAS score††	46.1	49.2	46.9	47.8	0.08 (-0.76, 0.92)	-0.06 (-0.87, 0.75)†

*St George's Respiratory Questionnaire; ††Visual Analogue Scale; †Adjusted for baseline score, age, %predFEV_1 and $PM_{2.5}$.

7.8 Moved house during study

Over the duration of the study twelve participants moved house[2], half of whom lived in social housing. The mean NHER of these twelve homes was 5.4. Five out of the twelve involved a move into sheltered accommodation. As a group, participants who moved house were slightly younger at 66 years than those who stayed in the same house throughout the study. They did not differ significantly in terms of marital status, deprivation score, SGRQ activity limitation, SGRQ disease impact, and VAS score. However they had significantly worse SGRQ symptom scores than those who did not move (83 vs 75.3, $p = 0.02$).

By the end of the study, a further twelve participants had moved house, six of these into sheltered accommodation.

7.9 Perception of warmth

At the end of the study 139/178 (78%) of participants completed the additional questions on their perception of warmth in their home.

Perception of living room temperature

51% of participants who responded to the heating questions felt their living room temperature was just right. Their homes' NHER was slightly higher (5.9) than those who thought their LR temperature was not always satisfactory (5.7) but the difference was not significant ($p=0.4$). There was no difference in satisfaction between males and females, and between participants who lived alone or with others. Owner occupiers were more likely to be satisfied with their living room warmth than social housing tenants, although there was no significant difference in actual measured warmth between the two groups (65 hours at 21^0C vs 64 hours at 21^0C, $p=0.9$). 32% were concerned with keeping living room heating costs down; these people were more likely to live in social housing. However, measured hours of warmth in the living room did not in practice differ between homes of those who reported being concerned about heating costs, and those who were not concerned.

[2] One died before end of follow up period.

Most participants were unconcerned about bedroom heating costs. Twenty participants reported deliberately choosing not to heat the bedroom and a number kept windows open at night even during winter months.

It appeared that although heating costs were of concern to a significant minority of participants they were able at this time to heat their homes to comparable levels with people who were not concerned about heating costs.

Participant comments show that people's perceptions of warmth vary considerably.

"*I don't use the central heating in the bedroom, its warm enough. I keep the window open all night, winter and summer"* Participant 520 reported her LR and BR temperatures were always just right. Actual mean temperatures were 18.3^{o}C at 5pm in the LR with no days at recommended levels, and 17.8^{o}C overnight in the BR.

"Sometimes it's too cool so I just turn it up to 5" said Participant 325 talking about the temperature in her living room. An actual mean of 20.8^{o}C at 5pm was found in the home of this widowed lady who goes out to visit her sister every day. She further reported that the bedroom *"was sometimes too cool in the morning so sometimes I keep the heating on all night"*. There were 41 hours of recommended 18^{o}C warmth in the bedroom over the monitored week.

Participant 614 spends all day at home on domiciliary oxygen and reported the temperatures in his living room and bedroom to be just right. *"The central heating is on a timer and we open windows every day to let in fresh air"*. This home did not achieve recommended temperature in the living room on any days of the week; mean was 18.4^{o}C, with bedroom mean at 16.8^{o}C. The NHER for this property was 7.1 and fuel costs estimated at £535. This participant reported not being concerned about costs but still fell short of the recommended temperature levels.

8 DISCUSSION

This study assessed the effect of an intervention aiming to improve energy efficiency of homes of vulnerable patients with a chronic respiratory disease. Specifically the study investigated whether such referral, and subsequent improvement of energy efficiency in homes in the study, led to increased indoor warmth and improved health status of patients.

The study found that the initial health status of patients taking part was significantly associated with warmth maintained in their homes during a one week monitoring period at baseline. Fewer hours of 21^{o}C warmth in living rooms[3] was associated with more respiratory symptoms, more restricted activities, and greater illness impact as measured by the St George's Respiratory Questionnaire. Living room warmth was also associated with General Health scores on the Euroqol VAS.

Bedroom hours of warmth at the commencement of the study were not significantly related to health status, but since in most homes in the study the recommended level of 18^{o}C heating was maintained in bedrooms the lack of association may reflect the lack of homes with very low bedroom temperatures.

Although many homes in this study did not reach recommended hours of 21^{o}C warmth, they were warmer than reported in previous UK studies. Indoor temperatures in living room at 5pm averaged 21^{o}C. These temperatures are similar to those of the Eurowinter study in Northern European homes and higher than temperatures of 19^{o}C in 554 UK homes of people over 60 years measured by Oresczczyn et al [13]. Oresczczyn found that mean temperatures increased by 1.6^{o}C in homes where central heating and insulation were upgraded through the Warm Front programme, but wide variation in temperature remained between homes, as found in the present study. Similarly Critchley et al[43] also

[3] Nine hours per day at 21^{o}C in living rooms, and 16 hours at weekends, (the 9H/21^{o}C index) is the minimum level recommended by housing guidelines for thermal comfort, and energy efficiency ratings are calculated using this level of warmth as the minimum on which warmth costs are calculated. For bedrooms, 18^{o}C is recommended, giving an index of 9H/18^{o}C.

found that older people had higher living room temperatures and lower average bedroom temperatures.

In the Oresczczyn study[13] the Warm Front programme increased energy efficiency and average temperatures in homes but did not remove wide warmth variation between homes. We do not know why participants choose to have fewer hours of warmth in homes raised to acceptable energy efficiency levels which should therefore not be in fuel poverty. Oresczczyn notes that a good heating system allows the possibility of increased warmth but personal preference may mean the user does not choose this. Critchley[43] suggests that two models of heating behaviour can be identified, a 'rational' style versus an 'adaptive' or preference style

The preference style is illustrated in the case studies in Section 8 of this report, which show that people living in homes with very low energy efficiency, and low average temperature, did not necessarily wish to have all the energy improvements identified as possible for them. For instance Mrs C had an NHER of 1.3 and a home consistently below guideline levels of warmth, but refused central heating.

There are no strong models linking heating behaviour, demographic factors, and respiratory health. Wilkinson et al[44] carried out a study of 15336 elderly people from 53 general practices. They found that winter mortality in this group was not related to demographic or socioeconomic factors, including self reported difficulty in making ends meet or keeping the house warm, but was higher among those with existing respiratory disease. In the present study there was evidence that higher potential fuel costs resulted in less hours of warmth within participants' homes, but the effect was small, and there was high variation in hours of warmth within homes of equal energy efficiency.

Aging is associated with less ability to maintain core temperatures when exposed to cold[45]. Loss of active muscle mass leads to lower metabolic heat production in older adults, and a need for higher ambient temperatures to maintain thermal comfort than for younger adults. Mercer[46] has commented that older people may become cold exposed under conditions which younger people would consider mild. The 16^{o}C level is regarded as the point at which health risks begin[35;47]. In this study the association between health and indoor temperature in this study was not the result of many homes having temperatures below 16^{o}C during the hours the living room was used. More than 75% of patients in the study had living room temperatures at 5pm over the monitoring weeks which were above 19^{o}C; only 5 homes out of 150 had temperatures below 16^{o}C.

Smokers showed more effects of lower indoor temperatures than non-smokers. This suggests that patients with COPD who continue to smoke will be more vulnerable to poor energy efficiency housing. The study also showed that environmental tobacco smoke is a major contributor to high indoor levels of $PM_{2.5}$. Indoor levels of $PM_{2.5}$ were significantly higher in homes with smokers, even where patients themselves did not smoke. These high levels of $PM_{2.5}$ were in turn associated with poor respiratory health status. Energy efficiency often entails reducing air exchange rates in homes, for instance, removing sources of draughts. The findings of the present study raise the question of what is desirable for ventilation within energy efficient homes.

After the initial baseline study of housing conditions the randomised study was put into effect.

Using intention to treat analysis this study found no benefit in health outcomes or housing characteristics for homes randomised to have community-based energy efficiency action, compared to a waiting list control group. However the comparison between intervention and control arms was blurred because less than half the homes randomised to intervention achieved energy efficiency action during the study, while at the same time a sizeable minority of control homes took independent energy efficiency action.

In pragmatic intervention studies people will take independent action, which cannot be under the control of the researchers. To exclude these people will distort the true picture of behaviour among groups whom we are investigating. An analysis comparing homes which had energy efficiency action with those which did not, independent of original randomisation status, found significant improvement in energy efficiency, estimated annual fuel cost and symptomatic health status. Activity limitation and illness impact scores showed non significant effects in positive directions.

Homes in the study were highly representative of Scottish homes in energy efficiency, and the study had the advantage of addressing housing improvement in privately owned homes. Average NHER did not differ between private and social housing, but privately owned homes predominated among those with very poor energy efficiency (below 3 on NHER). Forty per cent of privately owned homes would have needed to spend more than £600 per year to achieve recommended warmth levels, compared to 12% of council homes.

Homes where participants chose to have energy efficiency action, independent of randomisation, had significantly lower hours of warmth at the beginning of the study than homes which did not have action. Although these homes then achieved significantly higher NHER, and estimated fuel costs were significantly reduced, no change was observed in hours of warmth within the home. This parallels the results of the Howden-Chapman New Zealand study[15], and the Richardson and Somerville study in Devon[2]. In the New Zealand study installation of insulation was associated with improved health status, but less than 1^{o}C change in average indoor temperature. Richardson and Somerville found that after initial temperature and humidity benefit in the Watcombe study, temperatures and humidity returned to original levels.

The responses of participants to the questions on their perception of home warmth showed the complexity of attitudes. Satisfaction with warmth, concerns about heating costs, and perceptions that heating costs influenced warmth were not related to actual measured warmth in homes. It appeared that although heating costs were of concern to a significant minority of participants they were able at this time to heat their homes to comparable levels with people who were not concerned about heating costs.

Thomson and Petticrew[1] have previously raised the question of how benefits from improving housing are mediated. Change in indoor warmth and humidity does not appear to be essential for benefits to health from energy efficiency action. Richardson and Somerville have suggested that a more even distribution of warmth within the home may be significant in health outcomes. Alternatively, there may be broad psychosocial benefits from reduced fuel costs following home improvement, which impact on health.

We found that only a minority of homes would be rated as having very poor energy efficiency. Aberdeen Council has a continuing programme of upgrading council homes, and a reason for non participation of several eligible participants was that they were waiting for rehousing. Current Scottish policy aims to have all social housing with NHER of at least 5.0, and initial NHERs of social housing in the study was 5.6. Similarly, Castlehill Housing Association manages the Scottish Warm Deal programme for private homes, and initial NHERs of private housing in the study were 5.2. These results suggest that social intervention through Warm Deal is achieving its goals, particularly for older people who are in situations where need will be assessed, such as following a hospital admission. Most homes in the study clustered around the Scottish average of 5.4 NHER.

But the study also shows the difficulty of raising energy efficiency to the statutory requirement for new homes of NHER equal to 8. NHERs of 3 to 6, as in the present study, potentially allowed large improvement in the majority of homes taking part, but the average increase of NHER was only 1.0, again similar to that achieved in other intervention studies. This increase in NHER is very close to that reported by EAGA in urban homes undergoing upgrading through the Scottish Executive's Central Heating Programme and the Warm Deal[48]

Moving NHER by 1 to 2 points decreased estimated fuel costs, but had no effect on hours of warmth at recommended levels. The results from the baseline study showed that there was little association of hours of warmth with NHER between 3 and 7. Only in homes with NHER of 8 and higher was there markedly more warmth. An advantage of the study was the use of real objective measurement of warmth and other indoor environmental factors, rather than self perception of indoor environment characteristics.

The Aberdeen study demonstrates the difficulties of carrying out real life pragmatic trials of this kind of social policy intervention. We were able to identify a large group in the Aberdeen City population who would be targeted by current policy for energy efficiency action, because they were elderly and with chronic illness. These same characteristics made them less likely to be willing to take part in the study initially, and more likely to withdraw during the course of the study. This was also a group who had already been identified by social services. We found, from 178 entered into the study, only two participants whose benefits could be improved.

The blurring of randomisation weakened the power of the study for an intention to treat analysis. Ethical approval for the study was granted only on condition that all participants be told, and given written information, that they could independently apply to the Warm Front scheme for grants to have energy efficiency action carried out. Several participants applied to the Warm Front scheme. Others, as described above, ultimately did not have energy action in spite of initial agreement.

The study power was also limited by the numbers achieved and the study demonstrates the difficulty of achieving a sufficient sample size for power to detect benefit in a population of elderly patients with chronic illness. Although more than 1200 patients with COPD are admitted to Aberdeen Royal Infirmary each year, only 600 of these were eligible for entry to the study because almost half of those admitted are not living in independent housing. About one third of patients approached agreed to participate in the study, but ultimately less than half of those in the intervention arm had energy action. One reason for not wishing to be randomised was being on Council waiting lists for re-housing. Among those who initially agreed but then did not go forward with energy action reluctance to have the disruption of energy action was a major factor.

Randomised trials are held to give the strongest evidence for effect of an intervention. The improvement in respiratory health among those who had energy efficiency action in this study was an improvement in people who self selected energy action. This is weaker evidence for benefit from an intervention, since it is possible that these people differed in some way from those who chose not to proceed. Nonetheless, the analysis adjusted for initial health scores and demographic factors, so the improvement found for those who had energy action was not due to differences in health at baseline.

Does it matter that more vulnerable groups are difficult to access for a controlled trial of this kind? Can it be argued that benefits from home improvement observed in younger, healthier populations (the New Zealand study and the Somerville study) must translate to benefits for older, more ill populations? This is a dubious proposition. The activity involved in home improvement is stressful and disruptive. It may be the case that in homes with moderate energy efficiency, as in the present study, health benefits are not great enough to make a policy directed to this group cost effective. On the other hand, for those participants who actively sought energy efficiency action in the present study there was a large and significant gain in respiratory health status, a nine point change, which was more than twice the minimum required for clinical significance.

9 CONCLUSION

The results of this study suggest that people with a chronic respiratory illness who respond to encouragement to seek home energy efficiency action achieve a clinically significant improvement in symptomatic health, but that this is a difficult group to involve in energy action programmes. This has implications for current housing policy regarding groups that are targeted for improvements.

The monitoring of the indoor environment showed surprisingly high levels of $PM_{2.5}$ in many homes. This is an important finding and indoor air quality should be considered when evaluating benefits of energy efficiency action.

The initial baseline study also showed that fewer hours of 21°C warmth in homes which superficially appear to have adequate average indoor temperatures, is associated with worse respiratory health. The number of hours of indoor warmth was only weakly associated with energy efficiency, and there is wide variation in hours of warmth maintained in homes which have acceptable energy efficiency. Personal preference and adaptation appeared to be the major driver of heating styles in homes which fell in the average efficiency range of NHER (between 3 and 7). It was only in homes which had NHER of 8 and above that a clear increase in warmth appeared. Targets for improved energy efficiency in social housing (such as the Scottish target of 5.0 NHER by 2015) may be too low to achieve health benefits for vulnerable groups such as COPD patients.

APPENDIX A

BASELINE CASE STUDIES

Over the first winter a total of 148 homes were monitored. All homes had three visits from researchers; visit one consisted of setting up the monitoring equipment and visits two and three were made one day and one week later respectively to collect this equipment.

During these visits a wide variety of property types, methods of heating, and individual lifestyles were encountered. A great deal of variation between homes with similar NHERs was found, particularly those in the 'moderate energy efficiency' band, and the following case studies provide a more in-depth look at some of our participants' home environments.

Poor energy efficient homes (NHER ≤ 2)

ID 26 Mrs P (NHER 2.1)
Estimated Annual Fuel Costs: £935

This 82-year-old widow lives in a detached stone cottage in a nice residential area of Aberdeen. The home is a single storey, 2-bedroom property built prior to 1919 and the low NHER is mostly due to the house being a stone cottage with timber floor. The house appears well kept, the entrance taking you through the kitchen into the big living room, which has a floor area of 37m^2. All other rooms are off the living room. The total floor area is 94m^2. The main heating system is gas, with the secondary system being open solid fuel fire (according to client never used). Mrs P has lived there for more than 65 years and owns the property outright. She manages her household with the help of a cleaner who comes in a few times per week.

Several possibilities to increase the NHER were identified including underfloor insulation, blocking off the chimney and installing a gas fire with a flue, and installing a combi boiler with full controls. Carrying out these recommendations would increase the NHER to 4.0. Mrs P was allocated to the Intervention group and decided to have only the heating installed, giving the property a final NHER of 3.2.

Indoor temperature measurements obtained during the baseline monitoring week in April 2005 were an average of 20.8°C in the living room at 5pm (minimum 15.6°C, maximum 23°C) and an overall average of 15.4°C in the bedroom (minimum 12.8°C, maximum 23°C). Hours of warmth at recommended levels were 41 for the living room and 5 for the bedroom.

The average temperatures found in Mrs P's home were below the recommended levels, although her average living room temperature at 5pm was just below at 20.8°C. On only one day during the week's monitoring was her home at 21°C for at least 9 hours.

Mrs P awarded herself a VAS score of 50/100 for health on the day of completion of the health questionnaire.

ID 194 Mrs C (NHER 1.3)
Estimated Annual Fuel Costs: £1112

This 79-year-old lady lives alone in an end-terraced house in a popular residential area of Aberdeen. She is not too badly affected by her illness, does all the housework herself and only gets breathless when she has to walk up a hill. She is a very active lady doing voluntary work and taking the bus into town. She occupies her time with making beautiful quilts which she took pride in showing. As described by herself, her chest condition only stops her doing one or two things she would like to do.

She moved into this 2-storey property after it was built in 1954, and now owns her home which she acquired through the right to buy scheme. Downstairs comprises a small vestibule, hallway, a living room and separate kitchen. The property has all bedrooms on the first floor. The total floor area for this property is 75.2m^2. The main heating system

is modern storage heaters, with the secondary heating system being open coal fire in the living room. Windows are double glazed and the home is adequately draught-proofed. Improvements suggested were to upgrade the heating and top up the loft insulation. An application for the Keep Warm Keep Well scheme was also recommended.

Together these measures would raise the NHER to 5.9. Mrs C was randomised to the Intervention group but declined to have central heating installed, agreeing only to the loft insulation. Despite this work being carried out, the NHER for the property remained at 1.3.

Environmental measurements were recorded during the month of November 2004. Average living room temperature at 5pm was 16.5^{o}C (minimum 13.3^{o}C, maximum 19.2^{o}C) with no hours at 21^{o}C. Bedroom temperature average was 14.3^{o}C (minimum 12.9^{o}C, maximum 19.5^{o}C) with only one hour at recommended warmth of 18^{o}C.

The average temperatures in both living room and bedroom are below the recommended levels of 21^{o}C and 18^{o}C respectively. Mrs C did not keep her living room at the recommended level for at least 9 hours/day on any days of the week, and indeed the temperature in the living room did not reach 21^{o}C on any days during the week monitored. However, she reported that she found the temperature in the house to be comfortable for her and did not feel cold.

Filling in the VAS score she gave herself a 70/100 for health status.

Moderate energy efficient homes (NHER 3-6)

ID 375 Mr C (NHER 4.6)
Estimated Annual Fuel Costs: £357
Cold Home

54-year old Mr C lives alone in the city centre in a ground floor flat of a granite tenement property built prior to 1917. He has one room, kitchen and bathroom and has lived here for just over 4 years. The flat is cold, dirty and untidy, and smells strongly of cigarette smoke. The carpets are badly fitted, allowing draughts to come up between the floorboards. The windows are double glazed. Total floor area amounts to 38.7m^2. The main source of heat is a gas central heating system with a combi boiler. There is only one radiator in the bed-sitting room which Mr C claims does not provide sufficient heat. The flat opposite is boarded up but reportedly currently occupied by “squatters”. The entrance hall and stairway to upper floors are poorly kept.

Mr C was adamant that the radiator in the bed-sitting room was not adequate to heat the room and in addition identified a need for draught-proofing. Mr C agreed to randomisation and was assigned to the control group.

Mr C suffers from emphysema and reported having no good days free of chest trouble in the previous year, is unable to carry out housework or small repairs to improve his living conditions. He spends most of his day in the flat only going out when his health permits. On all 3 visits he was wearing a dressing gown over his clothes to keep warm. He reported that he had started to have a hot bath every day to "warm him up" while the heating "kicked in". He has a number of good friends who help out with shopping and who visit him regularly. Sometimes he can manage a trip to the pub on a Saturday night.

Mr C's bed-sitting room average temperature at 5pm was 16.1^{o}C (minimum 12.2^{o}C, maximum 18.3^{o}C, with no hours at 2^{o}C during the monitored week.

On no days during the week of monitoring did Mr C maintain the bed-sitting room temperature at recommended levels. He reports that the temperature in his bed sitting room was very much influenced by trying to keep heating costs down, as his only source of income is disability benefit. Annual estimated fuel costs would represent 11% of the maximum Disability Living Allowance in 2005.

Mr C gave himself a score of 20/100 on VAS score for current health state

ID 146 Mr H (NHER 4.4)
Estimated Annual Fuel Costs £343
Warm home

Mr H and his wife have lived in a popular residential part of Aberdeen for the past four years. Their council owned home is an end-terraced single storey house built between 1964 and 1974. Living space consists of a vestibule, living room, bedroom, kitchen and bathroom with a total floor area of 45.7^{2}m. The home on all occasions visited was tidy, warm and comfortable. The main source of heat is gas central heating with a wall-mounted boiler and radiators in all the rooms. Windows are all double-glazed and the house has adequate draught-proofing. Energy survey suggested wall cavity fill and replacing the existing boiler with a new combi boiler. This would raise the NHER to 7.5. Mr H agreed to randomisation and was allocated to the Intervention group.

78 year old Mr H reports his chest condition as causing him a few problems and considers it stops him doing everything he would like to do. Mr H is extremely deaf and has other health problems in addition to his chest condition. He cannot do housework or go out for shopping. He is practically housebound, spending a good deal of his time during the day in the living room. Mrs H is still active and looks after her husband as well as the household chores whilst maintaining her own social life.

In November 2004, average living room temperature at 5pm was 23.5^{o}C (minimum 17^{o}C, maximum 25.7^{o}C), with 89 out of a possible 168 hours at recommended warmth. The bedroom in this home had an average temperature of 20.3^{o}C (minimum 17.3^{o}C, maximum 22.1^{o}C), and the recommended 18^{o}C was achieved on 162 hours during the monitoring week.

In Mr H's home, recommended levels of 21^{o}C for 9 hours each day was achieved on 5 out of 7 days during the week monitoring took place. The average living room temperature at 5pm was recorded as 23.5^{o}C. The couple live on a state pension and Mrs H also has attendance allowance. They stated that the level of warmth in their living room and bedroom was not influenced by trying to keep the heating costs down.

On the VAS, Mr H chose a score of 50/100 for current health state.

Good energy efficient homes (NHER 7-10)

ID 16 Mr B (NHER 8.7)
Estimated Annual Fuel Costs: £340

Mr B lives with his wife in a mid-terraced 2-storey house which they own. They moved into the house in 1966, the same year the property was built. The floor area amounts to 72.6m^2, and consists of two bedrooms, living room, kitchen and bathroom. The energy survey established that the main heating system is a gas condensing boiler with radiators.

The windows are double glazed, the wall cavities are filled and the loft insulation is 20cm or over. The NHER was calculated as 8.7 and no recommendations, except 100% low energy lights, were made.

His chest problems started after retirement and he is not too restricted in his activities of daily living, even though he feels it would stop him doing most things he would like to do. He helps with the household chores and drives a car. Measurements were carried out in February 2005.

The living-room temperature was above the recommended 21^{o}C over 9 hours a day for the whole 7 day period the temperature was recorded. The average living room temperature at 5pm was 22.5^{o}C (minimum 18.2^{o}C, maximum 24.6^{o}C) Measurements in the bedroom were also within the recommended levels with an average of 20^{o}C (minimum 17.7^{o}C, maximum 21.9^{o}C). The couple keep the temperature in the house at a level they find comfortable and they are not concerned with keeping the heating costs down. .

Mr B decided on a VAS score of 50/100.

APPENDIX B

FOLLOW UP CASE STUDIES

By the end of the second winter a total of 178 homes were monitored. All homes had three visits from our researchers; visit one consisted of setting up the monitoring equipment and visits two and three were made one day and one week later respectively to collect this equipment.

Those who agreed to be randomised, and were assigned to the intervention group, were visited by the Energy Surveyor who discussed the options available to them to improve the energy efficiency of their home. Some participants decided to go ahead with the planned energy efficiency action while others decided not to have any action, although they were happy to continue in the study and have repeat environmental monitoring in twelve month's time.

Participants assigned to control (waiting list group) were not due to be visited by the Energy Surveyor until after the repeat environmental monitoring twelve months after their entry into the study. At that point, their energy efficiency action options would be fully discussed and, if they agreed, the work would then be scheduled. However during the twelve month waiting period several participants in the control group instigated independent energy efficiency action, despite having agreed to randomisation in the full knowledge they could be assigned to the waiting list control group.

The following case studies provide a more detailed look at some of these scenarios.

Intervention Group – no action carried out

ID 235 (Mr G)
Estimated Annual Fuel Costs: £639
NHER: 2.4 no change

Mr G is a 68-year old retired blue collar worker who lives with his wife in a flat built prior to 1917, which they own outright. The property has a sloping front garden and the entrance to the flat is reached up a short flight of stairs from the road, leading to a shared front doorway and vestibule, which then splits into two separate entrances, one for the upstairs flat and one for Mr & Mrs G's ground floor flat. They have lived here happily for 24 years but have recently been experiencing problems with their upstairs neighbour, particularly regarding the upkeep of the shared back garden. The flat is $50.4m^2$, currently has a gas back boiler with radiators, a gas fire in the living room, and the property is double glazed.

At her visit the Energy Surveyor recommended a replacement boiler. Indeed, Mr G had been told by the Gas Board that the current boiler would not be repairable if it broke down. This energy efficiency action would raise the NHER from 2.4 to 6.1, bringing the home above the Scottish average. Information about financial help was provided, such as low cost loans and any grants the household would be entitled to. Mr G declined to have energy efficiency action, stating that as everything was still in working order, and the house was warm and comfortable, they had decided not proceed in the meantime.

Direct temperature monitoring over one week in November 2005 found that the average living room temperature at 5pm was 25.9^oC, and on every day of the week the living room was heated to 21^oC for at least 9 hours, with a total of 145.5 hours out of a possible 168 hours at 21^oC. Bedroom hours of warmth were 135 at 18^oC and every day this temperature was achieved for at least 9 hours. Average overnight temperature in the bedroom was 18.4^oC. On the corresponding week in November 2006 similar temperatures were found, with a living room 5pm average of 25.9^oC, 146.5 hours at 21^oC; the bedroom overnight temperature averaged at 19.1^oC and was kept at the recommended 18^oC for 164.5 hours.

This case illustrates one reason why participants were not keen to accept energy efficiency action: they were happy with the level of warmth currently being maintained within the home and saw no reason to involve them in expense to change the existing heating system. When we asked Mr G about the temperature in his living room and bedroom he responded that they were 'always just right'. The household live on a state pension plus Mr G has a private/occupational pension of an undisclosed sum. It is unlikely however, with estimated annual fuel costs of £639 that they are in fuel poverty. However, Mr G said the temperature in his home was somewhat influenced by trying to keep the costs down.

ID 551 (Mrs R)
Estimated Annual Fuel Costs: £392
NHER: 6.6 No change

Mrs R is a delightful 75 year old widow who lives alone in a ground floor tenement flat in a fairly deprived neighbourhood. The property was built between 1918 and 1929 and is council owned. She is totally housebound, spending around 15 hours a day on the living room sofa and 9 hours in bed. She has good neighbours who help her get up in the mornings and get ready for bed at night. The only occasions Mrs R leaves the flat are to attend hospital appointments for which patient transport is always arranged.

The double-glazed flat is 53.6m^2 and has gas heating with combi boiler and radiators installed. Energy survey identified the need for underfloor insulation and this energy efficiency action would potentially raise the NHER to 6.9. As the property is council owned, the work would be carried out under the Scottish Executive's Warm Deal Programme, and the cost would be borne by Aberdeen City Council. Unfortunately, it was discovered that there was not enough room under the floor of the property to enable the workforce to install the insulation, and therefore no energy efficiency action was carried out.

Temperatures in Mrs R's flat did not change much between February 2005 and February 2006. Living room average temperature at 5pm was 19.2^{o}C and 20.4^{o}C respectively, while hours at 21^{o}C increased from zero to 12.5 hours. In the bedroom, overnight temperatures were very low at 13^{o}C in 2005 and 11.8^{o}C in 2006. Bedroom hours of warmth were 1.5 and 0.5.

Mrs R reported that the temperatures in both living room and bedroom were sometimes too cool, and these rooms were draughty and difficult to heat. She was not however concerned with trying to keep costs down. In view of Mrs R's concerns she was visited by an Energy Surveyor from the Council's Housing Department who assessed the heating system in the property. It was found that the radiator in the living room was sufficient to heat the room to a design temperature of 21^{o}C and above. The boiler thermostat was only set at the halfway point and this was reset to maximum. Mrs R was advised to turn on the radiators in the hall and kitchen in order to reduce the cold air streaming into the living room whenever these doors were opened. The opinion of the surveyor was that if these radiators are not kept on, for whatever reason, there would probably always be a perception that the living room was colder than it is, and he could suggest nothing further to improve the heating.

This demonstrates how, in some cases, while participants were willing for work to be carried out, physical characteristics of the property meant that nothing could actually be done to improve energy efficiency. It also demonstrates the role personal preferences play in heating behaviour. Although Mrs R stated that she was not concerned with heating costs, the fact that she did not keep on the radiators in the hall and kitchen suggest that this might not be the case.

ID 77 (Mr S)
Estimated Annual Fuel Costs: £476
NHER: 5.6 no change

Mr S and his wife have lived for 23 years in their council owned semi-detached house in a popular suburb of Aberdeen City. Built between 1950 and 1963, the property is 61.6m^2, with double glazing, cavity wall insulation and is heated by mains gas with a wall mounted boiler and radiators. Sixty-seven year old Mr S has co-morbidities and has been identified as eligible for medical need housing points. Mr S can get out and about if he takes his time, but is only able to do light tasks in the home such as making tea and emptying the dishwasher. His wife still has a part-time job so he is alone for periods of the day.

The Energy Surveyor made a number of recommendations for this property. A change to a combi boiler, together with underfloor insulation and topping up of loft insulation were all suggested, potentially bringing the NHER up to 7.3. Mr S's identified medical need meant that the work of clearing the loft prior to topping up the insulation would be carried out by the handyman employed by Aberdeen Care and Repair.

No energy efficiency action was carried out in Mr S's home. This was mainly due to the fact that the couple were not willing to have their recently laid laminate flooring lifted to accommodate the new central heating and underfloor insulation. In addition the loft insulation was not topped up because Mr S reported that it was going to cost £300 to have the loft cleared and this was an expense he was not willing to incur.

Indoor temperature monitoring of this home in April 2005 and 2006 revealed the living room average temperature at 5pm to be 19.4^{o}C and 20.2^{o}C respectively. Hours of warmth at 21^{o}C were 28.5 in 2005 and 4.5 in 2006. Mr S spends around 15 hours a day between his computer room and his living room and when we visited in April 2006 he reported his living room as sometimes too warm. Average overnight bedroom temperatures in the two years monitored were 20^{o}C and 19.7^{o}C, with 159.5 and 168 hours of recommended warmth of at least 18^{o}C. This level of warmth was achieved in their bedroom despite the couple reporting they did not use the central heating in this room.

So it can easily be seen how people are unwilling to involve themselves in extra upheaval and financial burden if they are already happy with the level of warmth within their home. This case emphasises the difficulties we experienced in achieving energy efficiency action in homes identified as benefiting from improvements.

8.2 Control Group –action carried out

ID 325 (Mrs M)
Estimated Annual Fuel Costs: £438
NHER: 3.2 up to 4.0

Mrs M is a single pensioner who lives alone in her first floor 4-in-a-block property on a busy thoroughfare in Aberdeen City. The property is council owned and was built between 1950 and 1963. It has three exposed outside walls. Mrs M's flat is clean and nicely decorated, and she took great pride in giving us a guided tour. She has been a smoker for 50 years, smoking around five cigarettes a day.

At the energy survey it was recommended that this property would benefit from an upgraded boiler and top up of loft insulation, which would increase the NHER to 4.0. Mrs M agreed to randomisation and was assigned to the Control group. This was in January 2005. It was made clear to Mrs M that the energy surveyor would not be back to discuss the upgrade work for twelve months. At the first repeat monitoring visit in January 2006, Mrs M told us that she had had a new boiler, gas fire and four new radiators installed in June 2005 as part of the council's rolling programme of improvements. These improvements raised the property's NHER to 4.0.

The average living room temperature at 5pm in 2005 was 23.5^{o}C while in 2006 this had dropped to 20.8^{o}C. Hours of living room warmth dropped from 161 in 2005 to 51 in 2006. Similarly average bedroom overnight temperatures dropped from 18.9^{o}C the first year and 17^{o}C in year two, with hours of recommended warmth down by 100 hours to 41 during the monitoring week in January 2006.

Although the upgraded central heating system raised the NHER to 4.0 this was still below the Scottish average of 5.4. Mrs M's recorded temperatures were consistently lower in 2006 and indeed at this time she reported that the warmth in her living and bedroom was sometimes too cool, causing her to keep the heating on in the bedroom overnight. She did not report being concerned with the cost of heating. She mentioned that she spent a large part of each day at her sister's house, leaving home in the morning at around 9am and coming back at 4pm. It might well be the case that the lower living room 5pm temperature was due to the heating being off during the day when Mrs M was out, but does not explain why the bedroom was below recommended levels especially if the heating was indeed at times kept on all night.

This case highlights the difficulty of real life research where circumstances outwith our control, ie the council's ongoing programme of improvements, interfered with the assignment to waiting list control group for this participant.

ID 539 (Mr M)
Estimated Annual Fuel Costs: £577
NHER: 2.8 up to 5.5

Mr M is a 71 year old single pensioner who lives in a first floor flat of a granite tenement property built before 1917. The flat is owned outright, and Mr M has lived here alone for 15 years. This property is heated by mains gas with a wall mounted boiler and radiators in all rooms but one. The size of the property is 47.6m^{2}. Mr M was recruited into the study in January 2005. Prior to this he was visited by the Energy Surveyor who recommended a change to the central heating boiler, the current one being more than 15 years old. Mr M agreed to randomisation and was assigned to the control group. He was aware that the monitoring visits would be repeated in twelve months, after which time he would be visited again by the Energy Surveyor with a view to discussing his energy efficiency improvement options.

At the repeat monitoring visits in January 2006, Mr M mentioned that he had a new boiler installed in August 2005 by Scottish Gas. Following the monitoring visits, the Energy Surveyor returned to Mr M's property and calculated his new NHER to be 5.5 and estimated annual fuel costs to have dropped to £430.

Interestingly, Mr M's indoor temperatures fell between January 2005 and January 2006 despite the new boiler. His average living room temperature at 5pm dropped from 18.7^{o}C to 16.1^{o}C and he had no living room hours at the recommended temperature of 21^{o}C in either year. His bedroom overnight temperature also dropped from an average of 17.2^{o}C to 15.4^{o}C in the second year. These temperatures were now lower than WHO recommended levels for thermal comfort. However, when we asked Mr M about his indoor temperature he stated that his living room and bedroom were always just right; he reported no problems with adjusting the new heating, and no concerns with heating costs.

Mr M actively decided to go ahead and have a new boiler installed which is rather different than being swept up in an ongoing planned programme of council upgrading, and illustrates again the problems and pitfalls of research in real life situations.

Monitor Only Group – action carried out

ID 561 (Mrs S)
Estimated Annual Fuel Costs: £680
NHER: 5.4 up to 5.9

Mrs S lives with her husband in a quiet neighbourhood in the city. Their home, which they own outright, is a semi-detached 2-storey granite house built between 1930 and 1944 of 192.7m^2. On all occasions the house was warm and welcoming. The main source of heat is gas central heating with a back boiler and radiators in all the rooms. Windows are all double-glazed and the house has adequate draught-proofing.

Energy survey suggested topping up the loft insulation and replacing the existing boiler with a new combi boiler. They decided to go ahead with the improvements but without the restrictions of the study. Therefore they were not randomised but did agree to environmental monitoring.

Mrs S reports that they pay into a "stay warm" scheme which allows them to keep the heating on as high and for as long as they like for an agreed monthly sum, so she was not concerned with heating costs. A new combi boiler was installed in November 2005 but further loft insulation was not possible due to the loft being floored. A grant of £500 was awarded for this work.

During the two years of monitoring, the indoor temperatures in this home were as follows: average living room 5pm temperature was 20.5^{o}C with 9.5 hours at 21^{o}C in December 2004 and 19.1^{o}C with no hours at 21^{o}C in December 2005 shortly after the new boiler was installed. Due to problems with getting upstairs, Mrs S moved to a bedroom downstairs in the intervening year so the bedroom temperatures in 2005 are not for the same room. In both years the average overnight bedroom temperatures were at or above the recommended 18^{o}C but we cannot compare years for bedroom hours of warmth.

The family were keen to make the recommended improvements and were unwilling to commit themselves to the restraints of the research project: they did not want to wait 12 months for the work to be carried out in the event of being randomised to the control group.

APPENDIX C

SUPPLEMENTARY DESCRIPTION OF METHODS

Indoor air quality monitoring

Particulate data were measured for $PM_{2.5}$ mass in micrograms per metre^3 (µg/m^3). Measurements were taken using a DustTrak Aerosol monitor a laser photometer calibrated from 0.001 to 100 mg/m^3. The DustTrak was placed in participants' living rooms, usually 1-1.5m high, between 12pm and 5pm and collected the following day between 9am and 12pm. The DustTrak was powered by 4 Duracell LR14 batteries which allowed monitoring for up to 18 hours. After collection from participants, data were downloaded using Trakpro software, and test statistics were recorded in the database. The inlet port was cleaned and flow rate calibrated after every use. Batteries were replaced daily.

Adjustment of PM $_{2.5}$ values DustTrak monitors use a light scattering method and are widely used to estimate particulate mass. They have less measurement uncertainty than devices which use gravimetric methods, but are now known to overestimate particulate mass, by comparison with gravimetric methods. From real life observations, Heal et al(Heal et al. 2000) reported DustTrak overestimates of PM_{10} by a factor of 2.2. Chung(Chung et al. 2001) compared five real-time continuous airborne particle monitors and also found that DustTrak overestimated concentrations by a factor of approximately three. Jenkins et al(Jenkins et al. 2004) have carried out a study under controlled (chamber conditions) followed by real life observations in hospitality venues, comparing DustTrak to gravimetric samplers, for four aerosols: Environmental Tobacco Smoke (ETS), cooking oil, wood smoke and propane stove particles. Particulate concentration ranges were 28 µg/m^3 to 2660 µg/m^3. They found that under laboratory conditions DustTraks overestimated particles from ETS, cooking oil and wood smoke by 2 – 4 times. In field test the DustTrak overestimated particulates in non-smoking venues by 2.6, in smoking venues by 3.2. Thus, DustTrak readings were corrected by a factor of three in the present study.

Outdoor $PM_{2.5}$ Outdoor readings were collected from a DustTrak monitor at the Department of Environmental and Occupational Medicine which is based approximately three miles from the Aberdeen City centre, in a medium density suburban area. The DustTrak was based inside the laboratory but fitted with a probe to allow external monitoring. Readings were taken every 5 minutes. Monthly averages were calculated from daily averages. Calibration was done after every download (approx every three days). These readings are also adjusted by a factor of three.

Endotoxin dust samples were collected using a Morphy Richards 2000 watt vacuum cleaner with HEPA filtration, following the methods used in the US Department of Housing First National Survey of Lead and Allergens in Housing (Vojta, Friedman, Marker, Clickner, Rogers, Viet, Muilenberg, Thorne, Arbes, Jr., & Zeldin 2002). A cellulose thimble (19mm x 90mm, Whatman International Ltd) was placed in the end of the vacuum extension tube and a clean suction head placed over this. An area in front of the living room sofa measuring 2m x 1m was vacuumed for 5 minutes. Dust samples were sealed in plastic bags, refrigerated at <5^{o}C and sent within two days to the Institute of Occupational Medicine in Edinburgh. On the day of receipt samples were weighed and transferred to sterile glass tubes. The bulk weight was recorded and the glass tubes capped with Parafilm and stored at 4^{o}C. Samples were sieved using a 425 µm grate; the resulting fine dust weighed and placed in a new sterile glass tube. The fine dust was eluted in pyrogen free water containing 0.05% v/v Tween 20 for two hours. These samples were stored at 4^{o}C until the assay was carried out. The eluates were analysed using a Pyrochrome *Limulus* Amebocyte Lysate (LAL) end-point assay (Associates of Cape Cod, Maine). The sample eluates were dispensed in duplicate into a pyrogen free micro titre plate (costar) and incubated with 50µl of Pyrochrome reagent for 30-45 minutes (as per Pyrochrome Lot directions) at 37^{o}C. The sample reaction was then stopped with the addition of 50% acetic acid to each well and the absorbance read at 405nm. A standard curve was constructed from a range of known endotoxin standards (1 – 0.0625 EU/ml) and the endotoxin concentration of the unknown samples interpolated from this. The endotoxin results are expressed in endotoxin units (EU)/mg (bulk samples). The detection limit for this assay is 0.0625 EU/ml. On receipt all results were entered in database.

Indoor NO_2 was measured with passive samplers (Palmes tubes) in living room (LR) and bedroom (BR). Sample tubes were placed away from windows and doors, usually at 1-1.5m height. Samplers were left for one week. On collection, diffusion tubes were capped, sealed in plastic bags, date and time of collection recorded, and refrigerated at $<5^oC$. On a weekly basis samplers were sent in padded bags to Gradko International Ltd in Winchester for analysis. Nitrogen dioxide absorbed as nitrite by triethanolamine was determined spectrophotometrically at 540 nanometers using a Camspex UV/visible Spectrophotometer. Concentrations of $\mu g/m^3$ and NO_2 in air in parts per billion were then calculated using a precalibrated response factor and exposure times. Nitrite solutions used were regularly checked against a calibration graph. Analysis reports for each home monitored were received at fortnightly intervals and ppb values entered into database.

St Georges Respiratory Questionnaire (Jones et al. 1992) Scores are generated in three areas; Symptoms, Activity Limitation and Disease Impact. A change of four points on an SGRQ scale is regarded as clinically significant (Hajiro & Nishimura 2002).

> Symptoms: Frequency and severity of symptoms, and exacerbations, assessed by a five-point Likert scale,
> Activity Limitation: Summative score of activities, which cause and are limited by breathlessness, scored using a dichotomous (yes/no) scale,
> Disease Impact: Questions on social functioning and psychological distress which result from the airways disease, scored using a dichotomous (yes/no) scale.

Scores are expressed as percentages ranging from 0 to 100. Higher scores represent worse heath status.

Appendix D: Clinical and demographic covariates

	Unadjusted analyses		
SGRQ-Symptoms	**B (SE)**		**p value**
Age	-0.31	(0.15)	0.001
%PredFEV_1	-0.11	(0.08)	0.15
%Pred FVC	-0.10	(0.07)	0.18
COPD prior admissions	2.51	(1.2)	0.04
Marital status	1.9	(2.3)	0.40
SIMD	0.18	(0.07)	0.02
Mean outdoor maximum[1]			
Mean outdoor minimum[1]			
SGRQ-Activity	**B (SE)**		**p value**
Age	0.20	(0.17)	0.25
%PredFEV_1	-0.29	(0.08)	<0.001
%Pred FVC	-0.24	(0.08)	0.002
COPD prior admissions	2.10	(1.3)	0.11
Marital status	1.58	(2.8)	0.41
SIMD	0.19	(0.12)	0.01
Mean outdoor maximum[1]			
Mean outdoor minimum[1]			
SGRQ-Impact	**B (SE)**		**p value**
SIMD	0.24	(0.14)	0.09
Age	-0.49	(0.20)	0.01
%PredFEV_1	-0.34	(0.09)	<0.001
%Pred FVC	-0.32	(0.09)	<0.001
COPD prior admissions	2.8	(1.5)	0.07
Marital status	7.5	(3.3)	0.03
SIMD	0.14	(0.09)	0.06
Mean outdoor maximum[1]			
Mean outdoor minimum[1]			
EQ-VAS	**B (SE)**		**p value**
Age	0.03	(0.02)	0.13
%PredFEV_1	0.02	(0.01)	0.003
%Pred FVC	0.02	(0.01)	0.04
COPD prior admissions	0.08	(0.13)	0.53
Marital status	0.09	(0.28)	0.75
SIMD	0.02	(0.01)	0.78
Mean outdoor maximum[1]			
Mean outdoor minimum[1]			

[1]Over the one week study period

APPENDIX E

Indoor Temperature Comfort Questionnaire

1. In a normal 24 hours how many hours do you spend in your

Living room ___________hours
Kitchen ___________hours
Bedroom ___________hours

2. Over the past week was the temperature in your living room

Sometimes too warm ☐	Always just right ☐	Sometimes too cool ☐

3. Is the warmth of your living room influenced by any of the reasons below

Heating difficult to adjust	Very much ☐	Somewhat ☐	Not at all ☐
Other people prefer it warmer than you do	Very much ☐	Somewhat ☐	Not at all ☐
Other people prefer it cooler than you do	Very much ☐	Somewhat ☐	Not at all ☐
Room is difficult to heat (eg draughty)	Very much ☐	Somewhat ☐	Not at all ☐
Try to keep heating costs down	Very much ☐	Somewhat ☐	Not at all ☐

4. Over the past week was the temperature in your bedroom

Sometimes too warm ☐	Always just right ☐	Sometimes too cool ☐

5. Is the warmth of your bedroom influenced by any of the reasons below

Heating difficult to adjust	Very much ☐	Somewhat ☐	Not at all ☐
Other people prefer it warmer than you do	Very much ☐	Somewhat ☐	Not at all ☐
Other people prefer it cooler than you do	Very much ☐	Somewhat ☐	Not at all ☐
Room is difficult to heat (eg draughty)	Very much ☐	Somewhat ☐	Not at all ☐
Try to keep heating costs down	Very much ☐	Somewhat ☐	Not at all ☐

Thank you for answering this questionnaire

12 REFERENCES

1. Thomson H, Petticrew M. Housing and health. *BMJ* 2007;**334**:434-5.

2. Richardson G, Barton A, Basham M, Foy C, Eick SA, Somerville M. The Watcombe housing study: the short-term effect of improving housing conditions on the indoor environment. *Sci.Total Environ.* 2006;**361**:73-80.

3. Howden-Chapman P. Housing standards: a glossary of housing and health. *J.Epidemiol.Community Health* 2004;**58**:162-8.

4. Wilkinson, D. Poor housing and ill health: a summary of the research evidence. 1999. Edinburgh, Scottish Office Central Research Unit.

5. Wilkinson P, Landon M, Armstrong B, et al. *Cold comfort: The social and environmental determinants of excess winter deaths in England, 1986-96* . Bristol: The Policy Press, 2001.

6. Rudge J, Gilchrist R. Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough. *J.Public Health* 2005;**27**:353-8.

7. Evans J, Hyndman S, Stewart-Brown S, Smith D, Petersen S. An epidemiological study of the relative importance of damp housing in relation to adult health. *J Epidemiol.Community Health* 2000;**54**:677-86.

8. Strachan DP. Damp housing and childhood asthma: validation of reporting of symptoms. *BMJ* 1988;**297**:1223-6.

9. Williamson IJ, Martin CJ, McGill G, Monie RD, Fennerty AG. Damp housing and asthma: a case-control study. *Thorax* 1997;**52**:229-34.

10. Zock JP, Jarvis D, Luczynska C, Sunyer J, Burney P. Housing characteristics, reported mold exposure, and asthma in the European Community Respiratory Health Survey. *J.Allergy Clin.Immunol.* 2002;**110**:285-92.

11. Allen T. Private sector housing improvement in the UK and the chronically ill: Implications for collaborative working. *Housing Studies* 2005;**20**:63-80.

12. Hopton J, Hunt S. The health effects of improvements to housing: A longitudinal study. *Housing Studies* 1996;**11**:271-86.

13. Oreszczyn T, Hong S, Ridley I, Wilkinson P. Determinants of winter indoor temperatures in low income houses in England. *Energy and Buildings* 2006;245-52.

14. Thomson H, Petticrew M, Morrison D. Health effects of housing improvement: systematic review of intervention studies. *BMJ* 2001;**323**:187-90.

15. Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T *et al*. Effect of insulating existing houses on health inequality: cluster randomised study in the community. *BMJ* 2007;**334**:460.

16. Rudge J, Nicol F. Cutting the Cost of Cold: Affordable Warmth for Healthier Homes. London & New York: E & FN Spon, 2000.

17. Bornehag CG, Bonini S, Custovic A, Kunzli N, Malmberg P, Matricardi P *et al*. Dampness in buildings as a risk factor for health effects, EUROEXPO - Multidisciplinary review of the literature (1988-2000) on dampness and mite exposure in buildings and health effects. *Epidemiology* 2001;**12**:S94.

18. Dales RE, Zwanenburg H, Burnett R, Franklin CA. Respiratory health effects of home dampness and molds among Canadian children. *Am.J.Epidemiol.* 1991;**134**:196-203.

19. Packer CN, Stewart-Brown S, Fowle SE. Damp housing and adult health: results from a lifestyle study in Worcester, England. *J.Epidemiol.Community Health* 1994;**48**:555-9.

20. Spengler J, Neas L, Nakai S., et al. Respiratory symptoms and housing characteristics. *Indoor Air* 1994;**4**:72-82.

21. Walker JJ, Mitchell R, Platt SD, Petticrew MP, Hopton J. Does usage of domestic heating influence internal environmental conditions and health? *Eur.J Public Health* 2006;**16**:463-9.

22. Gemmell I. Indoor heating, house conditions, and health. *J Epidemiol.Community Health* 2001;**55**:928-9.

23. Donaldson GC, Seemungal T, Jeffries DJ, Wedzicha JA. Effect of temperature on lung function and symptoms in chronic obstructive pulmonary disease. *Eur.Respir.J.* 1999;**13**:844-9.

24. Somerville M, Mackenzie I, Owen P, Miles D. Housing and health: does installing heating in their homes improve the health of children with asthma? *Public Health* 2000;**114**:434-9.

25. National Energy Centre, Milton Keynes. National Home Energy rating. 2006.

26. Wilkinson, B and Pickles, D. SAP targets and affordability in social housing. Energy Action . 2005.

27. Vojta PJ, Friedman W, Marker DA, Clickner R, Rogers JW, Viet SM *et al*. First National Survey of Lead and Allergens in Housing: survey design and methods for the allergen and endotoxin components. *Environ.Health Perspect.* 2002;**110**:527-32.

28. Kind P, Dolan P, Gudex C, Williams A. Variations in population health status: results from a United Kingdom national questionnaire survey. *BMJ* 1998;**316**:736-41.

29. Vickers AJ, Altman DG. Statistics notes: Analysing controlled trials with baseline and follow up measurements. *BMJ* 2001;**323**:1123-4.

30. Osman LM, Douglas JG, Garden C, Reglitz K, Lyon J, Gordon S *et al*. Indoor Air Quality in Homes of Patients with Chronic Obstructive Pulmonary Disease. *Am.J.Respir.Crit Care Med.* 2007.

31. Cormack, D, Friel, K, Grainger, S, Millen, D, and Robinson A. Fuel Poverty in Scotland: Further Analysis of the Scottish House Condition Survey. 2004. Edinburgh, Communities Scotland and Scottish Executive .

32. WHO. WHO Air Quality Guidelines - Global Update. 2005. Geneva.

33. Scottish Homes Communities Scotland. Scottish House Condition Survey 1996 3rd Edition. 1996. Edinburgh, HMSO.

34. Scottish Homes Communities Scotland. Scottish House Conditions Survey 2002. 2005. Edinburgh, HMSO.

35. Boardman, B, Darby, S, Killip, G, Hinnells, M, Jardine, C. M, Palmer, J, and Sinden, G. The 40% House. 2005. University of Oxford, Environmental Change Institute.

36. Jarvis DL, Leaderer BP, Chinn S, Burney PG. Indoor nitrous acid and respiratory symptoms and lung function in adults. *Thorax* 2005;**60**:474-9.

37. Sippel JM, Pedula KL, Vollmer WM, Buist AS, Osborne ML. Associations of smoking with hospital-based care and quality of life in patients with obstructive airway disease. *Chest* 1999;**115**:691-6.

38. Simoni M, Jaakkola MS, Carrozzi L, Baldacci S, Di Pede F, Viegi G. Indoor air pollution and respiratory health in the elderly. *Eur.Respir.J.Suppl* 2003;**40**:15s-20s.

39. Nayha S,.Hassi J. Cold and mortality from ischaemic heart disease in northern Finland. *Arctic Med.Res.* 1995;**54 Suppl 2**:19-25.

40. Saumet JL,.Dittmar A. Heat loss and anticipatory finger vasoconstriction induced by a smoking of a single cigarette. *Physiol Behav.* 1985;**35**:229-32.

41. Stout RW,.Crawford V. Seasonal variations in fibrinogen concentrations among elderly people. *Lancet* 1991;**338**:9-13.

42. Tapson VF. The role of smoking in coagulation and thromboembolism in chronic obstructive pulmonary disease. *Proc.Am.Thorac.Soc.* 2005;**2**:71-7.

43. Critchley R, Gilbertson J, Grimsley M, Green G. Living in cold homes after heating improvements: Evidence from Warm-Front,England's Home Energy Efficiency Scheme. *Applied Energy* 2007;**84**:147-58.

44. Wilkinson P, Pattenden S, Armstrong B, Fletcher A, Kovats RS, Mangtani P *et al*. Vulnerability to winter mortality in elderly people in Britain: population based study. *BMJ* 2004;**329**:647.

45. Hassi J, Rytkonen M, Kotaniemi J, Rintamaki H. Impacts of cold climate on human heat balance, performance and health in circumpolar areas. *Int.J.Circumpolar.Health* 2005;**64**:459-67.

46. Mercer JB. Cold--an underrated risk factor for health. *Environ.Res.* 2003;**92**:8-13.

47. WHO. WHO technical meeting on "Housing Health Indicators". European Centre for Environment and Health. 2004. Bonn, World Health Regional Office for Europe.

48. Central Heating Programme and the Warm Deal - Annual Report 2001/02. Scottish Office . 2003.