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Abstract

The health impacts of energy performance investments in low-income areas: a mixed-methods approach

Wouter Poortinga,[1]* Sarah E Rodgers,[2] Ronan A Lyons,[2] Pippa Anderson,[3] Chris Tweed,[1] Charlotte Grey,[1] Shiyu Jiang,[1] Rhodri Johnson,[2] Alan Watkins[2] and Thomas G Winfield[3]

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Background: Cold homes and fuel poverty contribute to health inequalities in ways that could be addressed through energy efficiency interventions.

Objectives: To determine the health and psychosocial impacts of energy performance investments in low-income areas, particularly hospital admissions for cardiorespiratory conditions, prevalence of respiratory symptoms and mental health status, hydrothermal conditions and household energy use, psychosocial outcomes, cost consequences to the health system and the cost utility of these investments.

Design: A mixed-methods study comprising data linkage (25,908 individuals living in 4968 intervention homes), a field study with a controlled pre-/post-test design (intervention, $n = 418$; control, $n = 418$), a controlled multilevel interrupted time series analysis of internal hydrothermal conditions (intervention, $n = 48$; control, $n = 40$) and a health economic assessment.

Setting: Low-income areas across Wales.

Participants: Residents who received energy efficiency measures through the intervention programme and matched control groups.

Main outcome measures: Primary outcomes – emergency hospital admissions for cardiorespiratory conditions, self-reported respiratory symptoms, mental health status, indoor air temperature and indoor relative humidity. Secondary outcomes – emergency hospital admissions for chronic obstructive pulmonary disease-related cardiorespiratory conditions, excess winter admissions, health-related quality of life, subjective well-being, self-reported fuel poverty, financial stress and difficulties, food security, social interaction, thermal satisfaction and self-reported housing conditions.

Methods: Anonymously linked individual health records for emergency hospital admissions were analysed using mixed multilevel linear models. A quasi-experimental controlled field study used a multilevel repeated measures approach. Controlled multilevel interrupted time series analyses were conducted to estimate changes in internal hydrothermal conditions following the intervention. The economic evaluation comprised cost–consequence and cost–utility analyses.

Data sources: The Patient Episode Database for Wales 2005–14, intervention records from 28 local authorities and housing associations, and scheme managers who delivered the programme.

Results: The study found no evidence of changes in physical health. However, there were improvements in subjective well-being and a number of psychosocial outcomes. The household monitoring study found that the intervention raised indoor temperature and helped reduce energy use. No evidence was found of substantial increases in indoor humidity levels. The health economic assessment found no explicit cost reductions to the health service as a result of non-significant changes in emergency admissions for cardiorespiratory conditions.

Limitations: This was a non-randomised intervention study with household monitoring and field studies that relied on self-response. Data linkage focused on emergency admissions only.

Conclusion: Although there was no evidence that energy performance investments provide physical health benefits or reduce health service usage, there was evidence that they improve social and economic conditions that are conducive to better health and improved subjective well-being. The intervention has been successful in reducing energy use and improving the living conditions of households in low-income areas. The lack of association of emergency hospital admissions with energy performance investments means that we were unable to evidence cost saving to health-service providers.

Future work: Our research suggests the importance of incorporating evaluations with follow-up into intervention research from the start.

Funding: The National Institute for Health Research Public Health Research programme.

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Glossary

Arbed The area-based, supply-led part of the Welsh Government Warm Homes programme. The scheme took place in two separate phases between 2010 and 2015 and aimed to improve the energy efficiency of existing homes in low-income areas. Arbed means 'save' in Welsh.

Nest The demand-led part of the Welsh Government Warm Homes programme. The scheme was established in 2011 and offers free advice and support to low-income households with energy-efficient homes. Free home energy efficiency improvements are offered to eligible households.

List of abbreviations

A&E	accident and emergency
ACOS	asthma–COPD overlap syndrome
ALF	Anonymous (Individual) Linking Field
ANOVA	analysis of variance
AQoL	Assessment of Quality of Life
BISF	British Iron and Steel Federation
BMI	body mass index
CBA	cost–benefit analysis
CCA	cost–consequences analysis
CEA	cost-effectiveness analysis
CEAC	cost-effectiveness acceptability curve
CEP	cost-effectiveness plane
CI	confidence interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COPD	chronic obstructive pulmonary disease
CUA	cost–utility analysis
EQ-5D	EuroQol-5 Dimensions
ERDF	European Regional Development Fund
FEV	forced expiratory volume
GOLD	Global Initiative for Chronic Obstructive Lung Disease
GP	general practitioner
HDD	heating degree day
HSUV	health state utility value
HUI	Health Utilities Index
ICD-10	*International Classification of Diseases*, Tenth Edition
ICER	incremental cost-effectiveness ratio
IGRP	Information Governance Review Panel
LA	local authority
LSOA	lower super output area
MCS	Mental Health Composite Scale
NICE	National Institute for Health and Care Excellence
NWIS	NHS Wales Informatics Service
ONS	Office for National Statistics
OR	odds ratio
PCS	Physical Health Composite Scale
PEDW	Patient Episode Database for Wales
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSA	probabilistic sensitivity analysis
QALY	quality-adjusted life-year
QWB	Quality of Well-Being
RALF	Residential Anonymous Linking Field
RH	relative humidity
RSL	registered social landlord
SAIL	Secure Anonymised Information Linkage
SD	standard deviation
SE	standard error
SF-6D	Short Form questionnaire-6 Dimensions
SF-12	Short Form questionnaire-12 items
SF-36	Short Form questionnaire-36 items
SREC	School Research Ethics Committee
SSC	study steering committee

STROBE	Strengthening the Reporting Observational Studies in Epidemiology
WDS	Welsh Demographic Service
WHO	World Health Organization
WIMD	Welsh Index of Multiple Deprivation

Plain English summary

What was the question?

Living in cold homes can be harmful to people's mental and physical health. In this study, we wanted to see whether or not improving the energy efficiency of homes, through measures such as wall insulation and new heating systems, could improve the health of people living in them.

What did we do?

We analysed the health records of people who received energy efficiency measures to assess changes in emergency admissions to hospital over time. We also interviewed residents before and after they received energy efficiency measures, and monitored the homes of a smaller number of households.

What did we find?

We found that energy efficiency measures contributed to people's general well-being by making homes warmer, and easier and cheaper to heat to a comfortable level. Warmer homes also made people feel less socially isolated. However, we found no evidence that energy efficiency measures improved people's mental and physical health.

What does this mean?

Improving the energy efficiency of homes provides social and economic benefits to people living in them. However, area-based programmes may not improve chronic health conditions, reduce the number of hospital visits or reduce costs for the health service.

Scientific summary

Background

Research suggests that living in fuel poverty and cold homes contributes to poor physical and mental health, and that interventions targeted at those living in poor-quality housing may lead to health improvements. Most studies thus far have focused on a limited number of health outcomes and have excluded psychosocial outcomes that may be part of pathways to health. Furthermore, anonymous data linkage of routinely collected health-service utilisation data has not been used before to examine the impact of energy efficiency improvements. The overall aim of the study was to determine the health and psychosocial impact of energy performance investments in low-income areas through a mixed-methods programme of work. The research focused on a major investment programme that took place in Wales in two separate phases between 2010 and 2015.

Objectives

The project aimed to determine the impact of an energy performance investment programme on (1) hospital admissions for cardiorespiratory conditions, (2) the prevalence of respiratory symptoms and mental health status of residents, (3) internal hydrothermal conditions and household energy use and (4) psychosocial outcomes that may be part of pathways to health. It also aimed to (5) estimate the costs and consequences of the energy performance investments to the health system and (6) undertake a cost–utility analysis (CUA) of these investments.

Methods

The project used multiple methods to evaluate the health impact of energy performance investments in low-income neighbourhoods, including data linkage, a community-based field study, a household monitoring study and an economic evaluation. The project included a number of qualitative focus groups as part of the resident engagement.

Data linkage study

Data linkage was used to undertake a longitudinal analysis of residents living within homes who received energy efficiency improvements in 2010 and 2011. Routinely collected data were anonymously linked to intervention records provided by local authorities (LAs) and social housing providers who delivered the schemes. Counts of emergency hospital admissions from 2005 to 2014 were extracted from the Patient Episode Database for Wales. Primary health outcomes were obtained for baseline and follow-up periods for 25,908 people residing within the intervention homes ($n = 4968$) as well as for two comparator populations: 48,261 people living in 12,350 social homes and 524,596 people living in 118,982 homes in the top 10% of deprived areas according to the Welsh Index of Multiple Deprivation. Mixed multilevel linear regression models were constructed to assess associations of change in cardiorespiratory emergency admissions before and after the intervention, adjusting for potential confounders.

Community-based study

The community-based study had a quasi-experimental, controlled before-and-after design (intervention, $n = 364$; control, $n = 418$) to investigate the short-term health and psychosocial impacts of the intervention. The community-based study specifically focused on schemes that were delivered in 2014 and 2015. Matched control areas were identified with the assistance of LAs. Data were collected through self-completion questionnaires in the winters before and after installation of energy efficiency measures, and at the same time in the matched control areas. The primary health outcomes were changes in mental health status and self-reported respiratory and asthma symptoms. Secondary health outcomes were changes in self-reported health-related quality of life (and subjective well-being). Secondary psychosocial outcomes included changes in fuel poverty status, financial difficulties and stress, food security, social interaction, thermal satisfaction and reported housing conditions. Data were analysed using a multilevel modelling, repeated measures approach, with measurement occasions nested within the intervention or control individuals.

Household monitoring study

The household monitoring study used a quasi-experimental, controlled before-and-after design consisting of high-resolution long-term monitoring of indoor air temperatures and relative humidity (RH) levels in two consecutive heating seasons, before and after energy efficiency improvements, and controlled for external hydrothermal conditions. The final data set consisted of 99 households (intervention, $n = 50$; control, $n = 49$) at baseline and 88 households (intervention, $n = 48$; control, $n = 40$) at follow-up that were observed for a minimum of 4 weeks in the two periods. The main outcomes of the household monitoring study were average indoor air temperature and RH at different times of the day and in different rooms within the home, and the average daily duration and cumulative substandard internal hydrothermal conditions (i.e. the duration and time intensity integral of indoor temperatures of < 18 °C or < 16 °C and RH levels of > 60%). The final data consisting of 15,771 data points were analysed by constructing a series of controlled multilevel interrupted time series regression models.

Economic evaluation

The main health economic evaluation involved a cost–consequence analysis (CCA) and a CUA utilising the health outcomes from the data linkage study and utility values from the literature. The CCA considered resource use and cost impacts of the intervention associated with secondary care. The health consequences for the CCA were changes in emergency hospital admissions for cardiovascular and respiratory conditions. The CUA was undertaken using utility values for the relevant chronic obstructive pulmonary disease (COPD) health states for people who experienced an emergency hospital admission for an exacerbation. Each adverse health event resulting in an emergency hospital admission had a survival curve mapped from these utility values across the study period. This approach incorporated an initial impact of the event on utility and a time-variable component, using the area under the curve approach to generate an incremental cost-effectiveness ratio (ICER). Negative binomial regression models were constructed for both the CCA and CUA.

Resident engagement

A reconvened focus group study was conducted as part of the wider resident engagement of the project. Three focus groups were held with residents before ($n = 28$) and then again after ($n = 22$) they received energy efficiency improvements under the intervention programme. The focus groups were conducted to obtain a better understanding of the views and experiences of residents living in energy-inefficient houses, and to explore the ways in which the intervention may have improved those experiences. The recorded and transcribed discussions were analysed according to the themes of health and well-being, thermal comfort, staying warm and the use of living space, fuel poverty and experiences with the intervention programme.

Results

Data linkage study

The data linkage study assessed the impact of the intervention on health service use. No significant effect was found on our primary outcome of cardiorespiratory emergency hospital admissions [adjusted results: Δ 0.0011, 95% confidence interval (CI) –0.0103 to 0.0125]. No association was found with admissions for respiratory-related conditions (Δ 0.0042, 95% CI –0.0046 to 0.131), COPD (Δ 0.0002, 95% CI –0.0025 to 0.0022) or cardiovascular conditions (Δ 0.0014, 95% CI –0.0083 to 0.0055). We subsequently analysed the same outcomes for people aged ≥ 60 years. No evidence was found that the intervention had a significant effect on outcomes, with the exception of cardiovascular-related emergency hospital admissions. A significant increase was found in cardiovascular-related emergency hospital admissions after adjusting for potential confounders (Δ 0.0273, 95% CI 0.0068 to 0.0479).

Community-based study

The community-based study found no evidence that investments in energy efficiency improve respiratory or mental health in the short term. It was found that, after controlling for sex, age, housing benefits, household income and smoking status, investments were not associated with improvements in Mental Health Composite Scale scores [unstandardised regression coefficient (B) 0.00, 95% CI –1.60 to 1.60], self-reported respiratory symptoms (B –0.14, 95% CI –0.54 to 0.26) or self-reported asthma symptoms (B –0.14, 95% CI –0.54 to 0.25). Furthermore, no evidence was found that they provide physical health benefits in the short-term, as indicated by Short Form questionnaire-12 items Physical Health Composite Scale scores (B 0.38, 95% CI –0.34 to 2.29). The study found that, compared with participants in control households, participants who received the intervention reported improved subjective well-being (B 0.38, 95% CI 0.12 to 0.65; $p = 0.004$) as well as fewer financial difficulties (B –0.15, 95% CI –0.25 to –0.05; $p = 0.003$), higher thermal satisfaction [odds ratio (OR) 3.83, 95% CI 2.40 to 5.90] and higher satisfaction with the improvement of their homes (OR 3.87, 95% CI 2.51 to 5.96). Participants in the intervention group were also less reluctant to invite friends or family to their homes after they received the energy efficiency measures (OR 0.32, 95% CI 0.13 to 0.77; $p = 0.012$). The results were similar before and after controlling for socioeconomic covariates selected a priori.

Household monitoring study

The study found that the intervention raised indoor air temperature by an average of 0.84 °C (95% CI 0.64 to 1.04 °C), whereas daily gas usage dropped by an average of 37%. Similar increases were observed across different heating demand conditions. The largest changes were observed in the evening (1.17 °C, 95% CI 0.94 to 1.39 °C) and at night (1.01 °C, 95% CI 0.79 to 1.24 °C), and in the living room (1.01 °C, 95% CI 0.78 to 1.23 °C) and bedroom (1.28 °C, 95% CI 1.04 to 1.52 °C), suggesting that the biggest increases were for spaces that were in use. The intervention measures were not equally effective: external wall insulation (1.12 °C, 95% CI 0.69 to 1.55 °C) and connection to the gas mains network (0.69 °C, 95% CI 0.29 to 1.09 °C) significantly increased indoor air temperatures; windows and doors (–0.02 °C, 95% CI –0.39 to 0.35 °C) or a new heating system (–0.19 °C, 95% CI –0.69 to 1.09 °C) did not.

Overall, the intervention did not increase indoor RH levels (0.04% RH, 95% CI –0.74% to 0.83% RH), although some individual measures did. Both a gas network connection (3.86% RH, 95% CI 2.31% to 5.41% RH) and the installation of new windows and doors (5.15% RH, 95% CI 3.73% to 6.57% RH) increased indoor RH levels. External wall insulation (–0.60% RH, 95% CI –2.26% to 1.06% RH) and installation of boilers or heating systems (–1.59% RH, 95% CI –3.52% to 0.34% RH) did not change indoor RH levels.

The intervention reduced the cumulative amount of indoor air temperature of < 18°C (3.62 °C·hour, 95% CI –6.95 to –0.30 °C·hour) and < 16 °C (4.20 °C·hour, 95% CI –6.64 to –1.76 °C·hour) and the average daily duration (1.14 hours, 95% CI –2.00 to –0.28 hours) and cumulative amount (19.32% RH·hour, 95% CI –29.68% to –8.96% RH·hour) of indoor RH levels of > 60%.

Economic evaluation

In the CCA, the disaggregated outcomes derived from the intervention were balanced against the costs. The intervention resulted in no meaningful change in emergency admissions from the pre-intervention period. When undertaking the CUA, exploring the impact on quality-adjusted life-years (QALYs) of the change in rate of emergency admissions for people with COPD, the small non-significant change in emergency admissions for COPD is overpowered by the cost of the intervention, and the ICER of > £10M per QALY gained is not cost-effective using commonly accepted norms, even with discounted costs and benefits to present-day values in line with best practice.

Resident engagement

The reconvened focus group study found that living in a cold home was generally viewed as depressing, stressful and detrimental to both mental and physical health. According to residents, the energy efficiency work made great improvements to their comfort and indoor temperatures, opened up spaces within the home and substantially reduced their heating bills. This not only helped to relieve financial stress and fuel poverty but made them less reluctant to invite others to their homes. Residents felt that physical health improvements following the work were secondary to improvements in thermal comfort and their ability to invite friends and family into their homes. Although the improvements were, for the most part, positively received by residents, and clearly fulfilled the goal of the programme to make homes warmer and cheaper to heat, the focus group study identified the need to consider community engagement and communication to involve residents more closely in the decision-making and delivery of affordable warmth programmes.

Discussion

The research found no evidence of demonstrable effects of the intervention on health or health service utilisation in the short and medium term. As a result, the health economic analysis concluded that the intervention may not be considered cost-effective in a traditional sense. These findings are in line with a recent systematic review that concluded that area-based programmes are less likely to produce measurable health improvements than those that specifically target at-risk populations. It is nevertheless surprising that no apparent effects were found, given that the intervention programme targeted low-income neighbourhoods with poor-quality housing where residents were consequently at a higher risk of living in fuel poverty.

That does not, however, mean that the intervention is without substantial merit. The main purpose of the intervention was to deliver affordable warmth, alleviate fuel poverty and reduce CO_2 (carbon dioxide) emissions. The research found clear evidence that this was achieved. The research showed that the intervention provided a wide range of benefits to residents. Public health decision-makers and budget holders may feel that these improvements alone are worth the investments. The lack of association with emergency hospital admissions may indicate that benefits do not show up in hospital statistics; future evaluations should perhaps focus on less-severe conditions that may be treated in primary care settings.

Strengths of our study include the use of multiple methods to explore the health impacts of a government-led energy efficiency programme. Together, the methods provide a more comprehensive evaluation of the intervention than could have been delivered by a single method alone. For example, although the community-based field study was subject to a number of biases, it was able to cover a wider range of subjective psychosocial outcomes and, although routine data may lack detail regarding subjective health experiences, it minimises selection and attrition biases with near-complete follow-up. Household monitoring showed objective changes in internal hydrothermal conditions, and focus groups provided an in-depth exploration of how residents experienced the intervention. Limitations included a lack of randomisation and, as with all observational studies, the potential for unmeasured confounding remains. Data quality was also an issue. The effort required to validate and clean intervention records received from data providers was considerable, and there was missing data for many intervention homes.

Future housing improvement programmes should build in health and economic evaluation components from conception with longer follow-ups; strategies may then be developed to increase response and retention rates. A stepped wedge randomisation in the delivery of a programme, together with improved reporting standards regarding the timing, delivery and costs, would provide more-robust evidence regarding health and psychosocial benefits. This research has shown that the use of multiple methods is preferable over single-method evaluations, and that there is a need to directly compare area-based with more-targeted affordable warmth programmes. Finally, process evaluation should become an essential part of testing complex housing-based interventions.

Funding

Funding for this study was provided by the Public Health Research programme of the National Institute for Health Research.

Chapter 1 Background and aims

Introduction

It has long been recognised that poor housing conditions can have a detrimental impact on health.[1] Early evidence, dating back to the late nineteenth century, suggested a link between cold and damp housing and poor physical health.[2] At around that same time, cold and damp living conditions were also linked to poor mental health.[3] However, it has only been within the past 10–20 years that empirical studies have drawn strong links between housing quality and health.[4]

The recent literature on housing and health has shown that low indoor air temperatures are associated with increased risk of stroke, heart attack and respiratory illness in temperate climates, as well as with common mental disorders.[5] Countries with the lowest thermal efficiency standards have the highest levels of excess winter mortality and people living in the least energy-efficient housing are at higher risk of death than those living in more energy-efficient homes.[6–8] Excess winter deaths are almost three times as high in cold homes as in warm homes.[6,8] The World Health Organization (WHO) estimates that 40% of excess winter deaths are caused by living in a cold home.[9]

Excess winter mortality is thought to be linked predominantly to circulatory and respiratory conditions.[6,10–12] Prolonged exposure to low temperatures can have an impact on blood pressure and blood chemistry[13–15] as well as blood viscosity and vasoconstriction.[16,17] Low temperatures can also suppress the function of the immune system,[18] raising the risk of respiratory infection among vulnerable groups.[10] Living in low temperatures has been linked to a higher prevalence of respiratory infections and hospital admissions among the elderly,[19–21] as well as to increased severity and frequency of asthmatic symptoms in children.[4] Low indoor temperatures can also encourage the development of damp and mould in the home,[22] which are known risk factors for respiratory disease in adults[23–26] and children.[22,27]

In addition to links with cardiorespiratory conditions and excess winter mortality, living in cold and damp homes has been associated with negative impacts on mental health.[6,28,29] Living in cold and damp homes may be stressful for a number of reasons, including stigmatisation, financial worries, a lack of control over the living environment and prolonged thermal discomfort.[6,30–33] Harris *et al.*[29] found that people with common mental disorders are also more likely to experience different aspects of fuel-related poverty; living in a cold home, the presence of mould and using less fuel than needed because of worries about costs were all found to be associated with common mental disorders, even after adjusting for financial and socioeconomic factors. Living in a cold home may also have an impact on social interactions:[31] it may make people reluctant to invite others into their homes and it may prevent them from going out as a result of financial concerns and fears of returning to a cold home.[4,6,34] Social isolation can increase the risk of depression and coronary heart disease, thereby having the potential to exacerbate the negative effects of living in a cold home.[35]

Those affected by fuel poverty often adopt various strategies to deal with their financial circumstances.[36] Households may reduce fuel usage through rationing, or self-disconnect where pre-payment meters are present.[37–41] Studies have found that fuel-poor households reduce lighting usage or limit their consumption of hot water.[42–44] Others may trade warmth for other essentials, such as food.[34,45,46] This phenomenon has become known as the 'heat-or-eat' dilemma.[45,46] When heating is prioritised, disposable income and food choices become restricted, affecting both the quantity and quality of foods purchased and consumed.[34,36] Households may also choose not to adopt coping strategies and instead continue their normal spending patterns, which can lead to arrears in fuel payments and the accumulation of debt.[47]

Health impacts of energy efficiency improvements

It is clear that housing quality is associated with a range of health and psychosocial outcomes. However, most evidence is derived from cross-sectional research. This is problematic, as those living in poor housing are most likely to be socioeconomically deprived and have long-standing illness. The causal pathways between poor housing and poor health can therefore be determined only by intervention studies. In a systematic review of the literature, Thomson *et al.*[48] identified 39 housing intervention studies that reported quantitative or qualitative data on health and associated socioeconomic outcomes. Of these, 19 evaluated affordable warmth and energy efficiency improvements relevant to modern-day housing conditions (i.e. post 1985), including five randomised controlled trials, five controlled before-and-after studies and five uncontrolled or retrospective studies. Thomson *et al.*[48] concluded that affordable warmth and energy efficiency measures may produce improvements in general health, respiratory health and mental health, but that interventions targeting at-risk populations (i.e. those with inadequate warmth and pre-existing conditions) are more likely to be successful than general, area-based, programmes.

Two randomised controlled studies conducted in New Zealand by Howden-Chapman *et al.*[49,50] found that improving energy efficiency through insulation improved respiratory health in both children and adults, and that improved non-polluting heating systems reduced symptoms of pre-existing asthma in children. In the case of asthmatic children, benefits could be linked to the rise in temperature in both the living room and the child's bedroom as well as lower levels of nitrogen dioxide.[50] In a randomised trial, Barton *et al.*[51] found substantial reductions in non-asthma-related chest problems and the number of reported asthma symptoms among the intervention group for both adults and children.

Energy efficiency measures also appear to be beneficial for mental health, although studies have shown mixed results.[48] Howden-Chapman *et al.*[49] found significant improvements in three subscales of the Short Form questionnaire-36 items (SF-36), namely in the 'happiness', 'vitality' and 'role emotional' scales. However, the authors did not report the overall results for the Mental Health Composite Scale (MCS). Barton *et al.*[51] found no significant differences between the intervention and control groups regarding the mental health subscales of either the SF-36 or the General Health Questionnaire-12 items. Braubach *et al.*[52] similarly found non-significant differences in self-reported depression between the intervention and control groups. The authors noted that the follow-up questionnaire was distributed within a few months of the intervention, and that detailed analysis of the data had not been undertaken in order to better understand the impacts of both time and socioeconomic variables such as age. Shortt and Rugkåsa[53] reported that stress and mental illness increased significantly in the control group but showed a non-significant decrease in the intervention group.

Psychosocial impacts of energy efficiency improvements

Studies examining the impacts of energy efficiency improvement programmes have thus far focused primarily on a limited number of health outcomes. Few large-scale controlled studies have been undertaken to understand the wider psychosocial impacts of such programmes.[48] The predominantly qualitative literature suggests two inter-related pathways that may link energy efficiency investments to better mental and physical health.[54–56] The first pathway is the process in which energy efficiency improvements to homes lead to better thermal living conditions, through improved indoor air temperature and decreased humidity, both of which contribute to reduced damp-related housing problems.[57] Warmer, drier homes can contribute to improved respiratory health, and also better mental health through improved thermal satisfaction,[58] expanded living space and reduced social interactions.[59] The second pathway is the process in which energy efficiency measures lead to improved well-being by making heating more affordable.[6] Reduced spending on heating bills alleviates financial stress and fuel poverty among low-income households,[60,61] and helps to free financial resources for better food security[45,46] and reduced social isolation.[31] Social isolation may reduce further because people may become less reluctant to invite people into their homes with improved internal conditions.[62]

Energy efficiency improvements and internal conditions

The evidence of the impact of energy efficiency improvements on indoor conditions is limited. Overall, based on available studies that have been conducted so far, energy efficiency measures produce modest increases in mean indoor air temperatures and small increases in mean humidity levels.[48] The Warm Front study group reported mean living room temperature increases of 0.58 °C for insulation and 1.36 °C for heating measures, and mean bedroom temperature changes of 1.14 °C for insulation and 1.98 °C for heating measures, with greater changes for dwellings that received both heating and insulation measures (1.52 °C and 2.31 °C for living room and bedroom, respectively).[63] Howden-Chapman *et al.*[49] reported an average increase in bedroom temperature of 0.50 °C and an average decrease in humidity level of 2.3% relative humidity (RH). The Glasgow Warm Homes Study[60] reported increases in mean temperatures of > 2 °C in the living room and almost 3 °C in the bedroom, but no significant changes in RH levels.

More recently, there have been suggestions that increasing the energy efficiency of a home could have detrimental effects on people's health.[64] Reduced ventilation through insulation and draughtproofing may increase RH levels[65] and, as a result, promote mould growth.[66,67] Indeed, low ventilation rates and homes with greater energy efficiency are associated with asthma and allergic symptoms in children.[68–70]

The evidence on energy efficiency investments and indoor conditions, however, is scant. Most research in the area has been cross-sectional[71] and has not included control households,[72] spot measurements[8] or short-term monitoring.[60] As previously observed by Oreszczyn *et al.*,[68] most studies did not correct for external conditions during the monitoring periods. Evidence for increases in RH levels has been anecdotal or inferred from cross-sectional studies only. Raising indoor air temperatures through better insulation should reduce RH levels unless there is inadequate ventilation.[64] Overall, based on the available studies that have been conducted to date, it appears that energy efficiency investments produce modest increases in mean indoor air temperatures and small increases in mean humidity levels.[48]

Conclusion

The literature review presented here shows that housing improvements that increase the energy efficiency of homes have the potential to improve the health of residents, in particular if they are targeting at-risk populations with inadequate warmth and pre-existing conditions.[48] However, most research involves observational studies using self-completion questionnaires. Field studies that rely on survey methodologies are vulnerable to biases from low response rates, attrition and self-reporting. Anonymous data linkage of routinely collected health data, which is less vulnerable to such biases, has not, to our knowledge, been used before to examine the impact of energy efficiency improvements (see *Chapter 2*).[73] In addition, less is known about the wider psychosocial impact of energy efficiency improvements. There is a distinct lack of good-quality quantitative evidence regarding the pathways and processes that may contribute to better health in the longer term (see *Chapter 3*).[54] Moreover, only a limited number of household monitoring studies have been conducted to examine the impacts of energy efficiency improvements on indoor hydrothermal conditions. Research in this area has been marred by a number of methodological and analytical issues and has relied on studies with relatively small sample sizes (see *Chapter 4*). Finally, economic evaluations have rarely been carried out alongside housing improvement programmes to assess their health-related quality of life and economic impacts.[74] Health economic evaluations are essential to inform policy-makers about the value for money of energy efficiency investments (see *Chapter 5*).

Aims of the project

In this study, we make use of a major energy performance investment programme (referred to hereafter as 'the intervention') that took place in Wales in two separate phases between 2010 and 2015. Arbed is, along with Nest, part of the Welsh Government Warm Homes programme. It was established to bring environmental, social and economic benefits to Wales through co-ordinated investments in the energy performance of homes located in low-income areas (see *The intervention*). Our project aimed to examine whether or not the investments provided additional benefits in terms of improved health of residents.

More specifically, the project aimed to determine the impact of the intervention on (1) hospital admissions for cardiorespiratory conditions, (2) the prevalence of self-reported respiratory symptoms and mental health status of residents, (3) internal hydrothermal conditions and household energy use and (4) psychosocial outcomes that may be part of the pathways to health. It also aimed to (5) estimate the costs and consequences of the energy performance investments to the health system and (6) undertake a cost–utility analysis (CUA) of these investments.

The intervention

The Welsh Government tries to address fuel poverty through demand-led and area-based elements.[75] The Welsh Government Warm Homes programme provides funding for energy efficiency improvements to low income households on demand (Nest) and to those living in deprived communities across Wales (Arbed). The research reported here focuses on the area-based Arbed (meaning 'save' in Welsh) programme.

The Arbed energy performance investment programme was set up in 2009 by the Welsh Government to bring environmental, social and economic benefits to Wales. The programme was designed to improve the energy efficiency of existing homes in low-income areas and aimed to (1) reduce the number of households living in fuel poverty, (2) create jobs and regeneration in Wales and (3) combat climate change by reducing greenhouse gas emissions. The programme consisted of two phases. The first phase (Arbed 1) took place in 2010 and 2011. The second phase (Arbed 2) took place between 2012 and 2015.

Both phases of the intervention programme were Wales-wide, with work prioritised within the Welsh Government's seven Strategic Regeneration Areas of the Heads of the Valleys, Môn a Menai, North Wales Coast, Western Valleys, Swansea, Aberystwyth and Barry. Many of these schemes were in old slate- and coal-mining areas and in a number of deprived urban areas.

The first phase of the intervention programme focused specifically on energy efficiency improvements to homes in low-income areas as identified by social housing providers. A total of £36.6M was invested by the Welsh Government, with an additional £32M leveraged by energy suppliers, housing associations and local councils.[76] This phase consisted of 28 schemes across 18 local authorities (LAs) in Wales, and helped to improve the energy performance of around 7500 homes. It mainly improved social housing (79%), but also a number of privately rented and owner-occupied houses (21%). The programme funded retrofit measures such as solid wall insulation (> 4000 homes), solar panels (> 1800 homes), solar hot water (> 1080 homes) and heat pumps (> 100 homes). Leveraged funds from energy providers and social housing providers were used to enable homes to receive additional measures, such as boiler upgrades and replacements, window upgrades, roof extensions, structural work and energy saving advice.[77]

The second phase of the intervention programme was co-funded by the Welsh Government and the European Regional Development Fund (ERDF), and had an overall budget of £45M. This comprised £33M of ERDF funding and a further £12M from the Welsh Government. The second phase consisted of 32 schemes and helped to improve the energy performance of > 4800 homes. In contrast to the first phase, which primarily focused on social housing, the second phase of the intervention programme specifically targeted mixed-tenure, low-income neighbourhoods that had a high number of hard-to-heat, hard-to-treat homes, and when, as a result, people were at a higher risk of living in fuel poverty. 'Hard-to-heat, hard-to-treat' is a term used for low-energy-performance dwellings that, for whatever reason, cannot accommodate staple or cost-effective fabric energy efficiency measures.[78] Typical energy efficiency measures included external wall insulation, heating system upgrades (including gas combination boilers, heating controls and central heating systems), voltage optimisers and connecting communities to the gas mains network.

Both phases of the intervention programme aimed to boost local economies by using local businesses to manufacture, supply and install as many of the measures as possible and provide training and employment opportunities for local workers through a tendering process to recruit contractors and subcontractors.[77] There were, however, a number of differences in the delivery of the programme between the two phases.

The first phase of the programme was managed by LAs and social housing providers themselves, and delivered through contractors and subcontractors. The LAs and social housing providers submitted proposed schemes to the Welsh Government, which decided which were to be funded. The second phase of the programme was managed by two scheme managers: Melin Homes, a housing association, managed schemes in South Wales; and Wilmott Dixon, a private construction company, managed schemes in North and Mid Wales.

Local authorities were invited by the Welsh Government to propose schemes based on scoring criteria using proxies to identify areas at fuel poverty risk, and once a scheme was approved this was passed on to the two scheme managers for work to commence. The selected areas were visited by surveyors to determine the most appropriate and cost-effective measures for the schemes. Contractors were used to deliver the improvement work, overseen by the two scheme managers. The areas were subsequently visited by representatives and community events were set up to encourage households to sign up for the improvement programme.

For both phases, depending on the measures chosen for each home, residents would have been in contact with representatives of the scheme managers who recruited householders to the scheme, chose suitable measures for the property and allocated selected contractors and businesses to undertake the work. Each household would have been in contact with a variety of stakeholders from start to finish, including, but not exclusively, scheme managers, community engagement teams, project managers and contractors including building surveyors, scaffolders, insulation installers and central heating engineers. The process from initial contact with householders through community engagement to finishing the whole scheme could take up to a year or, in a few cases in which the work was delayed, longer.

A TIDieR (Template for Intervention Description and Replication) checklist is provided in *Appendix 6*.

The project

The project provided a multimethod investigation of the health impacts of energy performance investments in low-income neighbourhoods through four interlinked studies. The project comprised the use of the Secure Anonymised Information Linkage (SAIL) databank, a community-based field study, a household monitoring study and an economic evaluation. In addition, the project included a number of resident engagement activities.

The SAIL databank was used to retrospectively evaluate the first phase of the intervention programme. SAIL is an ethically approved tool, developed and hosted by Swansea University, that ensures that individuals remain anonymous and retain the ability to make links between different data sets.[79] Intervention records of the first phase of the programme were anonymously linked to individual health records to determine the impacts of the intervention on hospital admissions for cardiorespiratory conditions. Data generated in this work package were used in the economic evaluation to calculate the cost savings of the investments to the health system. Findings of the data linkage study are reported in *Chapter 2*.

A community-based study was set up to evaluate the second phase of the intervention programme. The field study aimed to determine the impact of the intervention on the prevalence of respiratory conditions and mental health status of residents as well as on psychosocial outcomes that may be part of pathways to health. The findings of the community-based study are reported in *Chapter 3*.

Chapter 4 presents the results from the household monitoring study. The household monitoring study was conducted to determine the impact of the intervention on internal hydrothermal conditions. It further provided evidence on whether or not the intervention resulted in lower household energy use and an expansion of living space.[61] Gas and electricity meter readings were taken during the installation and collection visits to determine the impacts of the programme on household energy use.

The fourth study, reported in *Chapter 5*, presents the results of an economic evaluation of the energy performance investments. Data from both the data linkage and community-based studies were used to determine whether or not the investments improved public health over and above the other intended benefits of the programme. A cost–consequences analysis (CCA) compared the costs of delivering the intervention to the cost savings as a result of reduced health service use. A CUA estimated the benefits of the programme as a result of improving the quality of life of residents of low-income neighbourhoods.

Resident engagement

A reconvened focus group study was conducted as part of the wider resident engagement of the research project. Three focus groups were held with residents before and after they received energy efficiency improvements in the second phase of the intervention programme. The aims of the focus groups were to obtain a better understanding of the views and experiences of residents living in energy-inefficient (hard-to-heat, hard-to-treat) houses, and the ways in which the programme may have changed those experiences. The protocol of the focus group discussions can be found in *Appendix 1*. The results of the reconvened focus groups are summarised in *Appendix 2*, with the consolidated criteria for reporting qualitative research (COREQ) checklist provided in *Appendix 3*. A number of focus group participants were subsequently invited to form a resident panel, which met on three occasions throughout the project and contributed to the biannual study steering committee (SSC) meetings. The resident panel provided advice on how to disseminate the findings at the end of the project. Findings of the community-based and household monitoring studies were disseminated through an easy-to-understand key findings brochure (see *Appendix 4*) and three community dissemination meetings. *Appendix 5* shows the pull-up banner that was used in meetings.

Chapter 2 The data linkage study

Introduction

This chapter follows the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) reporting guidelines for observational study designs.[81]

Background

This chapter describes the retrospective evaluation of the first phase of the intervention programme that ran in 2010 and 2011. The evaluation used anonymised, routinely collected health records held within the SAIL databank.[82,83] Intervention records of the first phase of the intervention programme were anonymously linked to individual health records to determine the impact of the intervention on hospital admissions for cardiorespiratory conditions and a number of secondary outcomes. The study used data on emergency hospital admissions for cardiovascular and respiratory conditions held in the Patient Episode Database for Wales (PEDW), which contains all hospital records for people treated at hospitals in Wales.

Governance approval (reference SAIL0273) for this research was received from the independent Information Governance Review Panel (IGRP) in March 2014. Membership of the IGRP consists of senior representatives from the British Medical Association, National Research Ethics Service, Public Health Wales, NHS Wales Informatics Service (NWIS) and the SAIL Consumer Panel.

Objectives

The overall aim of this study was to examine the long-term impact on health-care utilisation of energy efficiency investments. In particular, the study aimed to establish the change in the primary outcome of emergency hospital admissions for cardiovascular and respiratory conditions combined for people of all ages following the intervention.

The study had four secondary outcomes:

1. Change in emergency hospital admissions for cardiovascular conditions for people aged ≥ 60 years, and for people of all ages, following the intervention.
2. Change in emergency hospital admissions for respiratory conditions for people aged ≥ 60 years, and for people of all ages, following the intervention.
3. Change in emergency hospital admissions for chronic obstructive pulmonary disease (COPD) conditions for people aged ≥ 60 years, and for people of all ages, following the intervention.
4. Change in excess hospital admissions during the winter months for people aged ≥ 60 years, and for people of all ages, following the intervention.

Methods

Study design

The data linkage study consisted of a quasi-experimental analysis of residents living within homes having undergone energy efficiency improvements. The research utilised individual-level health data held within the SAIL databank anonymously linked with property-level intervention data provided by the housing scheme operators. Intervention and comparator groups were created through retrospective analysis of SAIL data from interventions carried out in 2010 and 2011. Health outcomes were obtained for the entire period that residents were present within the homes.

Setting

In the first phase of the intervention programme, a total of £68M was invested, including leveraged funding. The programme had the joint aims of delivering affordable warmth, alleviating fuel poverty, reducing CO_2 (carbon dioxide) emissions and boosting economic development and regeneration in Wales. LAs and registered social landlords (RSLs) submitted project plans to improve the thermal efficiency of homes in Wales. The majority of homes were social homes. Work for 28 schemes was carried out in 2010 and 2011; it covered a wide geographical area across Wales and is referred to as the intervention study group (*Figure 1*).

Participants

Intervention home addresses and measures were collated and imported into the SAIL databank through a split file method designed to maintain the anonymity of people living in the properties.[83] The first part of the split file containing addresses and unique property reference numbers was sent to a trusted third party, the NWISs, and replaced with a Residential Anonymous Linking Field (RALF).[79,84] The RALFs were securely transferred to the SAIL databank with a further level of encryption added by the SAIL technical team prior to being made available to researchers under controlled data access agreements. The second part of the split file contained intervention data with no identifiable data. This file was issued directly to SAIL and the two files were re-linked in the SAIL databank after removing the address data.

A similar split file method was followed to create anonymous (individual) linking fields (ALFs) for each person in the SAIL databank.[82] The first part of the split file containing identifiable data (including names and dates of birth) was issued to NWIS and replaced with the ALF prior to a further level of encryption

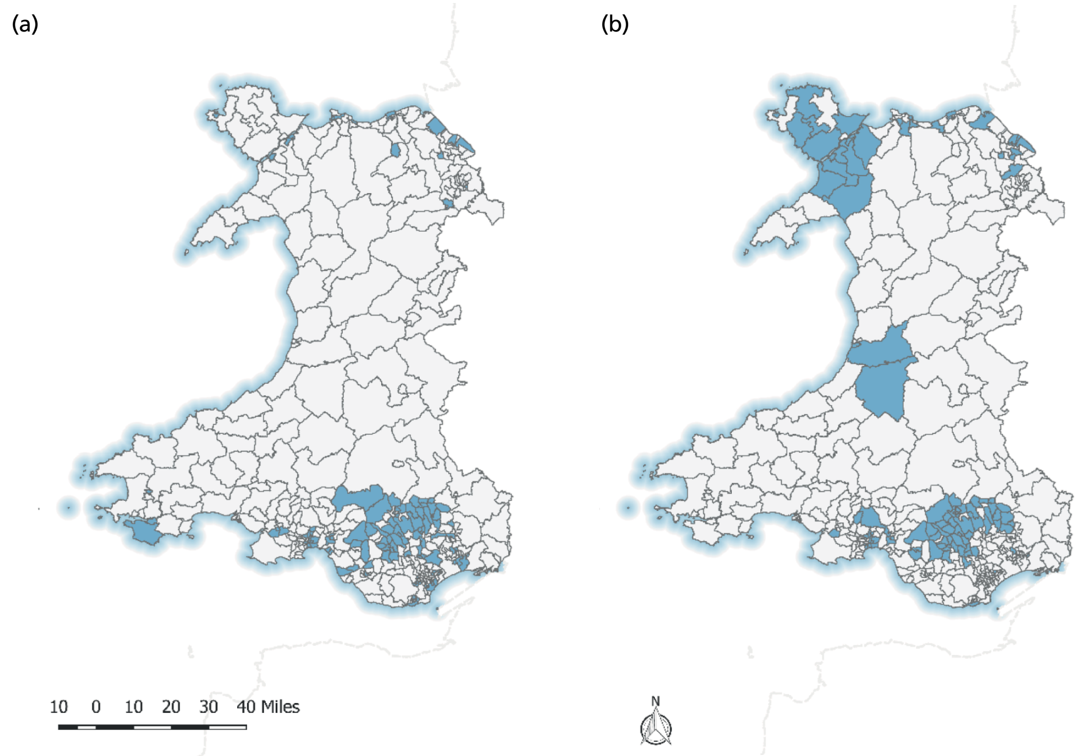

FIGURE 1 Locations (in blue) of (a) the top 10% of deprived areas; and (b) the intervention areas.

added prior to researcher data access. Data relating to health-care utilisation and other administrative data, as supplied to SAIL in the second half of the split file process, was relinked in the SAIL databank, ensuring that anonymity was maintained.

The encrypted property-level (RALF) data is linked to individual-level (ALF) data in the Welsh Demographic Service (WDS) data set, which contains details of every person registered with a general practitioner (GP) in Wales along with their address histories and are based on addresses registered with a GP. We extracted people living within intervention properties according to our study inclusion criteria: a person needed to be resident in the property for ≥ 60 days during the study period (2005–14). People were retained in the study if they were living in the property during the intervention, moved out pre intervention or moved in post intervention. We used multilevel modelling methods that take into account unbalanced data; people did not need to be in the study for both the before and after phases.

Obtaining individual ALFs registered as occupants of the houses in our study allowed us to link to individual-level health data and mortality records without ever seeing personal, identifiable information or low-level geographical information.

The same method was applied for two groups of comparator homes. Social housing addresses from a Welsh LA were provided for the first comparator group. The second comparator group comprised all homes located in the top 10% of deprived lower super output areas (LSOAs) in Wales, based on the 2011 Welsh Index of Multiple Deprivation (WIMD) income domain.

Data sources

Address and intervention data were collected through contacting and requesting standard information from 28 LAs and RSLs. The supplied information was collated into a master data set by researchers at Cardiff University who had no access to SAIL data. This was important to maintain data privacy so the SAIL data analyst did not have access to both the identifiable address data and the anonymised version. The data were subsequently imported into SAIL through a split file method by our trusted third-party supplier, as described previously. The procedure ensured that the anonymity of homes and, thus, residents was maintained. Intervention dates were received in SAIL in a non-standard, non-codified manner. Data cleansing was carried out within the SAIL databank to reformat intervention dates and descriptions with a number of rules applied, described in *Participants*.

A Welsh LA provided all addresses of their social housing stock, which were transferred into SAIL to form the first comparator group. A second comparator group was created by selecting LSOAs forming the top 10% of deprived areas in Wales from the WIMD 2011 income domain, then linked to homes within the WDS containing addresses based on GP address registrations.

Homes from the three groups were linked to individual residence records across the study period within WDS, providing start and end dates of residence.

The WIMD 2011 was used to obtain income-related deprivation data at the LSOA level. The urban/rural classification was obtained using the Office for National Statistics (ONS) classification. Person-level demographic data, including age and sex, were obtained from the WDS data set. When relevant, the date of death was obtained by linking the ONS death registration data to the WDS data set. When a conflict existed, the ONS deaths data set was used as the primary data source.

Data sets were set up in a panel design containing one record for each person within a home for each monthly period in which they were present in the study. Study entry dates were defined as the earliest date selected for either the date of moving into the property or the start of the study period (January 2005). Study exit dates were defined as the latest date selected for the month of death, date of moving out of the home or the end of the study period (December 2014). Variables such as comorbidity, outcomes and age were updated to be reflective of the specific period within the study.

Variables

Records of emergency hospital admissions for relevant conditions from 2005 to 2014 were extracted from the PEDW data set, which contains records of all inpatient and day case episodes of care undertaken in NHS Wales plus data on Welsh residents treated in other UK nations (primarily England). NWIS provides SAIL with a de-identified version of PEDW via monthly electronic feeds.

We selected the first episode from each case of emergency admissions, representing continuous periods of inpatient care for a single patient, for diseases indicated by the selection of specific *International Classification of Diseases*, Tenth Edition (ICD-10)[85] codes. Total admissions were counted for each month a person was included in the study. Our primary outcome was defined as any admission for cardiovascular (codes I00–I99) or respiratory (codes J00–J99) reasons. Episodes representing symptoms and signs involving circulatory and respiratory systems (R00–R09) in the first diagnostic position with no subsequent secondary diagnosis codes were also included in the primary outcome.

The secondary cardiovascular outcome consisted of records with ICD-10 codes I00 to I99, with the respiratory outcome identified by ICD-10 codes J00 to J99. Admissions that were attributable to COPD were selected using a combination of age and ICD-10 codes: any age for admissions with codes J40–J44, or R06 primary diagnostic position combined with J40–J49 any position, and codes J45–J46 for those aged ≥ 40 years (see *Appendix 7*).

Comorbidity was calculated using Bottle and Aylin's[86] algorithm, which was created using English National Health Service Hospital Episode Statistics data. We amended the algorithm, opting not to include ICD-10 code C44 (Non-Melanoma Skin Cancer) within the comorbidity algorithm to avoid potential bias as a result of differential treatment practices, which can be carried out in primary or secondary settings depending on geographical location in Wales.

Bias

We were supplied with address details for 5801 homes, from which we were able to geocode 4968 (86%). The 14% loss of property data was a result of a number of reasons, including incomplete or poor-quality address data, properties not present within WDS or properties with no residents registered within the study period. This loss of properties represents potential selection bias; however, as a result of the anonymised nature of SAIL and information governance, we were unable to explore this in more detail. The largest risk of selection bias arises from the exclusion of 509 properties that we were unable to link in the WDS. An analysis of non-matched properties showed that 70% were multiple-occupancy residences (blocks and flats), with the remaining 30% predominantly in terraced housing. From our experience, these linkage rates are typical of secondary address-level administration data.[87] This indicates a potential issue with source data and classification of properties at the National Land and Property Gazetteer.

Loss to follow-up bias is avoided because of the use of routinely collected data in SAIL. We were able to follow participants over a long period retrospectively, allocating health-care utilisation to individuals for the full period they were resident within an intervention home. Potential bias arising from background trends in emergency hospital admissions was explored by comparing changes in rates of emergency hospital admissions between study groups over a long period, taking into account pre-, mid- and post-intervention health-care utilisation. The trends were comparable and required no specific adjustment.

Study size

The process described in *Participants* generated our study data set, comprising 25,908 people living within the 4968 intervention homes over the 10-year study period, allowing for people moving in and out of homes. We had comparable data on two comparator groups. The first, a social housing comparator group, contained 48,261 people living within 12,350 homes; the second, drawn from the top 10% of deprived LSOAs in Wales, contained 524,596 people living in 118,982 homes.

Quantitative variables

Two date fields were received in relation to the intervention: start and end date. The quality and extent of these data were varied; some properties had both start and end dates recorded, whereas other properties had either start or end dates or no dates at all. We reviewed the data and imputed intervention dates based on the logic described in this section. We assumed that the month of the intervention end date represented the start of the 'after' period, all data prior to this month being allocated to the 'before' data collection period. Although we completed a validation exercise to ensure that we were using the correct addresses of intervention properties, there was no available method to validate dates or intervention measure data. We applied rules to allocate property dates by following these steps:

1. reversed dates when end date was prior to start date ($n = 22$)
2. calculated median days between start and end date for all homes with valid start and end dates (median = 92)
3. for homes with a valid end date only, subtracted the median days to impute a start date
4. for homes with a valid start date only, added the median days to impute an end date
5. calculated median start and end dates for all homes after applying steps 1–4
6. applied the static start and end dates from step 5 across all remaining homes.

Statistical methods

The methodological approach, adopted for the primary and secondary outcomes and the subgroup analyses, is based on initial investigations to assess the nature of any trends present in the observed data over the study period. This observed data is available on a monthly basis and, for both primary and secondary outcomes, comprises counts of events in that month. In the absence of any obvious trend over time, data on each individual's residence is conflated into two values, comprising the number of events occurring before and after the intervention. To take account of the different time durations in the pre- and post-intervention phases, these aggregated counts were transformed into annualised rates. These annualised rates were summarised and compared using mixed multilevel linear models featuring an indicator variable for phase, adjusting for explanatory factors and covariates, and incorporating random effects to account for clustering.

This approach takes the basic unit for clustering purposes to be a person's unbroken period of residence in a property, so data on an individual arising from a second residence is regarded as independent of data collected during that individual's first residence. This applies even if the two residences are the same, that is, when there is a break in a person's residence at a property. The pre- and post-intervention phases are defined using the assumption that the intervention is effective from its end date. We set the phase indicator to be 0 for pre intervention and 1 for post intervention, so that the coefficient for this variable corresponds to the effect of the intervention.

We included several individual-level covariates and factors in our analyses. Specifically, we considered covariates summarising participant age for each phase, calculated using the mid-point of residence in an intervention study home; a seasonality score for each phase; a single comorbidity score, ranging from 0 to 1, summarising comorbidities recorded across all months; and an indicator of sex (male, female).

We also considered area-based variables recording income deprivation (summarised by five ordered categories ranging from 1 = least deprived to 5 = most deprived) and a measure of rurality (1 = village and hamlet, 2 = town and fringe, 3 = urban), both obtained at LSOA level.[88]

We defined sine-based factors for each month, taking negative values for October to March inclusive and positive values for April to September inclusive, resulting in an aggregate factor of zero for each complete year. Our seasonality covariate was based on seasonality scores for each phase, defined as the sum of monthly factors across each phase.

To assess excess winter admissions, we created a binary indicator for winter or non-winter, set to 1 for December, January, February and March, and to 0 for all other months.[89]

Our modelling approach, aimed at obtaining the precise estimate of the intervention effect on each variable in turn, used appropriate univariate linear mixed models (implicitly assuming normality) and progressed by eliminating, in turn and starting with the least significant, all covariates and factors with a coefficient with a p-value of > 0.05, concluding when all remaining explanatory variables were statistically significant.

Results

Participants

Address records and intervention details for 5801 intervention homes were collated and supplied to SAIL for the intervention. There were 172 records with insufficient address data to allow data linkage. A further 99 records were excluded as a result of multiple source records matching to individual homes held within SAIL. A further 509 records were removed because there was no record of the home within the WDS data set. Finally, 53 records were removed when there were no residents recorded by the WDS as living in the home over the study period. This left 4968 properties for analyses, as shown in *Figure 2*. The supplied intervention addresses were validated against a separately sourced list of addresses from the Welsh Government, with 88% of addresses common to both sources. This is a conservative estimate because a number of addresses from both sources had insufficient address details to generate a linkable address. The number of individuals linked to these properties in the study period was 25,908.

Descriptive data

Our final study size was 25,908 people living within 4968 intervention homes over the study period. We arrived at the study size through the process described in *Methods*, *Participants* and *Results*, *Participants*.

Properties

Just over 70% of intervention homes received one energy efficiency measure, around 20% received two measures and the remainder received three or more. The most common type of intervention measure carried out on the intervention homes was the installation of external wall insulation. Over 50% of homes received external wall insulation, 30% received photovoltaics, 20% received solar hot water, 15% switched fuels and 5% received an air source heat pump.

Individuals

We summarised the data by property and participant, because the interventions apply to properties but outcomes relate to residents. Each property can house multiple residents, who can be present simultaneously or consecutively, and each study participant can reside in multiple properties continuously or with breaks over the study period. We have demographic data for individuals living within 136,300 distinct study homes, of which 4968 are intervention homes, 12,350 are social housing comparator homes and 118,982 are comparator homes in areas designated in the top 10% of deprived areas by WIMD 2011.

There were 4968 properties that received the intervention (*Table 1*): for 2021 properties (40.7%), both the start and end dates for the intervention were known and for a further 1739 properties (35.0%), either the start or end date was known and the other was imputed. For the remaining 1208 properties (24.3%), both the start and end dates were imputed. Many people moved home during the intervention period. The extent of residential mobility is indicated by the association of several residents with multiple homes (*Table 2*).

Main results

Monthly emergency admission rates per person across the study period offer a visual confirmation of little or no trend in this rate (*Figure 3*). There were approximately three or four admissions per month per 1000 people throughout the study. Corresponding time plots for the comparator groups showed only weak correlation with the intervention cohort for the primary outcome, and considerable noise (see *Appendix 8*). Therefore, we did not use the comparator groups to control the analyses.

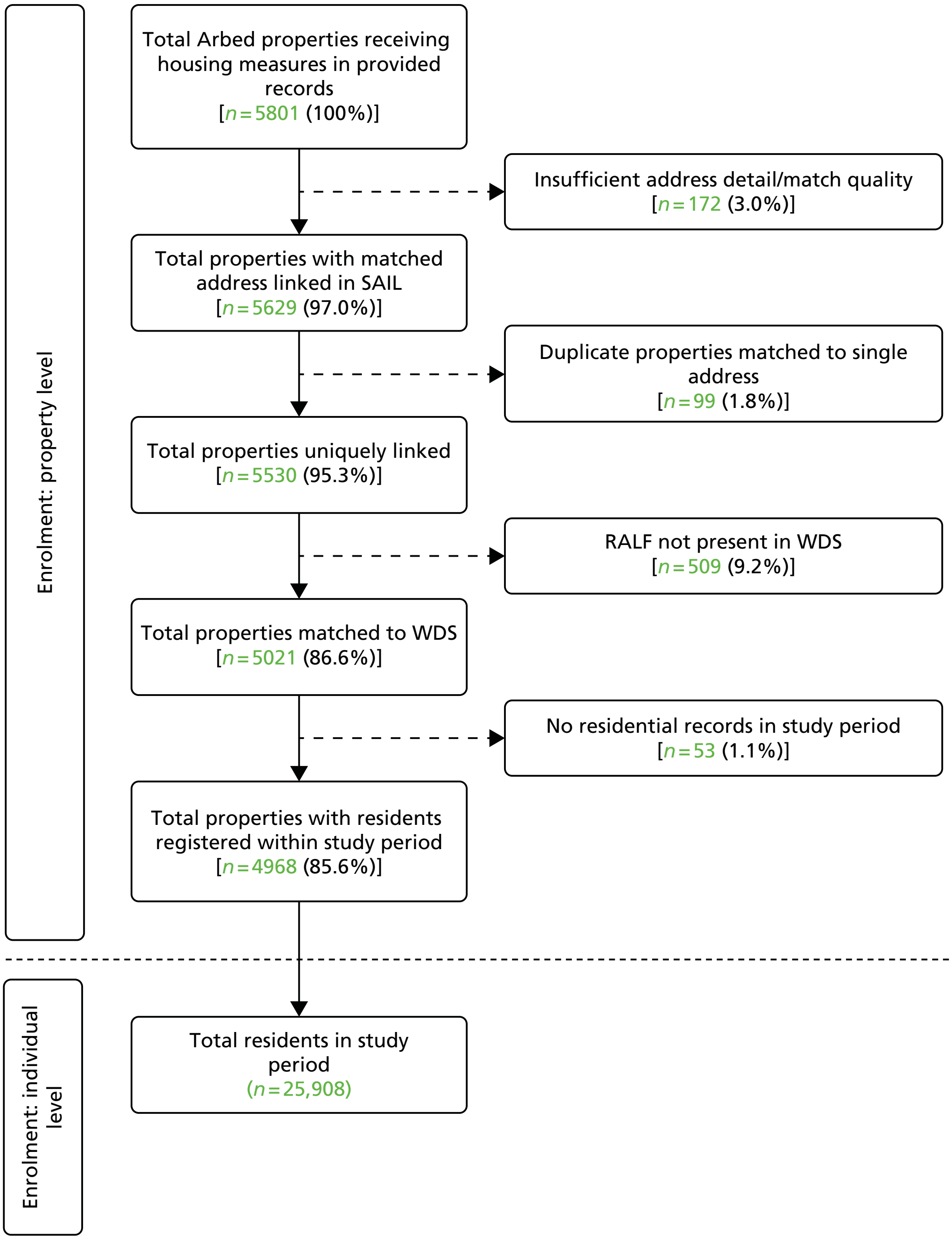

FIGURE 2 The flow diagram for the intervention group.

Data and model summaries for our primary outcome and several secondary outcomes are presented, firstly for all ages (*Table 3* and *Figure 4*) and then for older residents who are aged ≥ 60 years (*Table 4* and *Figure 5*). All outcomes possess both more skewness and kurtosis than is consistent with the assumption of normality.

The intervention did not have a statistically significant effect on our primary outcome, neither did it have a significant effect on any of our all-age secondary outcomes. *Table 3* and *Figure 4* show that the intervention was not significantly associated with a change in cardiorespiratory, COPD-related, cardiovascular or respiratory emergency admissions for people of all ages. The results include summaries of the raw, unadjusted data for the pre- and post-intervention phases, and the paired differences for those

TABLE 1 Intervention start and end months for 2021 properties with both start and end dates known

	Start date									
	2010						2011			
End date	July	August	September	October	November	December	January	February	March	May
2010										
August		1								
September	19									
October			1	68						
November		20		75						
December			10	126	2					
2011										
January			65	79		68	2			
February			83	100	86	4	9			
March			76	257	50	318	116	92	74	
April				45			40			
May				1						
June										
July			8							
August										
September				3						
October										
November			80							
December				2						

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TABLE 1 Intervention start and end months for 2021 properties with both start and end dates known (*continued*)

	Start date									
	2010						2011			
End date	July	August	September	October	November	December	January	February	March	May
2012										
January				35						
February										
March				2						
April										
May										
June										
July										
August										
September										4
Total	19	21	323	793	138	390	167	92	74	4

TABLE 2 Numbers of residents by property, subdivided by property groups

	Intervention only	Social housing only	Top 10% deprived areas only	Intervention and social housing	Intervention and top 10% deprived areas	Social housing and top 10% deprived areas	Intervention, social housing and top 10% deprived areas	Total
Sex[a]								
Male	8972	19,188	255,021	331	2995	4058	131	290,696
Female	9545	19,874	254,667	367	3410	4155	157	292,175
Residents associated with								
1 home	17,097	29,644	398,788	0	0	0	0	445,529
2 homes	1265	7101	79,633	454	3736	4271	0	96,460
3 homes	127	1723	21,439	183	1675	2335	112	27,594
4 homes	25	444	6472	37	583	966	99	8626
5 homes	2	110	2248	18	254	381	43	3056
6 homes	1	29	756	5	98	170	19	1078
7 homes	0	6	235	1	36	54	6	337
8 homes	0	5	69	0	14	22	5	116
9 homes	0	0	35	0	3	6	3	47
10 homes	0	0	10	0	4	5	0	19
11 homes	0	0	5	0	2	2	1	10
12 homes	0	0	0	0	0	1	0	1
Total	18,517	39,062	509,690	698	6405	8213	288	582,873

a Sex was not recorded for two residents.

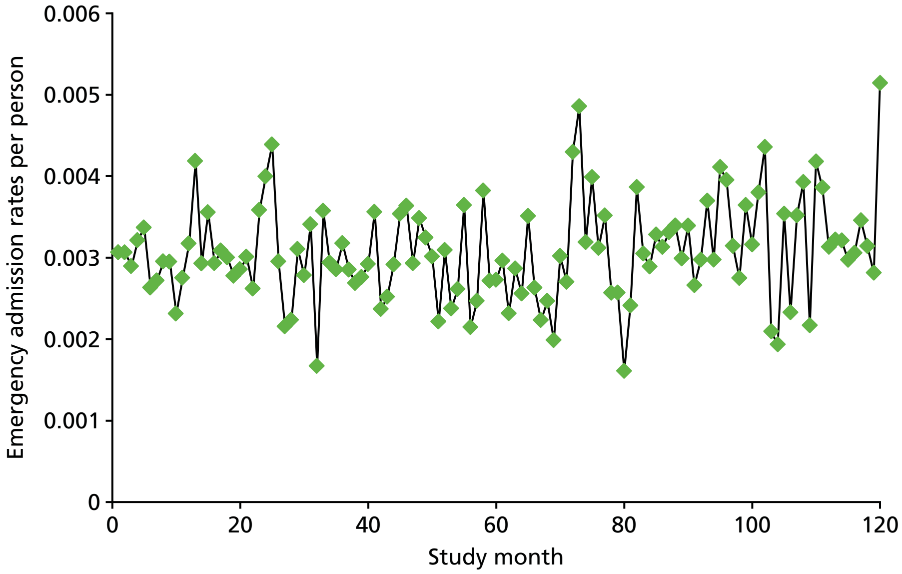

FIGURE 3 Monthly emergency admission rates per person (study month 1 is January 2005) for residents within intervention homes.

TABLE 3 Summary of analyses for primary and secondary outcomes for the full intervention group for people of all ages. Significant covariates are detailed in the footnotes

	Raw data, M (SD) [*n*]				
Outcome	**Post intervention**	**Pre intervention**	**Paired differences**	**Adjusted comparison**	**95% CI**
Primary					
Annualised rate of cardiorespiratory emergency admissions per person[a]	0.0577 (0.7079) [18,527]	0.0543 (0.4788) [22,209]	0.0152 (0.9144) [12,433]	Δ = 0.0011 ($p = 0.852$)	–0.0103 to 0.0125
Secondary					
Annualised rate of COPD-related emergency admissions per person[b]	0.0069 (0.1150) [18,527]	0.0062 (0.1468) [22,209]	0.0054 (0.1526) [12,433]	Δ = –0.0002 ($p = 0.895$)	–0.0025 to 0.0022
Annualised rate of cardiovascular-related emergency admissions per person[c]	0.0171 (0.4377) [18,527]	0.0179 (0.2709) [22,209]	0.0108 (0.5264) [12,433]	Δ = –0.0014 ($p = 0.694$)	–0.0083 to 0.0055
Annualised rate of respiratory-related emergency admissions per person[d]	0.0371 (0.5430) [18,527]	0.0324 (0.3720) [22,209]	0.0045 (0.7374) [12,433]	Δ = 0.0042 ($p = 0.348$)	–0.0046 to 0.0131

CI, confidence interval; M, mean; SD, standard deviation.
Significant factors and covariates ($p < 0.001$ unless otherwise stated):
a Age ($p = 0.003$), comorbidity score and sex.
b Age, comorbidity score and seasonality.
c Age, comorbidity score and seasonality.
d Age ($p = 0.005$), comorbidity score and sex.

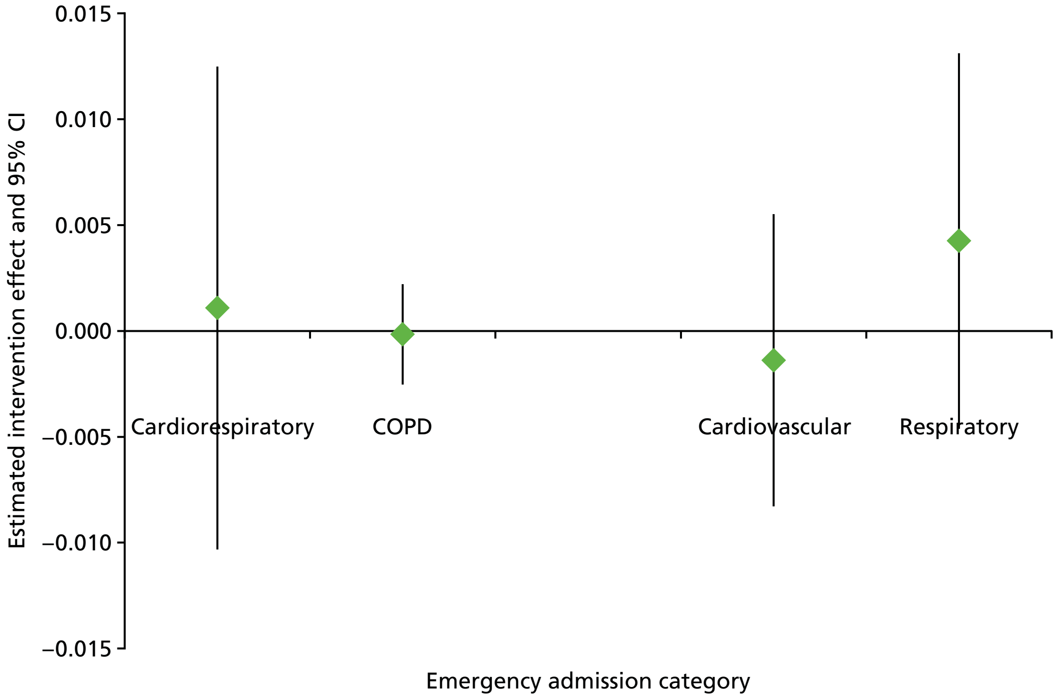

FIGURE 4 Graphical representation of the intervention effects in *Table 3* (with 95% CI) by emergency admission category for people of all ages.

TABLE 4 Summary of analyses for secondary outcomes for the intervention subgroup comprising people aged ≥ 60 years. Significant covariates are detailed in the footnotes

	Raw data, M (SD) [*n*]				
Outcome	Post intervention	Pre intervention	Paired differences	Adjusted comparison	95% CI
Primary					
Annualised rate of cardiorespiratory emergency admissions per person[a]	0.1805 (1.4538) [2226]	0.1714 (0.8747) [2804]	0.1152 (1.5524) [1991]	Δ = 0.0490 ($p = 0.136$)	–0.0153 to 0.1132
Secondary					
Annualised rate of COPD-related emergency admissions per person[b]	0.0391 (0.2656) [2226]	0.0386 (0.3945) [2804]	0.0229 (0.3595) [1991]	Δ = 0.0133 ($p = 0.109$)	–0.0030 to 0.0295
Annualised rate of cardiovascular-related emergency admissions per person[c]	0.0704 (0.3725) [2226]	0.0974 (0.7176) [2804]	0.0313 (0.3880) [1991]	Δ = 0.0273 ($p = 0.009$)	0.0068 to 0.0479
Annualised rate of respiratory-related emergency admissions per person[d]	0.1074 (1.3990) [2226]	0.0712 (0.4727) [2804]	0.0835 (1.4960) [1991]	Δ = 0.0412 ($p = 0.144$)	–0.0141 to 0.0964

CI, confidence interval; M, mean; SD, standard deviation.
Significant factors and covariates ($p < 0.001$ unless otherwise stated):
a Age, comorbidity score and seasonality.
b Comorbidity score.
c Age, comorbidity score, income category 3 and seasonality.
d Age ($p = 0.003$), comorbidity score and sex ($p = 0.050$).

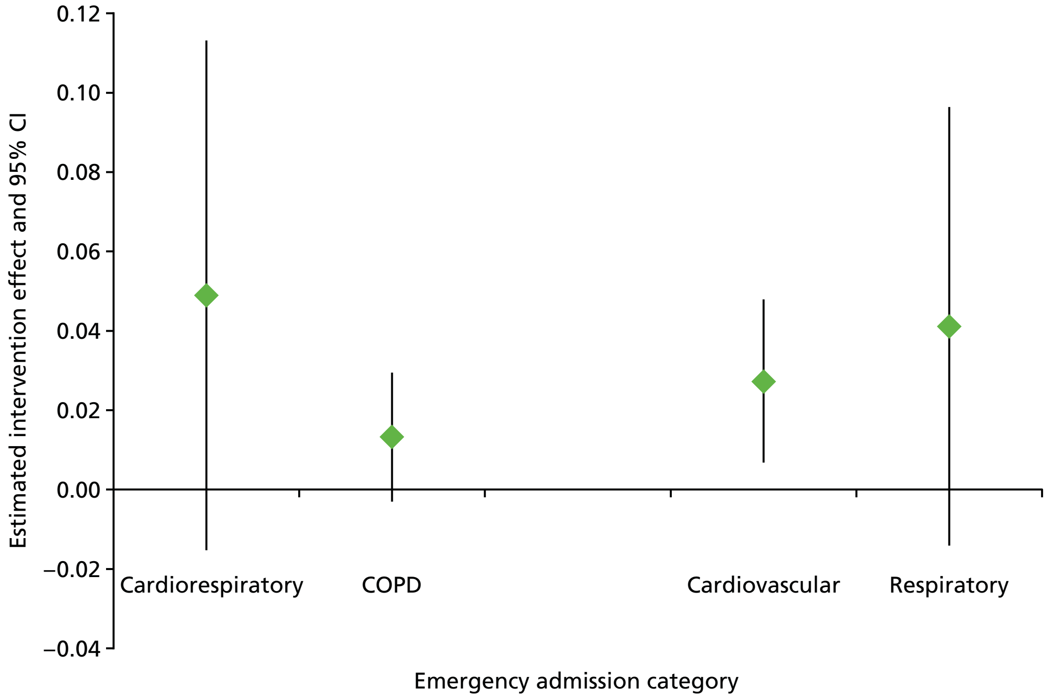

FIGURE 5 Graphical representation of the intervention effects in *Table 4* (with 95% CI) by emergency admission category for people aged ≥ 60 years.

people who were in the study for both phases (irrespective of the lengths of residency periods). We subsequently included covariates and factors in univariate linear models for each outcome, and the adjusted comparisons are taken from models that retain all significant covariates and factors (listed at the end of *Tables 3* and *4*). Age was a significant covariate in all 'all ages' models.

Estimates of overall intervention effects are small – for instance, the estimated $\Delta = 0.0011$ for the primary outcome equates to 1.1 further cardiorespiratory emergency admissions per year per 1000 people – and generally consistent with the differences in pre- and post-intervention rates. However, widths of the 95% confidence intervals (CIs) for the intervention effect vary quite considerably across outcomes, reflecting both prevalence and variability of that outcome in study data. There is only moderate agreement between the (adjusted) intervention effects and the (unadjusted) paired differences in rates for those in the study for both phases. More detailed consideration of the characteristics of that subgroup may further reconcile these summaries.

Figure 5 shows the associations of the intervention with changes in cardiorespiratory, COPD-related, cardiovascular or respiratory emergency admissions for people aged ≥ 60 years. This is a relatively small subgroup, so interpretation of these results should take account of the reduced sample size. The intervention was not linked to significant changes in emergency admissions for cardiorespiratory, COPD-related and respiratory conditions. However, it had a significant effect on cardiovascular-related emergency admissions. In contrast to expectations, there was an increase in admissions in the post-intervention period.

In order to determine the excess winter hospital admissions for the primary outcome of the study (the annualised rate of combined cardiovascular or respiratory emergency admissions per person), we classified months as winter (December to March) or non-winter (April to November). *Table 5* summarises the observed rates by phase (pre or post intervention) and season (winter or not winter).

Table 5 shows that, as per intuition, rates are higher in the winter months than in the non-winter months in both the pre- and post-intervention phases. In this analysis, we are also interested in the interaction between intervention phase and season. This is because the statistical interaction summarises the extent to

TABLE 5 Summaries for the primary outcome, categorised by phase and season

Season	Raw data		Adjusted comparison	95% CI
	Post-intervention phase, M (SD) [*n*]	Pre-intervention phase, M (SD) [*n*]		
Winter months	0.0582 (0.6771) [18,147]	0.0566 (0.5889) [21,750]	$\Delta_{PS} = 0.0097$ ($p = 0.074$)	−0.0009 to 0.0204
Non-winter months	0.0520 (0.6195) [18,226]	0.0461 (0.3319) [21,618]		

M, mean; SD, standard deviation.

which differences in admissions occur between seasons for each of the pre- and post-intervention phases separately. *Table 5* therefore presents details from the interaction analysis for this term (Δ_{PS}), adjusted for comorbidity score and sex (both with $p < 0.001$). The interaction between season and intervention phase was not significant.

Discussion

Key results

The study found no intervention effect of reduced admissions for either the primary outcome (combined cardiovascular and respiratory emergency admissions) or any of the secondary outcomes for people of all ages living in an intervention home. It also did not find an intervention effect of reduced cardiorespiratory emergency admissions when we focused analyses on residents who were aged ≥ 60 years. However, we did see a statistically significant intervention effect of increased cardiovascular-related emergency admissions for residents aged ≥ 60 years. Cardiorespiratory emergency admission rates were found to be higher in winter than in non-winter months, in both the pre- and the post-intervention phases. The interaction between season and phase was not statistically significant, so there was no evidence that the intervention had an effect on the difference between winter and non-winter rates.

Limitations

Routine data allowed us to evaluate this intervention using retrospective links from individuals living in intervention homes for the relevant times. We were able to retrospectively analyse health-care utilisation data for a large number of people across a 10-year period and minimise the bias experienced in more-traditional research caused by factors such as recruitment and subsequent loss to follow-up. Problems of recall bias are avoided with routinely collected health data that are based on observed health events and not subjectively reported conditions.

However, we were unable to randomise participants into intervention and control groups and, as with all observational studies, the potential for unmeasured confounding remains. For example, it is challenging to control for the multiple associations between poverty, poor housing and poor health.[90]

The study was only able to determine the impact of the intervention on events recorded as hospital admissions. The lack of association with emergency hospital admissions indicated that benefits do not appear in the hospital statistics within the follow-up period and that future evaluations should focus on less-severe conditions that may be treated in primary care settings, although recent research suggests that housing interventions may not necessarily change established patterns in primary health-care utilisation in populations with a long-term lack of well-being.[91]

Furthermore, we acknowledge the data limitations, including the lack of depth of the routine data. For instance, using routine data means that we cannot understand how people's lives have changed in their home; this needed the additional studies that were completed as part of this research (see *Chapter 3*).

Data quality was also an issue. Intervention home addresses and intervention dates required considerable time and effort to collect, and subsequently convert to a structured format that could be used within the databank. There were missing dates for several hundred intervention homes.

We relied on a routinely collected demographic data set (WDS) to link people into homes for the correct time periods. Research by the ONS suggested that some segments of the younger male population are more likely to be missing from this data set. Further work is needed to quantify potential bias in this routine anonymised data set.

Finally, we acknowledge that assumptions implicit in linear models are unlikely to be entirely satisfied by the study data, and that it would be useful to investigate further models that seek to account more explicitly for features observed in this data.

Interpretation

There was no evidence that energy efficiency investments, as implemented in the intervention programme, provided a reduction in health-care utilisation in the short to medium term. Residents were not involved in the intervention implementation and so may have felt a lack of control; this may have contributed to the lack of a significant reduction in health-care events.[92] Longer-term studies, of a decade or longer, may be needed to realise an intervention effect on health-care utilisation recorded using routine data, including hospital as well as primary care outcomes.

Generalisability

The research is generalisable to residents of homes located in temperate regions, with similar socioeconomic characteristics, living in homes in need of thermal efficiency measures. The intervention homes were predominantly social housing, maintained by LAs and RSLs and located within low-income areas. The results may also be generalisable to some extent to residents of private rented homes or homeowners in low-income areas.

Chapter 3 The community-based study

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Introduction

This chapter follows the STROBE reporting guidelines for observational study designs.[81]

Background

Chapter 2 reported on the impacts of energy efficiency investments on hospital admissions for cardiovascular and respiratory conditions using the SAIL databank. The first phase of the intervention programme, which took place between 2010 and 2012, was evaluated by anonymously linking address and intervention records to the PEDW, containing all hospital admissions and day case activity in Welsh hospitals and Welsh residents being treated in hospitals in England. The strength of this approach is that it can retrospectively evaluate the intervention without the results being biased as a result of low response rates and losses to follow-up. However, although national health records can be used to link the intervention to actual health service use, it does not detect mental health conditions that do not involve the use of health services, as well as more-subjective psychosocial aspects that may be part of pathways to health. The community-based study reported in this chapter specifically focused on mental health and well-being, self-reported respiratory conditions and wider psychosocial impacts of the intervention.

As discussed in *Chapter 1*, the literature suggests two interrelated pathways between energy efficiency investments and better mental and physical health.[54,56] Energy efficiency investments may improve living conditions through increased indoor air temperatures and fewer damp-related housing problems. Improving living conditions may not only contribute to better respiratory health but can also contribute to better mental health through improved thermal satisfaction.[58] Furthermore, an expansion of living space and improved social interactions (and therefore reduced social isolation) may be beneficial for residents' mental well-being.[59] Energy efficiency investments also contribute to improved well-being by making heating more affordable.[6] Reduced spending on heating bills alleviates financial stress and fuel poverty among low-income households[60,61] and helps to free financial resources for better food security[45,46] and social interactions.[31]

Objectives

This chapter describes the methodology and findings of the community-based evaluation of the second phase of the intervention programme. The overall aim of the study was to better understand the short-term health and psychosocial impacts of energy efficiency investments in low-income areas. More specifically, the study aimed to determine the impacts of (1) the intervention on the primary health outcomes of self-reported respiratory symptoms and mental health, (2) the intervention on the secondary health outcomes of overall physical quality of life and subjective well-being and (3) energy efficiency investments on secondary psychosocial outcomes that may be part of pathways to health, including self-reported fuel poverty, food security and financial difficulties and stress, as well as self-reported thermal satisfaction, housing conditions, the number of heated rooms and social interactions. An additional aim was the health economic evaluation of the extent to which the intervention changes the health-related quality of life of inhabitants, through the calculation of quality-adjusted life-years (QALYs).

The research described in this chapter received ethics approval from the School Research Ethics Committee (SREC) of the Welsh School of Architecture, Cardiff University (EC1308.160).

Methods

Study design

The community-based study used a quasi-experimental controlled pre-/post-test design and collected data through self-completion questionnaires. Questionnaires were distributed in low-income areas where energy efficiency improvements were scheduled but had not yet started, as well as in matched control areas where no energy efficiency improvements were scheduled. The intervention programme ran for 3 years between 2012 and 2015. The community-based study focused on schemes that were delivered in 2014 and 2015, respectively.

Setting

The energy efficiency investment programme targeted low-income mixed-tenure neighbourhoods. The schemes were selected on the basis of the number of low-income households, the number of households owning or privately renting their house and the number of hard-to-heat, hard-to-treat homes in the area. The schemes mostly took place in Strategic Regeneration Areas with high numbers of hard-to-heat, hard-to-treat homes. Matched control areas were selected using the WIMD and with the assistance of the LAs where the schemes were taking place. In total, 24 intervention and 23 control areas were included in the study. Anglesey was the only scheme that did not have a direct matched control area. *Figure 6* shows the locations of the intervention areas that were included in the study.

Baseline (pre-intervention) data for year 2 schemes were collected during the 2013/14 heating season, before energy improvement work had started on homes scheduled to receive the intervention. Follow-up (post-intervention) data for year 2 schemes were collected during the 2014/15 heating season, after the work was completed. Baseline and follow-up data for year 3 schemes were collected during the 2014/15 and 2015/16 heating seasons, respectively. Data for the intervention and control areas were collected during the same time periods. Data for one year 2 scheme (Gwynedd) could not be collected in two subsequent heating seasons as a result of delays in the delivery of the improvements. In this case, the follow-up data for both the intervention and matched control area were collected during the 2015/16 heating season, at the same time as the follow-up data for year 3 schemes.

Participants

We used a purposive sampling strategy to recruit residents living in the eligible intervention and control areas. The survey was administered using the drop-off-and-collect method of data collection.[93] Initial contact was made by postal letter, introducing the study and informing residents that they were going to be visited by researchers from the university. Researchers then visited all selected areas to deliver the questionnaires by hand and, when possible, personally invite residents to take part in the study. When at the time of delivery no residents were at home, a pack containing a cover letter, questionnaire and Freepost envelope was left in their letter box. Researchers then returned at a later date, usually within a week, to collect the questionnaires. Similarly, a reminder to return the questionnaire was left if occupants were away at the time of the return visit. The questionnaire could then be returned by Freepost. Participants were asked to provide their contact details and consent to be recontacted for the follow-up phase of the study. Any adult resident currently living in the selected intervention and control areas was eligible for inclusion.

The initial invitation letter and the questionnaire were both translated into Welsh. The Welsh version of the questionnaire was available on request.

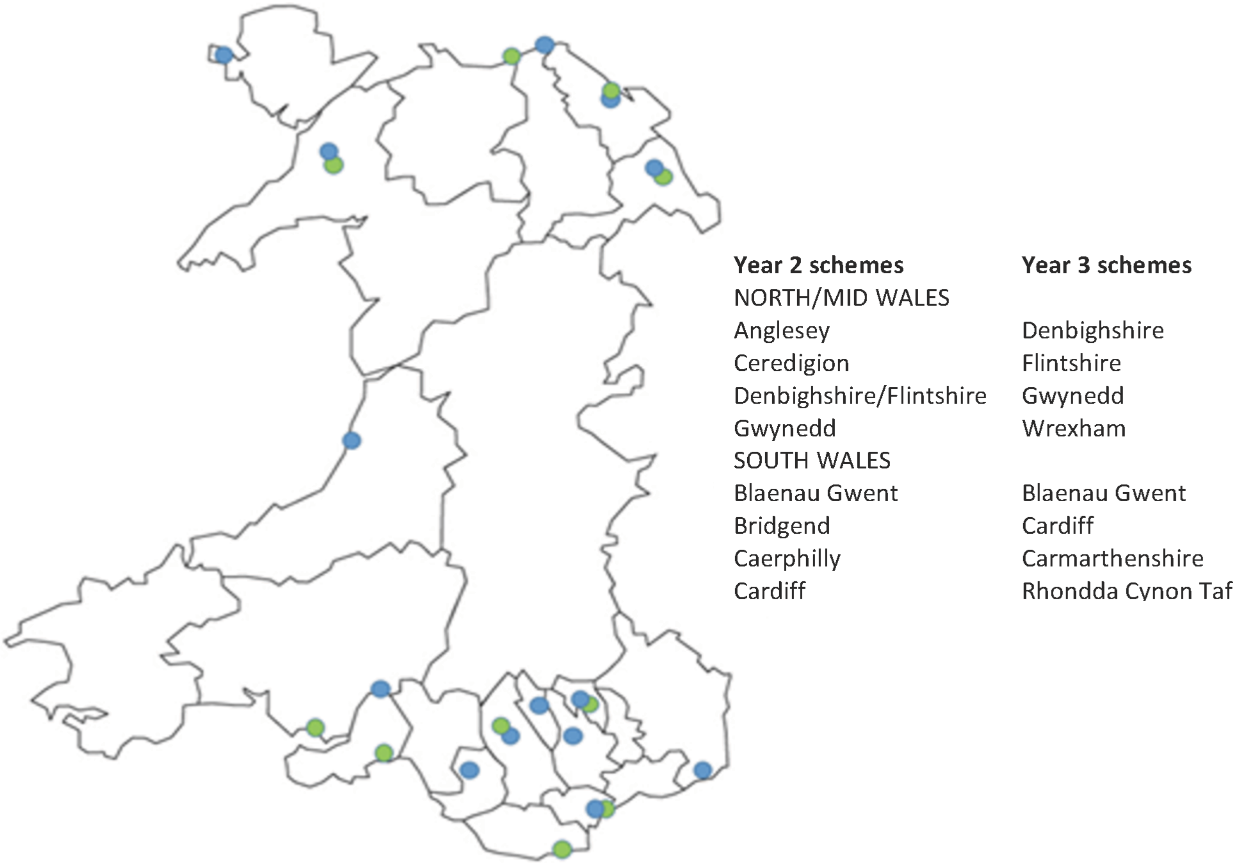

FIGURE 6 Locations of the intervention areas.

All participants who had returned a completed questionnaire in the baseline period and had consented to be recontacted were invited to fill out a second questionnaire for the follow-up. Participants were sent a postal questionnaire that was addressed to them personally. They were subsequently visited by researchers to collect the questionnaire in person when possible. A reminder was left if the participants were not at home during the follow-up visit.

Incentives were used to increase the baseline and follow-up response rates. Participants were entered into a prize draw for one of 25 £50 shopping vouchers (year 2 baseline) or for one of three iPads (Apple Inc., Cupertino, CA, USA) (year 3 baseline and all follow-up stages).

Not every eligible household within the scheme areas elected to have energy efficiency work done to their house. Records from the two scheme managers were used to confirm which properties were upgraded and which improvements were made. Respondents from intervention areas who did not have energy efficiency work done to their home became part of the control group. A small number of properties located within the matched control area of a delayed year 2 scheme (Gwynedd) became part of a year 3 scheme. Respondents from these properties became part of the intervention group.

Variables

Data were collected via a self-completion questionnaire covering the topics of health and well-being, fuel poverty, financial difficulties and stress, food security, social interactions, thermal satisfaction, housing conditions and number of heated rooms. The sociodemographic section of the questionnaire contained questions about sex, age, household composition, marital status, employment status, household income, smoking and housing benefits (see *Appendix 9*).

The primary health outcomes were changes in mental health status [MCS from the Short Form questionnaire-12 items (SF-12)] and self-reported respiratory and asthma symptoms. Secondary health outcomes were changes in self-reported health-related quality of life [Physical Health Composite Scale (PCS) from the SF-12] and subjective well-being. Other secondary psychosocial outcomes included changes in fuel poverty status, financial difficulties and stress, food security, social interactions, thermal satisfaction and reported housing conditions.

The Short Form questionnaire-12 items

The SF-12 is a validated and widely used measure to assess overall health-related quality of life.[94] The 12-item survey includes questions on physical and mental health, covering the eight subdomains of general health, physical functioning, physical role functioning, bodily pain, vitality, emotional role functioning, mental health and social functioning. The questions consist of 10 five-point items and two three-point items as measured on a Likert scale. The items were combined using a standardised scoring algorithm to form the separate PCS and MCS, which range from 0–100 with a standardised mean score of 50 and a standard deviation (SD) of 10. Higher scores represent better well-being.

Respiratory symptoms

Self-reported respiratory symptoms were measured using items adapted from Fisk *et al.*[26] and WHO.[95] Respondents were asked if they had experienced any of the following symptoms over the past month: coughing, bringing up phlegm, shortness of breath, wheezing attack, chest tightness, runny nose, blocked nose, sinus swelling, sneezing, sore throat and cold or flu. The respiratory symptoms were summed creating a scale ranging from 0 to 11.

Asthma symptoms

The short version of the European Community Respiratory Health Survey was included in the questionnaire, which contains nine questions about the presence of respiratory symptoms during the previous 12 months (wheezing and whistling, breathlessness, chest tightness, shortness of breath, nocturnal coughing), attacks of asthma during the previous 12 months, current use of asthma medication and nasal allergies including hay fever. The survey was designed to estimate prevalence of asthma, asthma-like symptoms and airway responsiveness.[96] The asthma symptoms were summed creating a scale ranging from 0 to 9.

Subjective well-being

Subjective well-being was measured using four questions developed by the ONS.[97] The questions measure three different aspects of subjective well-being, including respondents' life satisfaction (an evaluation or global assessment measure), happiness and anxiousness (both hedonic well-being measures, reflecting feelings over short periods of time) and worthwhileness (a eudemonic measure). Each of the four questions could be answered using an 11-point Likert scale. The four responses were combined into a single scale after reversing the anxiousness item (Cronbach's $\alpha = 0.90$). The final scale ranged from 0 (low subjective well-being) to 10 (high subjective well-being).

Fuel poverty

One self-reported indicator of subjective fuel poverty was used. Respondents were asked whether or not, within the past 12 months, they had put up with feeling cold to save heating costs. Respondents could answer yes or no. This question has previously been used in the New Zealand Housing, Heating and Health Study.[98]

Financial difficulties and stress

The study used a financial stress scale from the Renton-I study[99] that was used to measure how often respondents had difficulties meeting the cost of different house-related expenses, such as rent or mortgage, repairs or maintenance of home, fuel bills or credit payments. Each question could be answered using a four-point Likert scale ranging from 1 (never) to 4 (very often). The responses to the four items were averaged to create a single scale (Cronbach's $\alpha = 0.79$). Respondents were further asked about their general level of financial stress using a question derived from the INTERHEART study.[100] The question used a five-point Likert scale ranging from none (1) to high (5).

Food security

The questionnaire included three questions from the US Adult Food Security Survey (2012) to determine households' economic access to food in terms of quantity, quality and variety.[101] Food security is defined as access at all times to enough food for an active, healthy life, including readily available nutritionally adequate and safe foods that can be acquired in socially acceptable ways.[102] The following three questions were asked: (1) 'In the last 12 months, the food I bought just didn't last, and I didn't have money to get more'; (2) 'In the last 12 months, I couldn't afford to eat balanced meals'; and (3) 'In the last 12 months, did you ever cut the size of your meals or skip meals because there wasn't enough money for food?'. Each question could be answered using a four-point Likert scale ranging from 1 (very often) to 4 (never). The responses were averaged to create a single scale (Cronbach's $\alpha = 0.92$).

Thermal satisfaction

Thermal satisfaction was measured by asking respondents how satisfied they are with the temperature in their home on a typical winter day. The five-point response scale ranged from 1 (very dissatisfied) to 5 (very satisfied). This question was previously used in the Carmarthenshire Homes Standard Health Impact Assessment Study.[103]

Housing conditions

Housing conditions were assessed in two ways. First, respondents were asked about their satisfaction with the current state of repair of their home. Respondents could answer the question on a five-point Likert scale ranging from 1 (very dissatisfied) to 5 (very satisfied). Second, respondents were asked whether or not they were currently experiencing six housing-related problems. These were condensation, leaking roofs, damp walls and/or floors, rot in windows and door frames, draught and mould. The housing problems were summed, creating a scale ranging from 0 to 6.

Number of heated rooms

Respondents were asked about their heating behaviours, in particular which rooms were heated on a typical winter day and evening. The items were combined to provide a sum of the number of rooms that are typically heated during the day and in the evening, focusing on four key rooms within the home: the kitchen, main living room, main bedroom and bathroom. The sum of the number of heated rooms was used in the analyses.

Social interactions

Social interactions were measured by asking respondents whether or not, in the last year, they had ever felt reluctant to invite friends or family to their home because of difficulties with keeping it warm. The question originated from the Adult Psychiatric Morbidity in England study.[104] Respondents could answer yes or no.

The Short Form questionnaire-6 Dimensions

The Short Form questionnaire-6 Dimensions (SF-6D) utility score was calculated from the SF-12 into the SF-6D using the 'Sheffield algorithm'.[105] The weighting algorithm was calculated using the preference-based standard gamble approach. The resulting SF-6D index value incorporates all health domains from the SF-12, with higher numbers associated with better health utility. Full health is represented by a value of 1 and death corresponds to a score of 0. The SF-6D utility score allows for the calculation of QALYs. One QALY is equal to living 1 year in full health; the duration in years is multiplied by the utility score.

Bias

The community-based study reported in this chapter used a quasi-experimental, controlled pre-/post-test design to control for time-variable factors such as external hydrothermal conditions and other temporal trends. The assignments of participants to the intervention and control groups was not randomised. Selection bias occurs when selection to the intervention and control groups results in differences in unit characteristics between conditions that may be related to outcome differences.[106] In order to maximise initial comparability, the matched control areas were selected using the same criteria as the intervention schemes.

The drop-off-and-collect method of survey administration and incentives were used to reduce selection bias as a result of non-response as much as possible.[93] The overall response rate was 16.5%, with 1508 of the 9127 distributed questionnaires being completed and returned. Of the 1508 baseline respondents, 1288 consented to be recontacted (85.4%). The attrition rate between baseline and follow-up was 48.1% owing to a lack of consent and loss to follow-up ($n = 726$), resulting in a final total sample of 782 respondents who filled out both the baseline and follow-up questionnaires (*Figure 7*).

The overall response for the baseline data collection rates were similar for the intervention and control groups (15.0% vs. 17.9%), although there were some differences in attrition (44.5% vs. 50.9%) between the baseline and follow-up phases [$\chi^2(1) = 6.132$; $p = 0.013$]. Differences were also seen in the rate of consent between the intervention and control areas (89.0% vs. 82.6%) [$\chi^2(1) = 12.165$; $p = 0.000$]. The resulting intervention and control populations were comparable in terms of sociodemographics, with chi-squared tests showing non-significant differences between the two groups for all variables listed.

A loss to follow-up analysis showed that there were a number of socioeconomic differences between the respondents included in the final study sample and those who dropped out between baseline and follow-up (*Table 6*). Respondents lost to follow-up were more likely to be female [$\chi^2(1) = 9.661$; $p = 0.002$], younger in age [$\chi^2(7) = 73.053$; $p = 0.000$] and have children living in the household [$\chi^2(1) = 28.738$; $p = 0.000$]. Respondents lost to follow-up were also more likely to have a lower household income [$\chi^2(8) = 15.950$; $p = 0.043$] and to receive housing benefits [$\chi^2(1) = 8.763$; $p = 0.003$]. In terms of health outcomes, the respondents lost to follow-up were more likely to be at risk of common mental disorders, as measured by the MCS of the SF-12 [$\chi^2(1) = 8.594$; $p = 0.003$]. However, there were no differences with regard to physical health, as measured by the PCS of the SF-12, subjective well-being and self-reported respiratory and asthma symptoms.

Recall bias may be another possible source of bias, which was minimised by asking respondents to answer questions regarding the current heating season. Missing data bias is possible when respondents may have chosen not to answer specific questions in either questionnaire. Overall, there were few missing values, except for self-reported asthma symptoms. A missing-values analysis found that data were missing completely at random.

Study size

We aimed to achieve a total sample size of 1000 participants (intervention, $n = 500$; control group, $n = 500$) to have 80% statistical power to detect an effect size (d) of 0.16 at the 5% significance level. The final achieved samples of $n = 364$ for the intervention group and $n = 418$ for the control group provide 80% statistical power to detect effect sizes of $d = n = 0.18$ at the 5% significance level, which is in line with effect sizes observed in comparable field studies examining the short-term health effects of housing improvements.[48,51,107]

Statistical methods

Statistical analyses were conducted with IBM SPSS Statistics version 20.0 (IBM Corporation, Armonk, NY, USA) and MLwiN version 2.36 (MLwiN, Centre for Multilevel Modelling, Bristol, UK) software packages.[108–110] The effects of the intervention on the primary and secondary health and psychosocial outcomes were initially assessed using mixed design analyses of variance (ANOVAs) as proposed, and subsequently using a multilevel modelling, repeated measures approach. The two types of analyses produced similar results. Here we only present the results of the multilevel modelling analyses for the purpose of clarity.

A longitudinal data set was created with the two measurement occasions (level 1) nested within individuals (level 2), allowing the analyses to take into account non-independence between measurement occasions. The basic model included the intervention group (intervention vs. control) as an individual-level factor and measurement occasion (follow-up vs. baseline) as a within-person factor. Differential changes between the intervention and control groups were assessed with a cross-level interaction between measurement occasion and intervention group. Only the interaction effects indicating the differential changes between

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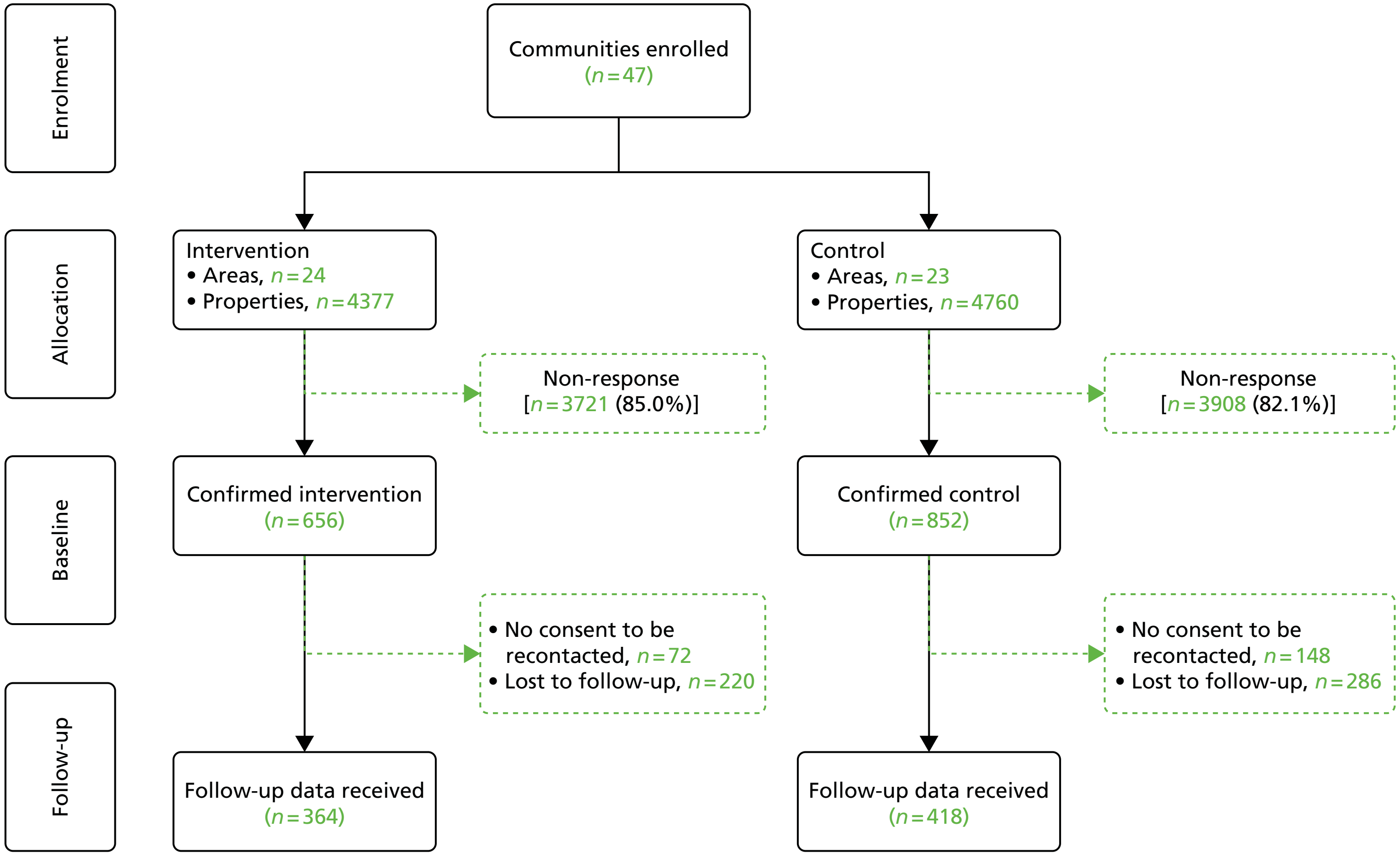

FIGURE 7 The flow diagram for the community-based study.

TABLE 6 Sociodemographic and health characteristics of study respondents and those lost to follow-up

Characteristics	Respondents, % (*n*/*N*)	
	Study	Lost to follow-up
Sociodemographic		
Sex		
Male	40.7 (311/764)	32.9 (230/700)
Female	59.3 (453/764)	67.1 (470/700)
Age (years)		
≤ 25	1.6 (14/776)	5.7 (41/712)
26–35	6.4 (50/776)	13.9 (99/712)
36–45	10.1 (78/776)	15.4 (110/712)
46–54	12.6 (98/776)	15.3 (109/712)
55–64	27.3 (213/776)	17.3 (123/712)
≥ 65	41.6 (323/776)	32.3 (230/712)
Household composition		
Households with no children	81.2 (623/767)	69.8 (484/693)
Households with children	18.8 (144/767)	30.7 (209/693)
Marital status		
Single	12.5 (97/778)	16.6 (119/716)
Married/cohabiting	53.3 (414/778)	51.5 (369/716)
Separated/divorced	19.1 (148/778)	17.1 (123/716)
Widowed	15.0 (117/778)	13.8 (99/716)
Household income		
£0–4999	3.6 (26/731)	7.6 (49/641)
£5000–9999	24.8 (182/731)	24.1 (155/641)
£10,000–19,999	35.0 (256/731)	37.2 (238/641)
£20,000–29,999	16.6 (121/731)	15.0 (96/641)
≥ £30,000	20.0 (146/731)	16.1 (103/641)
Housing benefits		
Yes	24.7 (187/756)	31.7 (222/700)
No	75.3 (569/756)	68.3 (478/700)
Fuel poverty (putting up with feeling cold to save heating costs)		
Yes	59.4 (464/774)	64.4 (457/710)
No	40.6 (310/774)	35.6 (253/710)
Health		
MCS		
At risk of CMD	57.1 (444/777)	64.6 (461/714)
Not at risk of CMD	42.9 (333/777)	35.4 (253/714)
PCS		
At risk of physical complaints	58.8 (456/776)	59.9 (427/714)
Not at risk of physical complaints	41.2 (320/776)	40.1 (287/714)

TABLE 6 Sociodemographic and health characteristics of study respondents and those lost to follow-up (*continued*)

Characteristics	Respondents, % (*n*/*N*)	
	Study	Lost to follow-up
Subjective well-being		
Very low	12.2 (95/781)	13.1 (95/724)
Low	24.6 (192/781)	28.5 (206/724)
Medium	29.2 (228/781)	30.4 (220/724)
High	34.1 (226/781)	28.0 (203/724)
Respiratory symptoms		
0	23.4 (183/781)	21.2 (154/725)
1	14.8 (116/781)	13.2 (96/725)
2	12.8 (100/781)	13.2 (96/725)
3	12.9 (101/781)	10.2 (74/725)
4	10.7 (84/781)	10.2 (74/725)
≥ 5	25.1 (197/781)	31.8 (231/725)
Asthma symptoms		
0	31.6 (225/713)	30.8 (199/646)
1	23.0 (164/713)	20.3 (131/646)
2	11.1 (79/713)	12.5 (81/646)
3	6.5 (46/713)	7.3 (47/646)
4	7.2 (51/713)	7.6 (49/646)
≥ 5	20.9 (41/713)	21.5 (139/646)

CMD, common mental disorder.
Note
Denominators vary because of missing data.

the intervention and control groups are reported. All analyses were conducted with and without adjusting for the covariates selected a priori: sex, age, housing benefit, household income and smoking status. Cohen's *d* was calculated to determine the size of interaction effects. Cohen's *d* is a standardised measure of the magnitude of an effect, with the values of 0.2, 0.5 and 0.8 generally taken to reflect 'small', 'medium' and 'large' effect sizes, respectively.[111,112]

Different types of models were constructed depending on the type of outcome variable. Linear regression models were constructed for the primary health outcomes of respiratory symptoms, asthma symptoms, MCS, the secondary health outcomes of PCS and subjective well-being, as well as for the secondary psychosocial outcomes of financial difficulties and food security. Ordered multinomial response models were constructed for the ordinal psychosocial outcome variables of financial stress, thermal satisfaction, satisfaction with the current state of repair of their home, number of reported housing problems and the number of heated rooms during the day and the evening. Logistic regression models were constructed for the two secondary psychosocial outcomes of fuel poverty and social interactions. For the ordered multinomial response and binomial models, a logit link function was used. Parameters in all models were estimated using Markov chain Monte Carlo with 50,000 iterations. All analyses were conducted with and without adjusting for the individual-level covariates of sex, age, housing benefits, household income and smoking status. The five covariates were selected a priori.

For the SF-12, missing data were dealt with using QualityMetric's Missing Score Estimation algorithm (QualityMetric, Lincoln, RI, USA), for which item response theory and regression methods were used to estimate scores on the health domain scales and component summary measures (MCS and PCS) using QualityMetric's Health Outcomes Scoring Software (QualityMetric, Lincoln, RI, USA).[113] All other missing data were excluded from the statistical analyses, which were conducted without imputation, as the percentage of missing values were in most cases low (< 3%). The missing values were higher for asthma symptoms (8.8%). Little's MCAR (missing completely at random) tests found that the data were missing completely at random [primary and secondary health outcomes and sociodemographic characteristics: $\chi^2(26) = 28.745$; $p = 0.323$; psychosocial outcomes: $\chi^2(60) = 63.720$; $p = 0.347$].

For the analysis of health-related quality of life and QALYs, the SF-6D index values were transformed into utilities implementing the area under the curve approach, with these values baseline-adjusted. A linear progression of SF-6D between baseline and follow-up was assumed in the absence of more data. For the main analysis, a multilevel modelling, repeated measures approach was used, adjusting for the individual-level covariates of sex, age, housing benefits, household income and smoking status.

Results

Participants

In total, 9137 questionnaires were distributed to eligible households across 47 intervention and control areas at the start of year 2 and year 3 of the intervention programme (see *Figure 6*). Of these, 1508 were completed and returned (656 from the intervention and 852 from the control areas), corresponding to an overall response rate of 16.5%. *Figure 7* illustrates the flow of participants through the study.

Out of the 1508 baseline participants in both the intervention and control groups, 220 did not consent to be recontacted and a further 506 participants were lost to follow-up, reflecting an overall attrition rate of 48.1%. Eighty-one participants from the original intervention areas did not receive any upgrades to their home as part of the intervention programme. These respondents were added to the control group. Some of the properties in the matched control area for the delayed year 2 scheme in Gwynedd were included in a year 3 scheme before follow-up data could be collected. The 22 respondents from these properties were added to the intervention group.

Descriptive data

Table 7 summarises the final study sample in terms of sociodemographic and building characteristics. The intervention and control populations were comparable in terms of sociodemographic and building characteristics, with chi-squared tests showing no significant differences between the two groups for any of the variables listed in the table. Because the intervention and control group are largely similar at baseline, there is a low likelihood of confounding.

Of the 782 respondents who completed both the baseline and follow-up questionnaires, the highest proportion was female, aged ≥ 65 years, did not live with children within their household, was either married or cohabiting and was retired. The highest proportion of respondents had no formal educational qualification, had a combined household income of £10,000–19,999. One-quarter of all respondents received housing benefits, reflecting the overall levels of deprivation of the intervention and control areas. The vast majority of respondents owned the properties they resided in and had lived in the same property for > 9 years. The building type tended to be either semi-detached or terraced, built either before 1919 or before 1945, with an average of three bedrooms.

External wall insulation was by far the most implemented measure (71.7%), followed by voltage optimisers (44.4%) and full central heating systems (new condensing boilers and radiators and pipes when needed; 39.0%). Respondents from three communities received a connection to the mains gas network together with a new heating system (13.9%). Voltage optimisers were only implemented in South Wales schemes.

TABLE 7 Sociodemographic and building characteristics of the intervention and control groups of the study cohort

Characteristics	Study cohort, % (*n*/*N*)	
	Intervention	Control
Sociodemographic		
Sex		
Male	41.2 (145/352)	40.3 (166/412)
Female	58.8 (207/352)	59.7 (246/412)
Age (years)		
≤ 25	1.4 (5/362)	2.1 (9/414)
26–35	6.9 (25/362)	6.0 (25/414)
36–45	10.8 (39/362)	9.4 (39/414)
46–54	14.1 (51/362)	11.1 (47/414)
55–64	30.1 (109/362)	25.1 (104/414)
≥ 65	36.7 (133/362)	45.9 (190/414)
Household composition		
Without children	79.1 (284/359)	83.1 (339/415)
With children	20.9 (75/359)	16.9 (76/415)
Marital status		
Single	13.8 (50/363)	11.3 (47/412)
Married/cohabiting	55.1 (200/363)	51.6 (214/412)
Separated/divorced	16.0 (58/363)	21.7 (90/412)
Widowed	14.9 (54/363)	15.2 (63/412)
Household income		
£0–4999	3.5 (12/339)	3.6 (14/392)
£5000–9999	23.5 (80/339)	25.8 (101/392)
£10,000–19,999	33.9 (115/339)	35.9 (141/392)
£20,000–29,999	18.0 (61/339)	15.3 (60/392)
≥ £30,000	20.6 (70/339)	19.4 (76/392)
Housing benefits		
Yes	25.1 (89/354)	24.4 (98/402)
No	7.9 (265/354)	75.6 (304/402)
Tenure		
Owner occupied	77.5 (276/356)	74.0 (307/415)
Private rental	3.9 (14/356)	6.7 (28/415)
LA rental	13.8 (49/356)	13.3 (55/415)
Housing association rental	3.4 (12/356)	5.3 (22/415)
Time lived at current address (years)		
< 1	3.3 (12/360)	4.3 (18/416)
1–4	9.4 (34/360)	11.8 (49/416)
5–9	14.4 (52/360)	12.7 (53/416)
> 9	72.8 (262/360)	71.2 (296/416)

continued

TABLE 7 Sociodemographic and building characteristics of the intervention and control groups of the study cohort (*continued*)

Characteristics	Study cohort, % (*n*/*N*)	
	Intervention	Control
Building		
Building type		
Detached house	12.5 (45/360)	12.3 (51/416)
Semi-detached house	38.1 (137/360)	28.8 (120/416)
Terraced house	41.1 (148/360)	46.9 (195/416)
Bungalow	5.0 (18/360)	5.3 (22/416)
Flat	1.4 (5/360)	6.0 (25/416)
Year of construction		
Before 1919	44.1 (152/345)	40.7 (166/405)
1919–1945	26.1 (90/345)	24.3 (99/405)
1945–1965	17.4 (60/345)	23.5 (96/405)
1965–1979	7.5 (26/345)	6.1 (25/405)
1980 or later	4.9 (17/345)	5.4 (22/405)
Number of bedrooms		
1	1.7 (6/358)	5.4 (22/409)
2	19.8 (71/358)	20.8 (85/409)
3	68.2 (244/358)	65.3 (267/409)
≥ 4	10.4 (37/358)	8.5 (35/409)

Note
Denominators vary because of missing data.

Main results

The impact of the intervention on the primary health outcomes

The primary health outcomes assessed were self-reported respiratory and asthma symptoms, and the mental health composite score of the SF-12 (MCS). The study found no evidence that the intervention had a significant impact on the primary health outcomes of the study. *Table 8* shows that there was a small reduction in the number of reported respiratory symptoms between baseline and follow-up for the intervention group. However, the change does not statistically differ from the one observed for the control group. Similarly, the reduction in the number of reported asthma symptoms for the intervention group did not significantly differ from the change observed in the control group. There was a slight increase in the MCS scores for the intervention group. However, the increase for the intervention group was similar to the increase for the control group.

The impacts of the intervention on the secondary health outcomes

The secondary health outcomes were the PCS of the SF-12 and subjective well-being. The study found no evidence that the intervention had an impact on physical quality of life, as measured by the PCS. Although there was a slight reduction in PCS scores for the intervention group, the reduction was not significantly different from the reduction observed for the control group.

Table 9 shows an increase in subjective well-being for the intervention group but a slight decrease for the control group. This represents a significant measurement occasion × intervention group interaction effect at the 1% level. The interaction effect remained significant after controlling for the covariates of sex,

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TABLE 8 Primary health outcomes at baseline and follow-up for the intervention and control group

			Study cohort, M (SD)										
			Intervention		Control		Effect size	Unadjusted			Adjusted[a]		
Outcome	Scale	Model	Baseline	Follow-up	Baseline	Follow-up	Cohen's *d*	B	SE	*p*	B	SE	*p*
Respiratory symptoms	0–11	L	2.97 (2.74)	2.91 (2.74)	2.94 (2.67)	3.05 (2.77)	0.061	–0.155	0.192	0.419	–0.141	0.202	0.485
Asthma symptoms	0–9	L	2.34 (2.55)	2.20 (2.45)	2.23 (2.50)	2.24 (2.51)	0.051	–0.088	0.247	0.722	–0.133	0.253	0.600
MCS	0–100	L	44.81 (12.56)	45.62 (11.94)	46.02 (12.06)	46.85 (12.36)	0.005	–0.059	0.789	0.940	–0.003	0.812	1.000

L, linear; M, mean; SE, standard error.
a Adjusted for sex, age, housing benefit, income and smoking status.

TABLE 9 Secondary health outcomes at baseline and follow-up for the intervention and control group

			Study cohort, M (SD)										
			Intervention		Control		Effect size	Unadjusted			Adjusted[a]		
Outcome	Scale	Model	Baseline	Follow-up	Baseline	Follow-up	Cohen's *d*	B	SE	*p*	B	SE	*p*
PCS	0–100	L	42.90 (13.94)	43.11 (13.80)	42.25 (14.47)	41.48 (14.24)	0.107	0.987	0.664	0.137	0.976	0.669	0.145
Subjective well-being	0–10	L	6.55 (2.50)	6.89 (2.25)	6.96 (2.42)	6.92 (2.42)	0.200	0.375	0.134	0.005	0.384	0.134	0.004

L, linear; M, mean; SE, standard error.
a Adjusted for sex, age, housing benefit, income and smoking status.

age, household income, housing benefits and smoking status (B 0.38, 95% CI 0.11 to 0.64). This suggests that the intervention had a small positive impact on people's overall feelings of well-being (Cohen's $d = 0.20$).

The impacts of the intervention on the secondary psychosocial outcomes

Table 10 shows the results for the secondary psychosocial outcomes of the study. Analyses indicate that the intervention had an impact on financial difficulties, thermal satisfaction, satisfaction of the state of repair of the home, the number of housing problems and social interactions.

The number of respondents reporting putting up with feeling cold to save heating costs decreased for the intervention group. A smaller decrease was observed for the control group. This represents a significant interaction effect at the 5% level. The interaction effect remained significant after controlling for the covariates [odds ratio (OR) 0.49, 95% CI 0.25 to 0.94]. The effect size of the interaction was small (Cohen's $d = 0.15$).

A significant interaction effect was observed for self-reported financial difficulties, even after controlling for sex, age, household income, housing benefits and smoking status (B –0.15, 95% CI –0.25 to –0.05). The size of the interaction effect was small (Cohen's $d = 0.20$). *Table 10* shows that self-reported financial difficulties decreased to a greater extent in the intervention group than in the control group.

A significant interaction effect was observed for thermal satisfaction, which remained after controlling for the covariates (B 1.34, 95% CI 0.91 to 1.77). This is a medium-sized effect (Cohen's $d = 0.46$). Although both the intervention and control groups saw an increase in thermal satisfaction, the increase was greater in the intervention group.

Significant interaction effects were observed for the two housing conditions variables. The effects remained significant after adjusting for the covariates for both people's satisfaction with the current state of repair of their home (B 1.35, 95% CI 0.92 to 1.79) and the number of reported housing problems (B –1.10, 95% CI –1.54 to –0.66). The effects were small-to-medium sized (Cohen's $d = 0.44$ and 0.39, respectively). *Table 10* shows that satisfaction with the state of repair of their home increased for the intervention group but decreased for the control group. The number of reported housing problems decreased for both the intervention and control groups but decreased to a greater extent in the intervention group.

Finally, a significant interaction effect was found for social interactions, which remained after controlling for the covariates (OR 0.32, 95% CI 0.13 to 0.77). The size of the interaction effect was small (Cohen's $d = 0.19$). The proportion of people feeling reluctant to invite friends or family to their home because of difficulties with keeping it warm fell to a greater extent in the intervention group than in the control group.

The impact of the intervention on health-related quality of life and QALYs

Mean baseline SF-6D scores for the intervention and control groups of 0.685 (SD 0.167) and 0.683 (SD 0.164), respectively, were observed. Mean scores for follow-up were higher for both the intervention 0.692 (SD 0.168) and control group 0.695 (SD 0.170). The baseline-adjusted QALY gain for the intervention group was 0.003, whereas the intervention group experienced an increase of 0.007 QALYs. SF-6D score at both time points, the resulting change in SF-6D, and the QALYs difference were all insignificant between groups {B –0.007 [standard error (SE) 0.016], 95% CI –0.04 to 0.02}. Accounting for covariates in a regression analysis framework resulted in an insignificant and negative coefficient for the intervention. These results suggest that the intervention did not have a significant impact on the quality of life or on the utility score of respondents.

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TABLE 10 Secondary psychosocial outcomes at baseline and follow-up for the intervention and control group

			Study cohort, M (SD)										
			Intervention		Control		Effect size	Unadjusted			Adjusted[a]		
Outcome	Scale	Model	Baseline	Follow-up	Baseline	Follow-up	Cohen's *d*	B	SE	*p*	B	SE	*p*
Fuel poverty													
Putting up with feeling cold to save heating costs	0–1	Bin	0.63 (0.48)	0.45 (0.50)	0.57 (0.50)	0.46 (0.50)	0.153	–0.720	0.324	0.026	–0.717	0.334	0.032
Financial stress	1–5	O	2.96 (1.40)	2.60 (1.35)	2.81 (1.38)	2.58 (1.36)	0.108	–0.381	0.213	0.074	–0.403	0.220	0.067
Financial difficulties	1–4	L	1.93 (0.90)	1.67 (0.73)	1.74 (0.75)	1.65 (0.73)	0.204	–0.148	0.047	0.002	–0.149	0.050	0.003
Food security	1–4	L	3.51 (0.77)	3.61 (0.73)	3.55 (0.77)	3.59 (0.73)	0.117	0.057	0.035	0.093	0.063	0.036	0.080
Thermal satisfaction	1–5	O	3.45 (1.15)	3.85 (1.10)	3.71 (1.16)	3.63 (1.22)	0.462	1.319	0.216	0.000	1.342	0.219	0.000
Housing conditions													
Satisfaction with state of repair of home	1–5	O	3.26 (1.28)	4.04 (1.06)	3.60 (1.26)	3.82 (1.20)	0.440	1.342	0.222	0.000	1.352	0.221	0.000
Number of housing problems	0–6	O	1.88 (1.53)	1.20 (1.32)	1.49 (1.53)	1.32 (1.45)	0.386	–1.065	0.221	0.000	–1.097	0.225	0.000
Number of heated rooms													
Day	0–4	O	2.74 (1.29)	3.01 (1.21)	2.69 (1.32)	2.78 (1.28)	0.137	0.387	0.212	0.067	0.408	0.213	0.055
Evening	0–4	O	2.24 (1.01)	2.31 (1.04)	2.21 (1.01)	2.19 (1.02)	0.096	0.239	0.205	0.242	0.239	0.205	0.242
Social interactions	0–1	Bin	0.24 (0.43)	0.12 (0.33)	0.18 (0.39)	0.14 (0.34)	0.195	–1.052	0.429	0.014	–1.149	0.456	0.012

Bin, binomial; L, linear; M, mean; O, ordinal.
a Adjusted for sex, age, housing benefit, income and smoking status.

Discussion

Key results

This was the first large quasi-experimental field study with a controlled pre-/post-test design to examine both the short-term health and psychosocial impacts of energy efficiency investments in low-income areas. This community-based study found no evidence that investments in energy efficiency improve respiratory or mental health in the short-term. Furthermore, no evidence was found that they provide physical health benefits in the short-term. However, those who received energy efficiency measures reported improved subjective well-being as compared with the controls, as well as improvements in a number of the secondary psychosocial outcomes that are conducive to better health. The study found that respondents who received the intervention also reported fewer financial difficulties, higher thermal satisfaction and higher satisfaction with the improvement of their homes. They also reported less reluctance to invite friends or family to their homes. The results were similar with or without controlling for a number of socioeconomic covariates.

Limitations

The field study in this chapter used self-completion questionnaires to be filled out by the study participants themselves. It is therefore subject to a number of biases. The study had a low initial response rate and a substantial loss to follow-up. However, the response and attrition patterns were similar for the intervention and control areas, and an analysis showed that there were only a small number of differences between study respondents and those lost to follow-up. The final samples appeared largely comparable in terms of their composition. The low response and retention rates are perhaps not completely surprising given the nature of the research. The study was conducted in low-income neighbourhoods, where response rates for mail and door-to-door data collection methods tend to be low.[114] Several strategies were used to increase the response rates, including incentives and door knocking.

In order to make the control group as comparable as possible to the intervention group, the matched control areas were selected using the same criteria as the intervention areas. This proved to be challenging, given that many comparable areas had already received energy efficiency measures through the intervention programme. A number of control areas were subsequently selected to receive energy efficiency investments in the year after the study. The composition of the final samples suggest that the control participants may be used as a robust 'non-exposed' comparator group.

A further limitation is the time frame of the study. Outcome measures were collected in the heating seasons directly before and after the intervention. The short follow-up period means that claims can only be made about the short-term effects of the intervention (see *Interpretation*). Studies with longer follow-up periods are needed to establish the long-term impacts of energy efficiency investments.[48] This has been done in the data linkage study (see *Chapter 2*).

According to Thomson *et al.*[48,115] interventions targeting at-risk populations provide clearer health benefits than area-based housing improvement programmes. The benefits of area-based programmes may be less pronounced because they do not target those who are most at need. Unlike other demand-led schemes such as Warm Homes Nest, the Warm Homes Arbed intervention was not tailored according to individual need. However, the intervention did target low-income areas with inadequate warmth owing to a large number of hard-to-heat, hard-to-treat homes within the area. Still, no clear physical health improvements were observed in this study, which may be explained by the limited follow-up period in the research. It would be useful to directly compare area-based (e.g. Warm Homes Arbed) and demand-led, targeted (e.g. Warm Homes Nest) schemes.

Researchers evaluating complex social interventions are faced with several challenges.[116,117] The study involved an evaluation of an external, in this case government-led, programme. That means that the researchers did not have control over the content or delivery of the programme. Furthermore, the intervention effects may be diluted by constant changes in the context. For example, it is possible that respondents may have independently chosen to undertake energy efficiency improvements to their home, therefore diluting the effects of the intervention programme.[117,118] However, there is no evidence that this happened in the study.

Interpretation

The study suggests that, although there is no evidence that energy efficiency investments provide physical health benefits in the short term, they improve social and economic conditions that are conducive to better health. Furthermore, they were found to be beneficial for subjective well-being. Longer-term studies are needed to establish the health impacts of energy efficiency investments. According to Thomson *et al.*,[48,115] most studies investigating the health impacts of housing improvements have limited follow-up periods. Studies have therefore been unable to detect longer-term health impacts. We would expect that the changes in the psychosocial outcomes are conducive to better health in the longer term. The observed changes in the social outcomes may be a valuable indicator of the potential for longer-term health benefits.

Generalisability

The results are likely to be generalisable to other low-income areas with inadequate warmth and other vulnerable at-risk populations. The public health implications are typical for other deprived areas across the UK with low-quality housing. The results may be less generalisable to other less-deprived areas.

Chapter 4 The household monitoring study

Introduction

This chapter follows the STROBE reporting guidelines for observational study designs.[81]

Background

It is widely acknowledged that living in cold conditions poses various health risks, in particular to low-income, fuel-poor households.[6] Improving the energy efficiency of the housing stock might bring multiple positive health gains through improved hydrothermal conditions and lower financial stress through reduced fuel consumption. More recently, there have been suggestions that increasing the energy efficiency of a home could have detrimental effects on people's health.[64] Reduced ventilation through insulation and draughtproofing may increase RH levels[65] and, as a result, promote mould growth.[66,67]

Only a handful of studies to date have attempted to identify and measure the impact of affordable warmth interventions on internal conditions and fuel consumption using a number of monitoring methodologies and data analysis techniques. Most research in this area has been cross-sectional,[71] reported means and/or temperature frequencies,[49,120] monitored events for a short period only[60] or did not include control households.[63,121] Furthermore, most studies did not make use of the granularity of the measurements, consider the non-independent repeated nature of monitoring data or control systematically for external conditions.

This household monitoring study addresses some of these issues through detailed long-term household monitoring of intervention and control households at baseline and follow-up. Both the internal and the external hydrothermal conditions are measured at a higher resolution than previous research and combined into a comprehensive data set that was amenable to multilevel interrupted time series analysis.[122] This approach allows the impact of the energy efficiency interventions to be estimated with a maximum level of statistical power, adjusting for external conditions at the same level as the internal measurements.

Objectives

This chapter describes the methodology and findings of the household monitoring study. The study had the overall aim to examine the impact of the second phase of the intervention programme on internal household conditions and energy use. It set out to determine the impact of (1) the intervention on whole-house indoor air temperature and RH; (2) individual measures on whole-house indoor air temperature and RH; (3) the intervention on indoor temperatures at different times of the day; (4) the intervention on indoor temperatures in different rooms within the home; (5) the intervention under different external hydrothermal conditions; (6) the intervention on the average daily duration and cumulative substandard internal hydrothermal conditions; and (7) the intervention on household energy use, in particular gas usage.

The research described in this chapter received ethics approval from the SREC of the Welsh School of Architecture, Cardiff University (EC1308.160).

Methods

Study design

The household monitoring study uses a quasi-experimental controlled before-and-after design consisting of long-term hydrothermal condition monitoring in two subsequent heating seasons. The monitoring took place in a number of households before and after they received energy efficiency improvements under the intervention programme. The study further included a number of control households that did not receive such improvements. The indoor measurements for the control households were taken at the same time as for the intervention households. All households for the monitoring study were recruited from the community sample described in *Chapter 3*.

Setting

The study was conducted in five low-income areas where energy performance investments were scheduled and in five matched control areas where no such investments were planned (*Figure 8*). The baseline measurements were taken in the 2013/14 heating season. The follow-up measurements were taken in the 2014/15 heating season.

The five intervention and control areas were selected from year 2 schemes included in the community-based study (see *Chapter 3*). The intervention areas and their matched control areas were in Brynamman (Carmarthenshire), Caerau (Cardiff), Llay (Wrexham), Hollybush (Caerphilly) and Pennydarren (Merthyr Tydfil). The areas were selected based on the scheduling of the intervention work and the returns of the baseline

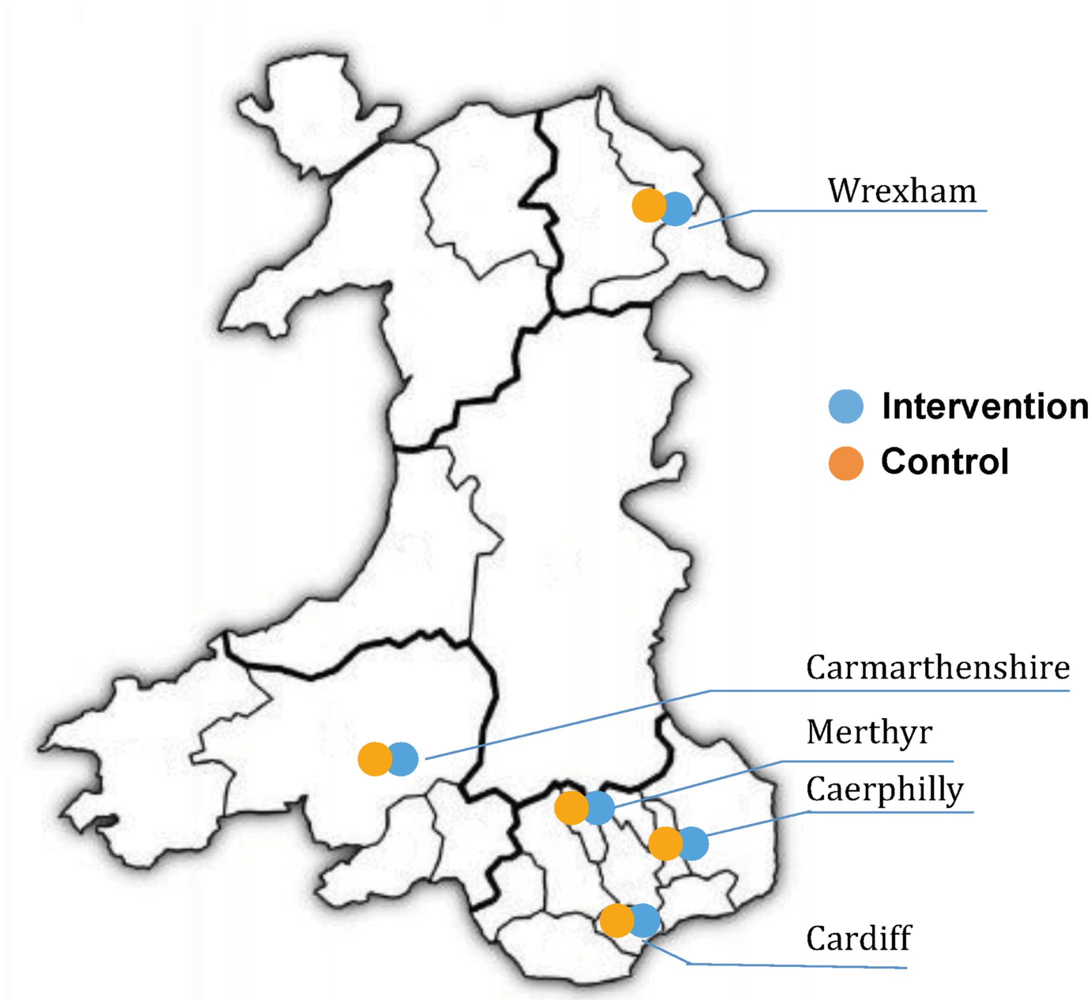

FIGURE 8 Locations of the intervention and control areas.

questionnaires from the community-based study. This was to ensure that a sufficient number of households could be recruited in time for the monitoring to take place in the 2013/14 heating season. The communities varied in terms of their location, climatic conditions and dominant housing type. The Cardiff and Merthyr Tydfil areas consisted predominantly of British steel-framed [British Iron and Steel Federation (BISF)] houses, Caerphilly and Carmarthenshire were off-gas areas and Wrexham consisted predominantly of terraced houses with solid walls. The control areas were selected to resemble the intervention areas as much as possible in terms of housing type and level of deprivation (see *Chapter 3*).

Respondents from the selected areas who provided consent to be recontacted were invited by telephone to have their house monitored. In total, 99 households agreed to take part in the study, of which 50 were located in the intervention areas and 49 in the matched control areas. Households were visited between 11 January and 1 February 2014 to install indoor data loggers, and again between 25 March and 17 April 2014 to collect them. In the baseline period, houses were monitored for a minimum of 28 consecutive days and a maximum of 71 days. On average, the houses were monitored for 46 days, with a SD of 9 days.

The households that took part in the first part of the study were recontacted by letter prior to the 2014/15 heating season for follow-up measurements. The reminder letter was followed up by a telephone call to arrange an installation visit. Households were visited between 1 November and 18 November 2014 to install indoor data loggers, and again between 12 April and 30 April 2015 to collect them. In the follow-up period, houses were monitored for a minimum of 97 days and a maximum 181 days. On average, houses were monitored for 127 days (SD 32 days). Loss to follow-up was low (11%), resulting in a final sample of 88 households (intervention, $n = 48$; control, $n = 40$). Local weather stations were installed in or close to the five monitoring areas to record external meteorological conditions during the baseline and follow-up periods. Gas and electricity meter readings were taken during the installation and collection visits.

Participants

Households for the monitoring study were recruited from the community sample described in *Chapter 3*. The aim was to recruit 100 households for the monitoring study, with a subset of households undergoing energy efficiency improvements ($n = 50$) and a control group that did not receive such improvements ($n = 50$).

Variables

The following exposure intervention and outcome variables were included in the analyses.

Intervention measures

The intervention measures included external wall insulation (with mechanical ventilation), new windows and doors, boiler and heating system upgrades, connection to the gas mains network and installation of voltage optimisers. The measures were recorded for each participating household. In this study, 35 households received external wall insulation, nine received new windows and doors, 48 received a new boiler or heating system and 46 had a voltage optimiser installed. Furthermore, 20 properties from two intervention areas were connected to the mains gas network. *Figure 9* shows that, on average, the measures increased the Standard Assessment Procedure ratings of the intervention households from 52 (SD 12) to 66 (SD 5). This is an average increase from Energy Performance Certificate rating band E to band D. The Standard Assessment Procedure was developed by the Building Research Establishment and is currently the methodology used by the UK Government to assess the energy performance of dwellings.[123] It presents the energy performance of homes in a figure ranging from 1 to 100. This has been subdivided into seven bands ranging from A to G.

Indoor air temperature and relative humidity

The main outcomes of the household monitoring study were indoor air temperature and RH at different times of the day and in different rooms within the home. These were measured with three Tinytag Ultra 2 data loggers (Gemini Data Loggers, Chichester, West Sussex, UK) that were positioned in the living room, kitchen and main bedroom, respectively. These rooms were selected as they represent the key living spaces in domestic dwellings. The data loggers were positioned away from any direct heat source and external

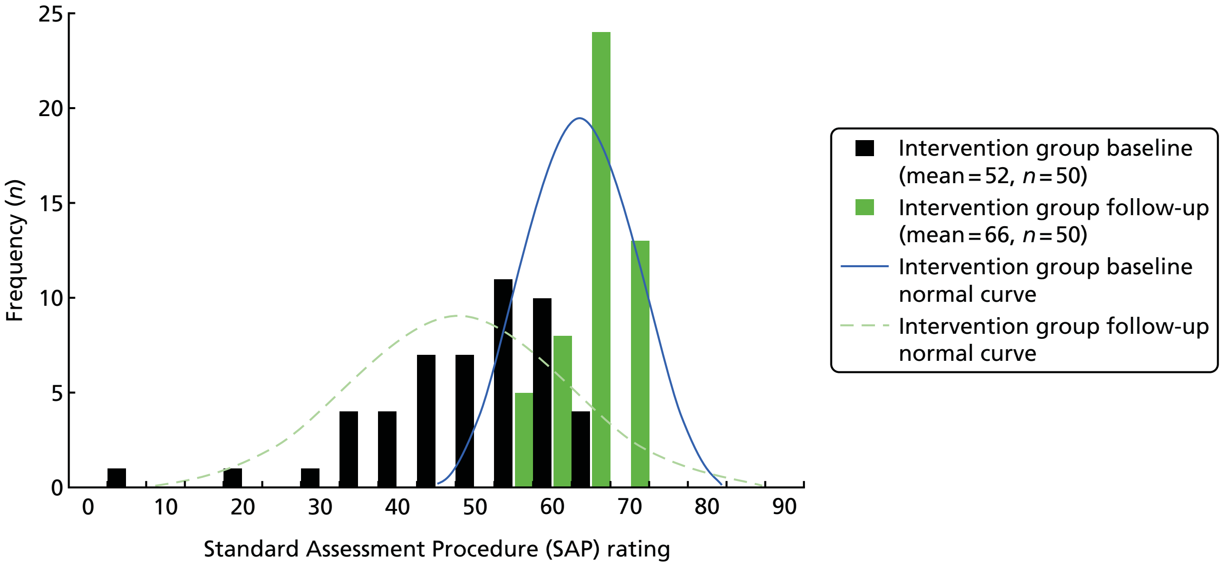

FIGURE 9 Standard Assessment Procedure ratings of intervention households before and after installation of the energy efficiency measures.

windows, in a location where they would cause the least disturbance to the occupants and were unlikely to get covered, typically on top of a cupboard or shelf at a height of about 2 metres. Owing to practical issues when placing loggers in households with diverse circumstances, furnishings and personal preferences, the exact locations where they were positioned within rooms varied. Indoor air temperature and RH were recorded every 15 minutes.

The data were used to calculate the average daily indoor air temperature and RH, as well as the average indoor air temperature and RH in the morning (06.00–09.00), during the day (09.00–18.00), in the evening (18.00–23.00) and at night (23.00–06.00). The data were used for the three rooms separately and combined to calculate a whole-house average.

The Tinytag Ultra 2 data loggers have an air temperature reading range of –25 °C to 85 °C, with a resolution of 0.01 °C and an error range of ± 0.35 °C, and a RH reading range of 0% to 95%, with a resolution of 0.3% and an error range of ± 3.0% at 25 °C.

Duration and cumulative substandard internal conditions

The study further explored the impact of the intervention on the duration and cumulative substandard internal conditions.

The duration of substandard internal conditions was determined by recording each day the time that the indoor air temperature dropped to < 18 °C and dropped to < 16 °C and that the indoor RH was > 60%. These thresholds were based on the literature, which shows that indoor air temperatures in winter of ≥ 18 °C pose minimal risk to the health of a sedentary person and to people aged > 65 years or with pre-existing medical conditions.[124] Indoor air temperatures of < 18 °C increase the risk of high blood pressure and this risk is heightened in temperatures of < 16 °C. Indoor air temperatures of < 16 °C may further diminish resistance to respiratory diseases.[125] RH levels of > 60% have been linked to respiratory and allergic conditions, as well as fungal growth and house dust mite infestations.[66,67]

The cumulative substandard internal conditions is the time intensity integral of substandard conditions beyond the chosen thresholds, thus representing the daily dose of substandard internal conditions to which householders are potentially exposed. The cumulative substandard indoor air temperature reflects the amount of underheating over the period of 1 day. The cumulative substandard indoor RH reflects the total amount of exposure to risky humidity levels.

The cumulative substandard internal conditions are expressed as °C·hour and % RH·hour for indoor air temperature and RH, respectively.

Outdoor air temperature and relative humidity

Outdoor air temperature and RH were measured by local weather stations that were installed in or close to the five monitoring areas, typically in a participating household's garden. Outdoor air temperature and RH were recorded every 15 minutes by local Delta-T-GP1 weather stations (Delta-T Devices, Burwell, Cambridgeshire, UK). Outdoor air temperature and RH were recorded for the full baseline and follow-up periods for each of the five locations.

The measurements were combined to calculate the average whole-day outdoor air temperature and RH, and to calculate the average outdoor air temperature and RH in the morning (06.00–09.00), during the day (09.00–18.00), in the evening (18.00–23.00) and at night (23.00–06.00).

Delta-T-GP1 weather stations have an air temperature reading range of –20 °C to 70 °C, with a resolution of 0.05 °C and an error range of ± 0.3 °C, and a RH reading range of 0–100%, with a resolution of 0.2% and an error range of ± 2% between 5% and 95% and of ± 2.5% for < 5% and > 95% RH.

Heating demand: heating degree days

The outdoor air temperature measurements were subsequently converted into daily heating degree days (HDDs).[126] HDDs reflect the demand for energy needed to heat buildings over a specific period, in this case 1 day. The heating demand is calculated by summing the differences between the outdoor air temperature and a reference temperature. As such, the HDD measure is an exposure measure reflecting the cumulative amount of degrees the temperature falls below the base temperature over 1 day. The reference temperature, 15.5 °C in the UK, reflects the outdoor temperature at which, generally, no heating is needed to maintain comfortable internal conditions.[127,128] In this study, HDDs are calculated as the mean temperature difference for the 96 daily readings, similar to the mean degree hour method, which is considered the most detailed method of calculating degree days.[126] The outside temperature is only included in the calculations when it is lower than the reference temperature.

Heating degree days provide some advantages over other methods that use mean outdoor temperatures to calculate energy demand: they take account of fluctuations in outdoor air temperature and exclude periods when space heating is not needed, therefore capturing extreme conditions in a way that mean temperature methods cannot. This makes them more reliable in predicting energy consumption, particularly in milder conditions and in periods with fluctuating or extreme cold snaps, when they capture both the magnitude and duration of an event. HDDs also have a number of shortcomings.[129] They are based on assumptions about when additional energy is needed to heat a building and ignore the fact that some buildings are only heated during specific periods. Furthermore, they do not reflect variations in the ability of different buildings to retain heat or to exploit solar gains.

Average daily gas usage

Average daily gas usage was calculated from meter readings taken during the installation and collection visits for both the baseline and follow-up periods. The change in average daily gas usage provides an indication of the effectiveness of the energy performance investments, as most of the metred gas will have been used for space and water heating. It was not possible to take gas meter readings in off-gas areas.

Bias

The household monitoring study was undertaken in a subset of households that had already participated in the community-based study. The biases described in *Chapter 3* therefore also apply to this part of the project.

Another potential bias was that the local climate could lead households in different areas to be exposed to different external hydrothermal conditions during the baseline and follow-up. To control for such biases, the study compared internal conditions of the intervention households with the control households located within the same areas. Furthermore, internal hydrothermal conditions were adjusted for external hydrothermal conditions as measured by weather stations installed in or near the different monitoring areas. This design minimised differences between households resulting from external hydrothermal conditions.

Selection and attrition bias have the potential to overestimate and underestimate the effects of the intervention. The household monitoring was undertaken in a subset of households that had already participated in the community-based study (see *Chapter 3*).

There was a risk of selection bias in the households agreeing to their house being monitored, as well as attrition bias between the baseline and follow-up monitoring. Households that had completed the questionnaire and consented to be recontacted were invited to participate in the monitoring study. The monitoring households and the overall sample from which they were selected were broadly similar in terms of their building and sociodemographic characteristics. The monitoring sample contained a higher percentage of terraced houses (47.9% vs. 29.0%) and private rentals (11.5% vs. 4.3%) than the overall area sample. *Figure 10* shows that the response rate for the intervention group (23.3%) was slightly lower than that for the control group (30.2%). However, that was mainly owing to the size of the area sample from which they were recruited. Attrition was higher for the control households ($n = 9$) than for the intervention households ($n = 2$), but no monitored area lost more than four households. A loss to follow-up analysis showed that attrition did not bias the samples in a systematic way. The final intervention and control samples were comparable in terms of building age, building type, number of bedrooms, tenure and household composition (i.e. with or without children) (see *Table 11*).

Study size

The study set out to monitor 100 properties over a 4-week period in two subsequent heating seasons. The 15-minute interval readings were combined to calculate whole-day averages, as well as averages for 4-day segments (i.e. morning, day, evening and night). This would ensure that the statistical analyses were based on ≥ 5600 data points clustered within the 100 households.

The eventual sample consisted of 99 households that were monitored for an average of 46 days (SD 9 days) during the baseline period and 88 households that were monitored for an average of 127 days (SD 32 days) for the follow-up period. This created a database with 15,771 data points for the different hydrothermal outcome variables after the removal of missing day values. All measurements were included in the final data set. This means that all 99 households contributed to the baseline estimates, but only the measurements of the 88 households included in both the baseline and follow-up contributed to the estimates for changes over time. This means that the parameters reported in this report were based only on the monitoring data of 88 households for which we had both baseline and follow-up periods.

Statistical methods

The data were analysed by constructing a series of controlled multilevel interrupted time series regression models, with daily internal conditions (level 1) nested within households (level 2) that either received an intervention or did not. The nested multilevel design makes it possible to take account of the clustering of the observations over time using random effects.[130] The approach also enables the handling of unbalanced data when the number of observations differ for the different households and time periods.[130] This makes the approach suitable for analysing monitoring data of multiple properties with different start and end dates.

Analyses were conducted with the MLwiN version 2.36 software package.[109] The software package is specifically designed for fitting multilevel models, in this case an interrupted time series regression analysis. The analysis involved the use of the time series of the daily averaged hydrothermal conditions that were measured during the baseline and follow-up periods in the intervention and control households. The interruption occurred between baseline and follow-up sampling periods when intervention households had improvement work done to their homes. Therefore, the interruption in the ‘interrupted time series’ refers to the energy efficiency improvements undertaken in the intervention households. This was then compared with control households that did not receive the energy efficiency investments during that period.

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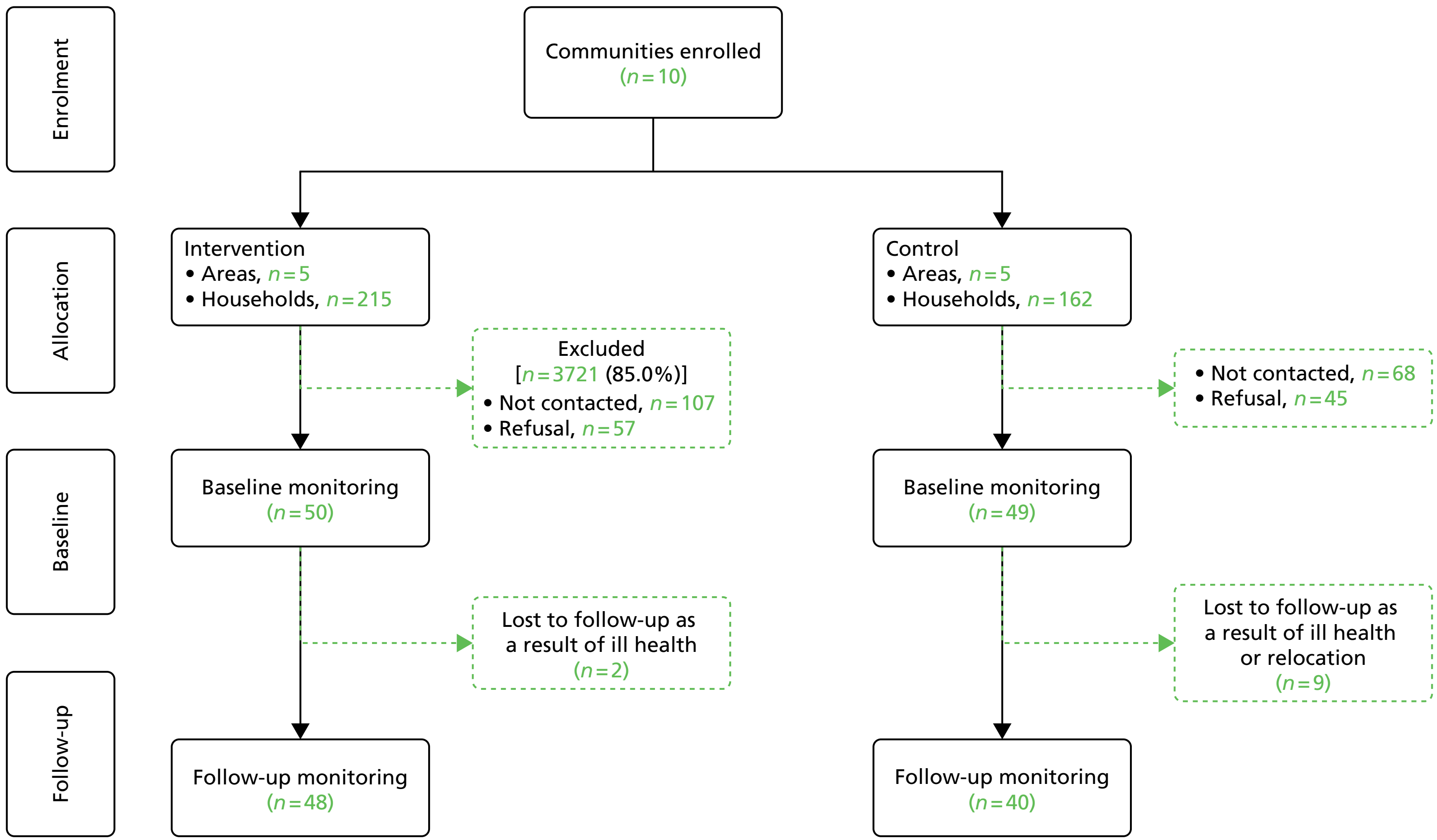

FIGURE 10 The flow diagram for the household monitoring study.

The basic statistical models included three independent variables: (1) the intervention group, (2) the measurement period and (3) an interaction between measurement period and intervention group. The intervention group variable indicated whether the measurements were taken in an intervention or a control household. The measurement period variable indicated whether the measurements were taken in the baseline or the follow-up period. The interaction term of the measurement period and intervention group variables indicated that the intervention has taken place in the follow-up period for the intervention households. The regression coefficient related to this term shows the level of change in internal conditions for the intervention group relative to the control group.

The statistical models were further controlled for external conditions. This was done by including the daily averaged external measurements as independent variables. The models with indoor air temperature as the outcome variable included daily HDD values as a covariate to control for external thermal conditions. The models with indoor RH as the outcome variable additionally included a measure of the average daily outdoor RH to control for external hydrological conditions.

Interrupted time series analyses typically include a time variable (indicating the time elapsed since the start of the study, as measured in days) and a time after the interruption variable (indicating the time elapsed since the intervention, as measured in days) in order to identify trends over time and changes in the trend after the intervention, respectively.[131] However, as no obvious trend over time was observed within the baseline and follow-up periods, these terms were excluded from the regression models.

One problem with repeated measurement data is that the measurements are often not independent, which violates one of the assumptions of ordinary least squares regression. Autocorrelation within time series, when measurements close to one another are more similar than measurements that are further apart, may lead to increased type 1 errors. The autocorrelation function and partial autocorrelation function in MLwiN indicated autocorrelation with a diminishing lag. Autocorrelation reflects the internal correlation within a time series, showing the degree to which the different measurements are interdependent.[131] An autoregressive model was constructed by adding a weight specifying that the error covariance decreases as the time distance between measurements increases in order to control for the observed dependency.[132]

Results

Participants

The household monitoring study took place in five intervention areas and their matched control areas nearby (see *Figure 8*). Respondents from these areas who provided consent to be recontacted were invited to have their home monitored. In total, 202 households were invited by telephone to participate, of which 99 agreed to have their house monitored (intervention, $n = 50$; control, $n = 49$). This corresponds to a response rate of 49%. The rest of the households were not contacted, either because they did not provide a contact telephone number or because the maximum number of households for the area was reached. Eleven households were lost to follow-up owing to ill health or relocation (intervention, $n = 2$; control, $n = 9$). This means that 99 households were monitored at baseline and 88 households at follow-up. *Figure 10* shows the flow of households through the monitoring study.

Descriptive data

Table 11 summarises the characteristics of the intervention and control households at baseline and follow-up. It shows that there were no statistically significant differences between the two groups in terms of building age, building type, number of bedrooms, tenure and household composition.

Table 12 shows the average internal conditions for the intervention and control households at baseline and follow-up, unadjusted for external conditions. The table suggests that indoor air temperatures increased for the intervention group but decreased for the control group between baseline and follow-up. The changes in indoor RH were less pronounced. Small reductions were observed for both the intervention

TABLE 11 Characteristics of the intervention and control households at baseline and follow-up

	Study cohort, % (*n*/*N*)			
	Intervention		Control	
Characteristics	Baseline	Follow-up	Baseline	Follow-up
Year of construction				
Before 1919	22.5 (11/49)	28.9 (13/45)	39.1 (18/46)	35.9 (45/39)
1919–1945	28.6 (14/49)	20.0 (9/45)	32.6 (15/46)	33.3 (14/39)
1945–1965	32.65 (16/49)	37.8 (17/45)	0.0 (0/46)	0.0 (0/39)
1965–1979	8.2 (4/49)	8. 9 (4/45)	26.1 (12/46)	28.2 (11/39)
1980 or later	8.2 (4/49)	4.4 (4/45)	2.2 (1/46)	2.6 (1/39)
Building type				
Detached house	4.0 (2/50)	4.4 (2/46)	4.1 (2/49)	4.8 (2/42)
Semi-detached house	42.0 (21/50)	47.8 (22/46)	49.0 (24/49)	40.5 (17/42)
Terraced house	52.0 (26/50)	45.7 (21/46)	40.82 (20/49)	47.6 (20/42)
Bungalow	0.0 (0/50)	0.0 (0/46)	2.0 (1/49)	2.4 (1/42)
Purpose-built flat	2.0 (1/50)	2.2 (1/46)	4.1 (2/49)	4.8 (2/42)
Construction type				
British steel framed	30.0 (15/50)	32.6 (15/46)	38.8 (19/49)	42.9 (18/42)
Masonry solid wall	60.0 (30/50)	58.7 (27/46)	57.1 (28/49)	54.8 (23/42)
Masonry cavity wall	10.0 (5/50)	8.7 (4/46)	4.1 (2/49)	2.4 (1/42)
Number of bedrooms				
1	2.0 (1/49)	2.2 (1/45)	4.1 (2/49)	4.8 (2/42)
2	8.2 (4/49)	8.9 (4/45)	10.2 (5/49)	9.5 (4/42)
≥ 3	89.8 (44/49)	89.0 (40/45)	85.7 (42/49)	85.7 (36/42)
Tenure				
Owner occupied	61.2 (30/50)	57.8 (26/45)	61.2 (30/49)	61.9 (26/42)
Private rental	14.3 (7/50)	11.1 (5/45)	8.2 (4/49)	11.9 (5/42)
LA rental	24.5 (12/50)	24.4 (11/45)	28.6 (14/49)	26.2 (11/42)
Housing association rental	2.0 (1/50)	6.7 (3/45)	2.0 (1/49)	0.0 (0/42)
Household composition				
Without children	68.8 (33/48)	67.4 (31/46)	81.3 (39/48)	80.5 (33/41)
With children	31.3 (15/48)	32.6 (15/46)	18.8 (9/48)	19.5 (8/41)

and the control groups. The internal conditions presented in the table are not adjusted for external hydrothermal conditions, which may differ across the monitoring periods and areas.

Table 13 shows the distribution of internal conditions for the intervention and control groups at baseline and follow-up, again unadjusted for external conditions. The figures represent the proportion of measurements falling into the different indoor air temperature and RH bands. The distribution of indoor air temperature was similar for the two groups at baseline [$\chi^2(3) = 1.761$; $p = 0.623$] but differed at follow-up [$\chi^2(3) = 18.231$; $p = 0.000$]. The proportion of substandard indoor air temperature measurements decreased for the intervention group but increased for the control group. In contrast, the proportion of indoor air temperature

TABLE 12 Average indoor conditions at baseline and follow-up for the intervention and control groups, unadjusted for outdoor conditions

Outcome	Study cohort, M (SD)			
	Intervention		Control	
	Baseline	Follow-up	Baseline	Follow-up
Average indoor air temperature (°C)				
Whole house				
Overall	18.35 (2.99)	19.03 (2.58)	17.62 (2.59)	17.30 (2.87)
Morning	17.23 (3.32)	17.95 (2.91)	16.27 (2.67)	16.12 (2.97)
Day	18.45 (3.09)	19.10 (2.59)	17.64 (2.89)	17.42 (2.92)
Evening	19.09 (3.02)	19.89 (2.81)	18.62 (2.81)	18.12 (3.13)
Night	18.18 (3.09)	18.93 (2.70)	17.48 (2.46)	17.06 (2.93)
Living room daily	18.82 (3.11)	19.43 (2.85)	18.32 (2.51)	18.12 (3.00)
Bedroom daily	18.37 (3.38)	19.09 (3.11)	17.63 (3.14)	16.57 (3.39)
Kitchen daily	17.86 (3.54)	18.69 (3.12)	16.92 (3.65)	17.20 (3.63)
Average indoor RH (%)				
Whole house				
Overall	55.71 (11.48)	53.26 (11.35)	57.86 (11.17)	56.50 (11.70)
Morning	56.42 (12.41)	53.57 (12.01)	58.99 (11.18)	57.00 (11.97)
Day	55.22 (11.40)	53.00 (11.11)	57.54 (11.20)	55.89 (11.62)
Evening	55.91 (11.48)	53.52 (11.76)	57.67 (11.79)	56.88 (12.12)
Night	55.99 (11.95)	53.27 (11.74)	57.92 (11.33)	56.80 (12.03)
Living room daily	53.30 (12.44)	52.17 (11.90)	55.75 (11.60)	53.35 (12.54)
Bedroom daily	56.78 (12.95)	53.47 (12.40)	57.85 (11.55)	59.32 (12.69)
Kitchen daily	57.12 (12.37)	54.14 (12.72)	59.96 (14.75)	56.83 (13.84)

M, mean.

TABLE 13 Distribution of indoor conditions at baseline and follow-up for the intervention and control groups, unadjusted for outdoor conditions

Outcome	Study cohort (%)			
	Intervention		Control	
	Baseline	Follow-up	Baseline	Follow-up
Indoor air temperature °C				
< 16	23.5	11.0	27.0	30.4
16–18	20.3	18.5	26.3	26.6
18–24	55.1	68.5	45.5	42.9
> 24	1.2	2.0	1.1	0.1
Indoor RH (%)				
< 40	5.2	9.8	3.5	6.1
40–50	30.3	34.3	26.5	25.3
50–60	30.7	29.3	25.1	34.8
> 60	35.4	25.0	45.0	33.8

within the 18–24 °C band (the recommended comfort zone) increased for the intervention group but decreased for the control group.

Furthermore, *Table 13* shows that the proportion of substandard RH measurements (i.e. > 60% RH) decreased for both the intervention and control groups. The distribution of indoor RH levels was similar at baseline [$\chi^2(3) = 2.659$; $p = 0.447$] and at follow-up [$\chi^2(3) = 3.001$; $p = 0.391$].

Main results

Indoor air temperature

Figure 11 shows the estimates and 95% CIs of the measurement occasion × intervention group interactions for the overall average whole-house temperature, and for the average whole-house temperatures in the morning, day, evening and night, respectively. These interactions indicate the levels of change in indoor air temperature observed in the intervention households in comparison to the control households. The figure shows that, on average, the intervention increased the indoor air temperature by 0.84 °C (95% CI 0.64 to 1.04 °C). The largest changes were observed in the evening (1.17 °C, 95% CI 0.94 to 1.39 °C) and at night (1.01 °C, 95% CI 0.79 to 1.24 °C). Slightly smaller changes were observed in the morning (0.51 °C, 95% CI 0.26 to 0.75 °C) and during the day (0.62 °C, 95% CI 0.40 to 0.85 °C).

Figure 12 shows that significant increases in indoor air temperatures were found for the living room and bedroom. On average, the intervention increased the indoor air temperature of the living room by 1.01 °C (95% CI 0.78 to 1.23 °C) in comparison to the control households. The largest change was observed in the bedroom: bedroom temperature in intervention households increased by an average of 1.28 °C in comparison to control households (95% CI 1.04 to 1.52 °C). The increases in the kitchen were the smallest and non-significant (0.24 °C, 95% CI –0.01 to 0.48 °C).

Figure 13 shows that some intervention measures were more effective than others in raising indoor air temperatures. External wall insulation produced the largest increase in indoor air temperature (1.12 °C, 95% CI 0.69 to 1.55 °C). Connecting a property to the gas mains network also increased the indoor air temperature significantly by an average of 0.69 °C (95% CI 0.29 to 1.09 °C). A new boiler or heating system (–0.19 °C, 95% CI –0.69 to 0.31 °C) and new windows and doors (–0.02 °C, 95% CI –0.39 to 0.35 °C) did not increase indoor air temperatures significantly.

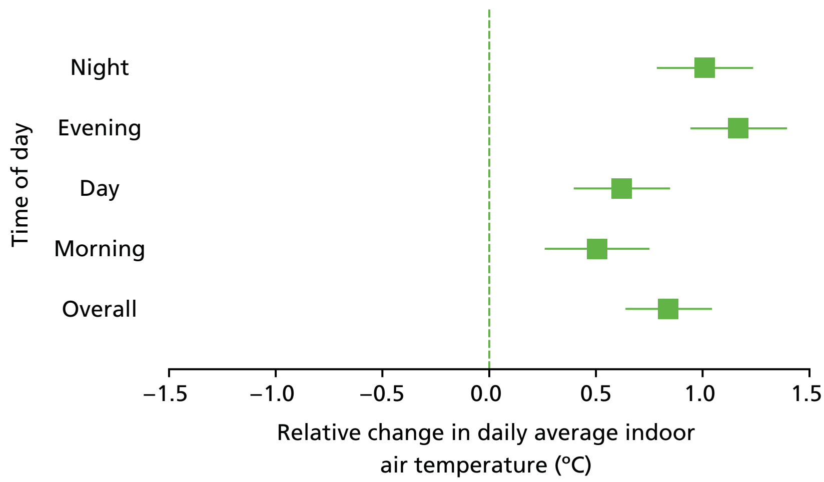

FIGURE 11 Relative change in daily average indoor air temperature during different times of the day for the intervention households.

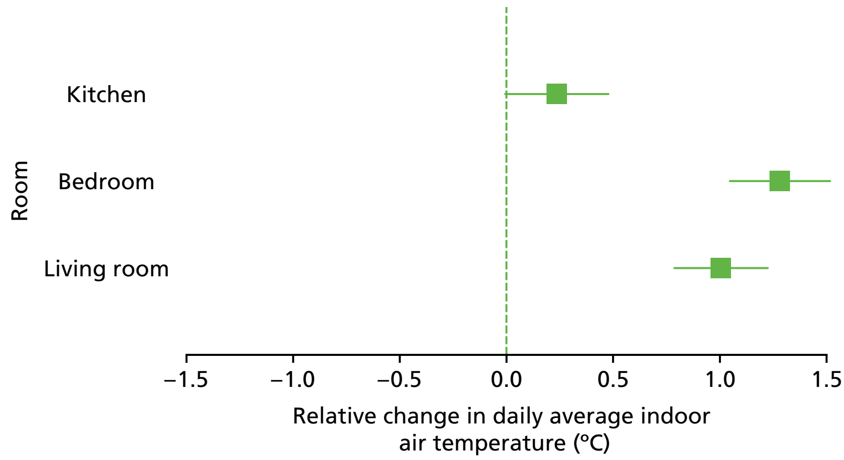

FIGURE 12 Relative change in daily average indoor air temperature for different rooms of the intervention households.

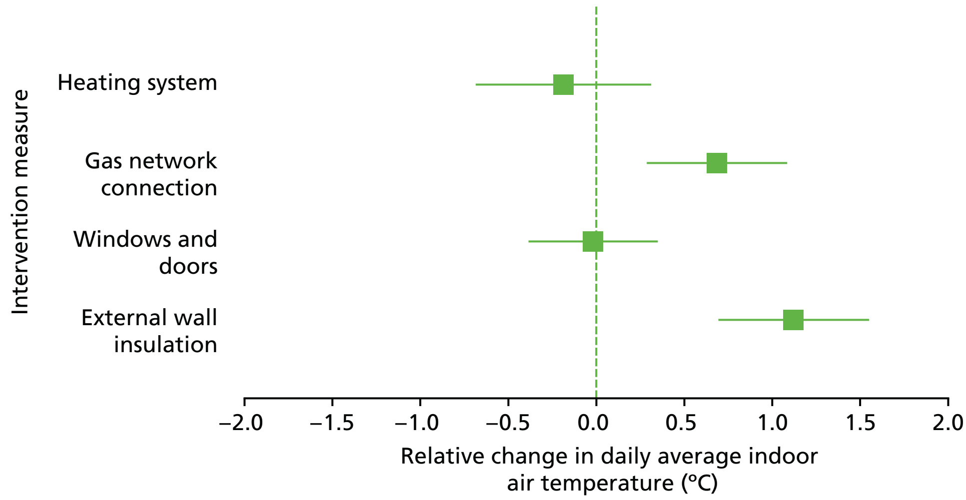

FIGURE 13 Relative change in daily average indoor air temperature for different intervention measures.

The effects of the intervention on indoor air temperatures were different for the different building construction types. *Figure 14* shows that the intervention increased indoor air temperatures in buildings with solid walls (1.54 °C, 95% CI 1.26 to 1.83 °C) and in British steel-framed (BISF) buildings (0.74 °C, 95% CI 0.51 to 0.96 °C). The intervention did not increase indoor air temperature in buildings with cavity walls (–0.17 °C, 95% CI –0.58 to 0.25 °C).

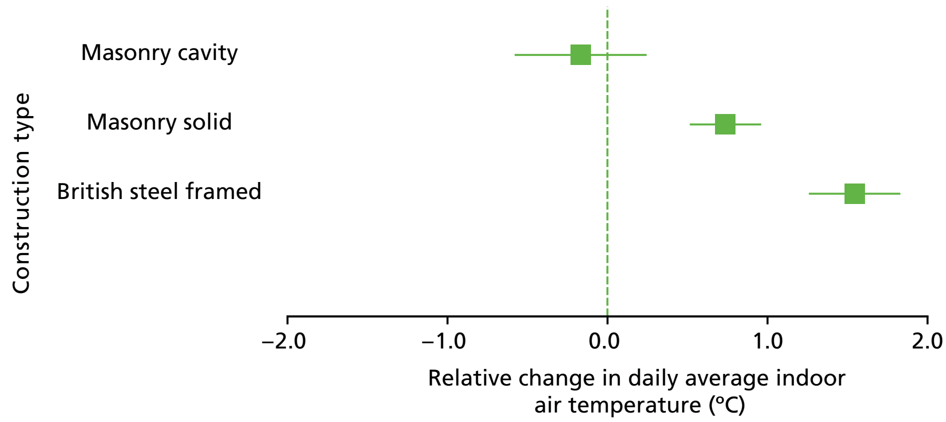

FIGURE 14 Relative change in daily average indoor air temperature for different construction types.

Figure 15 shows the change in indoor air temperatures as a result of the intervention under different heating demand conditions. The increases in indoor air temperature ranged between 0.59 °C and 1.03 °C, and were the highest for the lower heating demand conditions (i.e. below 6 HDDs and between 6 and 8 HDDs).

Indoor relative humidity

Figure 16 shows that, on average, the intervention increased indoor humidity levels by 0.04% RH in absolute terms. The increase in the intervention households was not significantly different from the one observed for the control households (95% CI –0.74% to 0.83% RH). The figure further shows that the changes were consistent for different levels of outdoor RH conditions. None of the changes differed significantly from the changes observed for the control households under the same conditions.

Figure 17 shows that the different intervention measures had differential impacts on internal hydrological conditions. Both a gas network connection (3.86% RH, 95% CI 2.31% to 5.41% RH) and the installation of new windows and doors (5.15% RH, 95% CI 3.73% to 6.57% RH) increased indoor RH levels. However, the increases were small in absolute terms. External wall insulation, which included the installation of mechanical ventilation, did not increase levels of indoor RH (–0.60% RH, 95% CI –2.26% to 1.06% RH) nor did the installation of boilers or heating systems (–1.59% RH, 95% CI –3.52% to –0.34% RH).

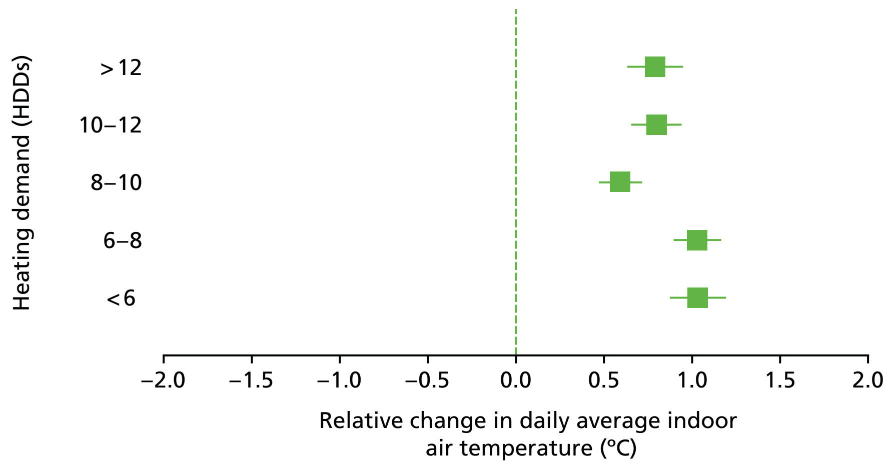

FIGURE 15 Relative change in daily average indoor air temperature under different heating demand conditions for the intervention households.

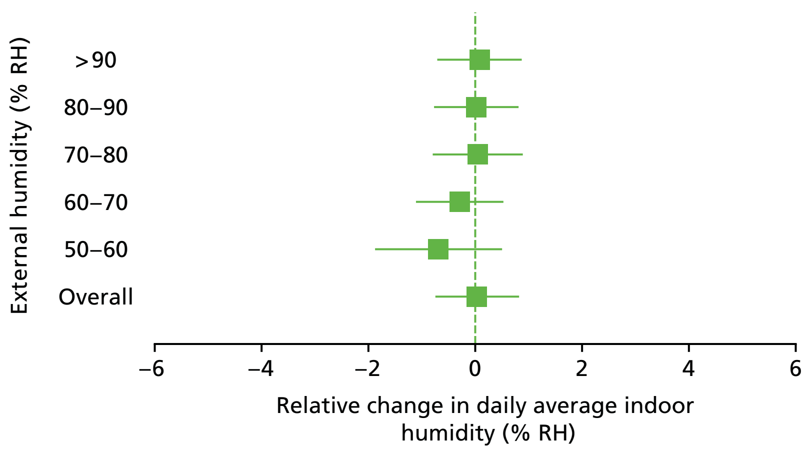

FIGURE 16 Relative change in daily average indoor RH under different external RH conditions for the intervention households.

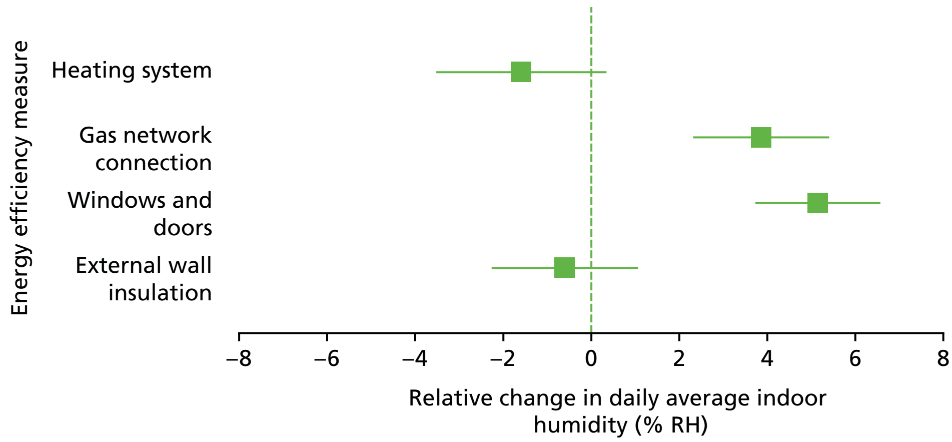

FIGURE 17 Relative change in daily average indoor RH for different energy efficiency measures.

The effects of the intervention on indoor RH levels were different for different building construction types (*Figure 18*). The intervention increased indoor RH in buildings with cavity walls by 4.57% RH (95% CI 2.94% to 6.20% RH). The intervention decreased indoor RH levels in buildings with solid walls (–0.90% RH, 95% CI –1.76% to –0.03% RH). The intervention did not change indoor RH levels in British steel-framed buildings (–0.35% RH, 95% CI –1.49% to 0.78% RH).

Duration and cumulative substandard internal conditions

The study further explored the impact of the intervention on the average daily duration and cumulative substandard internal conditions. *Figure 19* shows that there is no evidence that the intervention reduced the daily duration of temperatures of < 18 °C (0.27 hours, 95% CI –0.49 to 0.96 hours) or <16 °C (0.20 hours, 95% CI –0.48 to 0.88 hours). However, the intervention did reduce the duration of indoor RH levels of > 60% RH by 1.14 hours (95% CI –2.00 to –0.28 hours).

Figure 20 shows that the intervention had a positive effect on the three cumulative substandard internal conditions measures. The cumulative amount of indoor air temperature of < 18 °C was reduced by 3.62 °C·hour (95% CI –6.95 to –0.30 °C·hour). The cumulative amount of the indoor air temperature of < 16 °C was reduced by 4.20 °C·hour (95% CI –6.64 to –1.76 °C·hour). The cumulative amount of the indoor RH levels of > 60% was reduced by 19.32% RH·hour (95% CI –29.68% to –8.96% RH·hour).

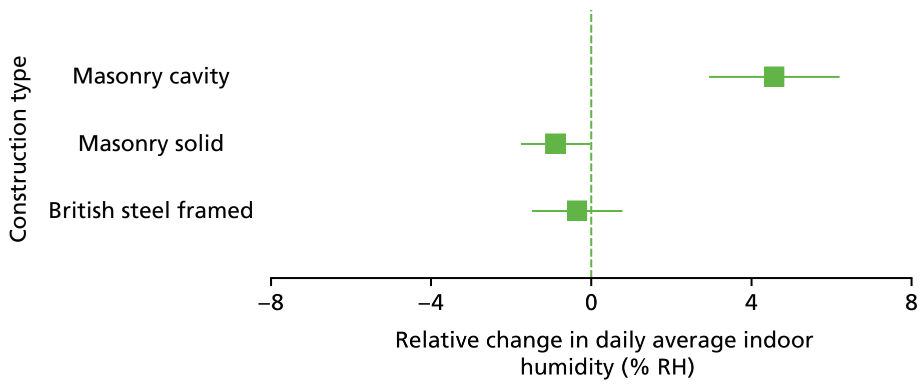

FIGURE 18 Relative change in daily average indoor RH for different construction types.

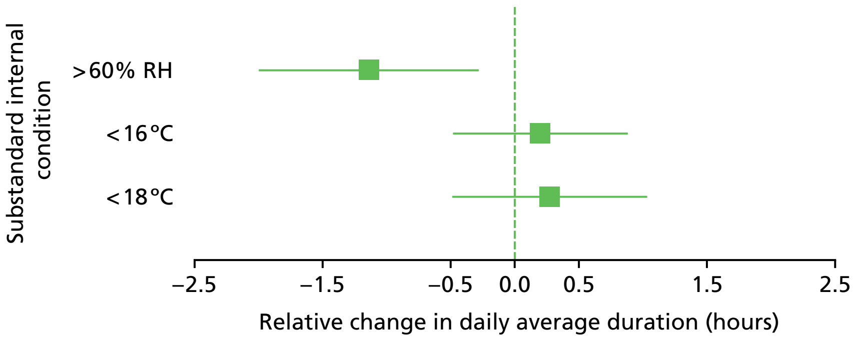

FIGURE 19 Relative change in daily average duration of substandard internal conditions for the intervention households.

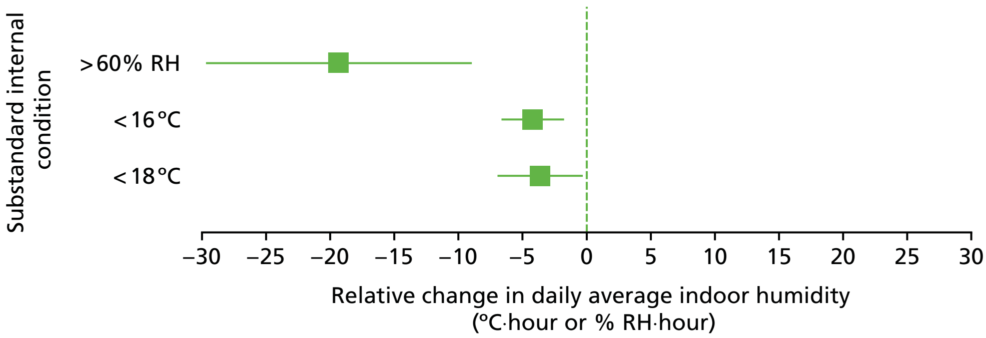

FIGURE 20 Relative change in daily average cumulative substandard internal conditions for the intervention households.

Average daily gas usage

Figure 21 shows the average daily gas usage for the intervention ($n = 26$) and control households ($n = 37$) at baseline and follow-up periods. The calculation excluded the households from the off-gas areas for which no gas meter readings could be taken. Average daily gas usage decreased from 3.88 m^3 to 2.45 m^3 in the intervention households, a decrease of 36.9%. In contrast, the average daily gas usage increased from 4.60 m^3 to 4.76 m^3 in the control households. Having controlled by individual household heating demand, a repeated measures ANOVA showed that the intervention group × measurement occasion interaction was significant [$F(1,60) = 35.985$; $p = 0.000$; $\eta^2 = 0.379$ (Cohen's $d = 1.41$)].

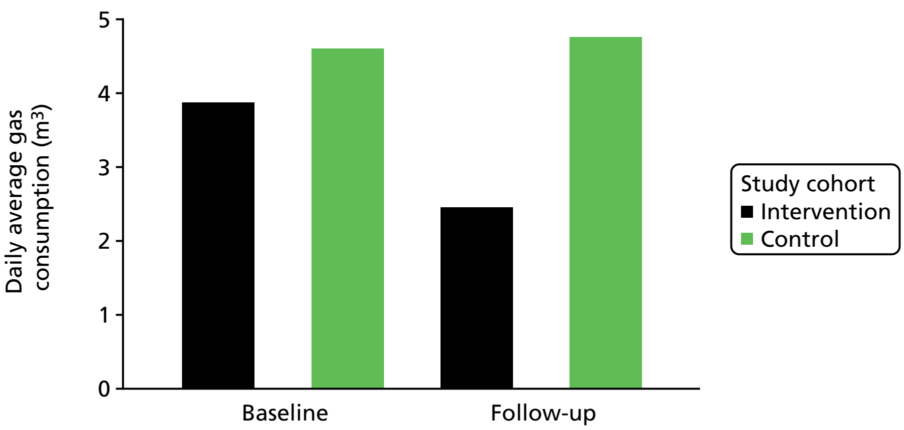

FIGURE 21 Daily average gas consumption for the intervention and the control households at baseline and follow-up.

Discussion

Key results

This study provided new evidence on the impact of energy efficiency investments on internal conditions and household energy use through detailed long-term household monitoring. Internal conditions were monitored for a minimum of 28 consecutive days before and after the installation of energy efficiency measures. These were compared with the internal conditions of households that did not receive such measures. The study found that the intervention raised indoor air temperature by an average of 0.84 °C, whereas average daily gas usage dropped by 37%. Similar increases were observed across different heating demand conditions. Furthermore, the intervention reduced the cumulative amount of the indoor air temperature that was substandard. Overall, the intervention did not increase indoor RH levels, although small increases were found for some individual measures. The study found that the intervention reduced the average daily duration and cumulative amount of indoor levels of > 60% RH.

The intervention measures were not equally effective. External wall insulation and connection to the gas mains network significantly increased indoor air temperatures; new windows and doors or a new heating system did not significantly increase indoor air temperatures. The increases in indoor air temperatures in British steel-framed buildings and buildings with solid walls could largely be attributed to the external wall insulation they received. Both new windows and doors and connection to the gas mains network increased indoor RH, although these increases were small in absolute terms. External wall insulation probably did not increase indoor RH because of mechanical ventilation. Increases in indoor RH levels were observed only in buildings with cavity walls, and not in British steel-framed buildings or buildings with solid walls. It shows the importance of using mechanical ventilation when making buildings more airtight.[64]

The observed changes in indoor conditions were similar to or somewhat smaller than those found in previous research. The results of these studies are discussed in *Chapter 1*. However, in order to be able to compare different studies, changes in indoor conditions need to be accompanied by data on energy use. The extent to which the benefits of improved energy efficiency are taken as energy saving or as extra warmth can then be assessed. The latter is also known as the rebound effect.[133,134]

Limitations

Although the study involved detailed long-term monitoring before and after the intervention, included a control group and controlled for external hydrothermal conditions, it did not monitor occupancy, heating or occupant behaviour. Occupancy and occupant behaviour have a large impact on the energy consumption and internal conditions of buildings. Including these aspects would improve our understanding of adaptive behaviours resulting from the energy efficiency investments. However, it was beyond the scope of the study to incorporate internal household dynamics into the research. The research uses estimates from meter readings made at the installation and collection of the monitors. This can only provide an indication of the energy savings as a result of the energy efficiency investments. Higher-resolution energy monitoring would allow the energy usage to be attributed to specific purposes and to provide information on occupancy and occupant behaviour.

Limitations regarding the sample are similar to the community-based study, from which participating households were recruited. These limitations are discussed in *Chapter 3*. The final sample of intervention and control households, however, were largely comparable, and the study had relatively low attrition. Although the study involved only a relatively small number of houses, they were observed for a minimum of 4 weeks before and after the intervention, resulting in a detailed data set with > 15,000 data points. The longitudinal study therefore allowed the model parameters to be estimated with far more precision, using 28–231 observations per household as opposed to just one.

The intervention involved a number of different energy efficiency measures, depending on the type and location of the properties. Although this means that the houses were non-identical and that the intervention differed across the different schemes, it allowed the study to estimate the effects of different energy efficiency measures in different types of buildings.

Interpretation

The study suggests that the intervention successfully increased indoor air temperatures. Although the overall increase was relatively small (in the order of 1.0–1.5 °C), it reflects long-term average increases, reducing the potential exposure of substandard temperatures: it brought the majority of indoor temperatures within the 'healthy' comfort zone of 18–24 °C.[124,125] An above-average increase in bedroom temperature suggests that the intervention helped to expand comfortable space within the home.[61] There is no evidence that insulation substantially increases indoor RH levels when accompanied by mechanical ventilation. This suggests that energy efficiency investment programmes such as Arbed will be beneficial primarily by providing improved living conditions that are conducive to good physical and mental health.[54] The reduction in gas usage suggests that the intervention has been successful in reducing financial pressure and improving living conditions in households in low-income areas, which were the main aims of the intervention programme.

Generalisability

The study involved detailed long-term household monitoring of a number of different households receiving a range of different energy efficiency measures through the intervention programme. There is little evidence that selection and attrition have systematically biased the sample, suggesting that the results may be generalised to similar energy performance investment programmes, as may the results regarding the specific measures and construction types. However, the results may not be directly generalisable to non-deprived communities or households with different financial circumstances, occupancy or heating patterns.

Chapter 5 The economic evaluation

Introduction

This chapter follows Consolidated Health Economic Evaluation Reporting Standards (CHEERS) reporting standards (see *Appendix 10*).[135]

Background

Health economic studies are intended to inform policy-makers and health-care decision-makers about which interventions, policies or services provide the best value for money. The challenge for such evaluations is to find the right methodology to evaluate social policy interventions that is not overburdensome in terms of data needs, yet appropriately informs decisions. The National Institute for Health and Care Excellence (NICE), for health technology assessment, defines a reference case that specifies the most appropriate methods consistent with the NHS objective of maximising health gain from limited resources. The reference case involves the use of the QALY as a single index to measure and value the health effects of interventions.[136]

Social policy interventions, such as structural energy performance investments, have multiple social, economic and environmental dimensions. This differentiates them from many other types of health intervention.[137] These investments do not always provide an immediate return in terms of health and other social benefits.[138] Therefore, they may not be considered cost-effective using accepted norms. There is some evidence, summarised in a review paper by Fenwick *et al.*,[74] that investments in the energy efficiency of social housing stock provide wider benefits to the health and lives of residents, and that these investments may furthermore have value in their benefits to the NHS and social services.

This chapter describes the analyses undertaken for the health economic evaluation of the intervention programme. The analyses explore whether or not the structural energy performance investments under the intervention programme have delivered health-related quality-of-life improvements and economic impact. The value for money of a social policy intervention depends on several factors, including the timing and setting of the intervention as well as the perspective of the evaluator. Considerations include the balance between the estimated costs of the intervention and the expected outcomes for the beneficiaries, and the time over which the costs fall and benefits are realised. Although energy efficiency programmes are generally not provided or paid for by the health services – the intervention was funded through ERDF and the Welsh Government – they may provide benefits to the health services in terms of cost avoided through reduced health service usage. Furthermore, the intervention may not only benefit the NHS through changing use of health services and a reduction in contact with health and social services, but it may also result in improved quality of life of residents. To inform decisions about energy performance investments, a comprehensive overview of the benefits of such investments and an understanding of how benefits are realised beyond the perspective of the funder of the investments are required, for example benefits to the health services.

Economic studies for public health

Health economic analyses take many forms but can be broadly classified into two categories: cost studies and economic evaluations. A short description of the different types of cost studies and economic evaluations is provided in *Box 1*. The difference between the two categories is that cost studies focus on the identification of resources, impact and costs related to providing interventions and any cost offsets that may arise, whereas economic evaluation studies are comparative analyses that take account of both costs and benefits of the intervention and a comparator.

BOX 1 Description of different types of cost studies and economic evaluations.

Cost studies

- Cost–offset analysis establishes whether or not health-care utilisation decreases as a result of a health intervention. A total offset occurs when general health-care savings exceed the cost of the health-care intervention, effectively resulting in the treatment paying for itself.
- Cost minimisation analysis addresses assessment of costs if the health benefits of competing health-care technologies have been demonstrated to have clinically equivalent outcomes.
- Cost–consequences analysis considers all the health and non-health benefits of an intervention across different sectors and reports them in a disaggregated form. It accepts that different types of benefit cannot be captured using the same units. All impacts and costs are considered when deciding which interventions represent the best value, even if the impacts cannot be costed.

Economic evaluations

- Cost-effectiveness analysis typically involves measuring a specific, one-dimensional health or clinical outcome for competing health technologies, for example 'asthma attacks averted'.
- Cost–utility analysis is a special type of cost-effectiveness analysis in which multidimensional health outcomes are reduced to a single dimension reflecting individuals' preferences for the diverse health outcomes. The most commonly used outcome in CUA is the QALY. For both cost-effectiveness and cost–utility studies, value for money is identified using a measure of the additional cost per additional outcome ratio (e.g. an incremental cost/QALY ratio) and comparing that with an external threshold or with the ratio achieved by alternative policies.
- Cost–benefit analysis involves the measurement and valuation of all outcomes of interest in monetary terms. Here the value for money is identified by positive net economic benefit associated with the intervention compared with an alternative (i.e. the monetary value of the outcomes exceeds the net costs of the intervention less any cost savings achieved elsewhere).
- Cost–utility analysis is a form of cost-effectiveness analysis (CEA) that uses the QALY as the measure of benefit and is specified in the NICE reference case[136] as a preferred method for conducting health economic evaluations, although it is recognised that it has limitations as well. CUA does not consider wider non-health benefits often associated with social policy interventions.[139] When evaluating social policy interventions, it is important to consider social and economic benefits beyond those for the health service, which cannot easily be captured by the QALY metric. In reality, benefits are measured and valued using different outcome metrics; therefore, an appropriate framework is needed that allows all relevant benefits of an intervention to be taken into account in the analysis. Cost–consequence analysis (CCA) and cost–benefit analysis (CBA) are considered suitable approaches by NICE, given that they allow all relevant benefits to be considered. The difference between CCA and CBA is that the former reports all health and non-health benefits in a disaggregated form, whereas the latter expresses all costs and benefits in monetary terms.

Previous economic studies of the health impact of housing improvement

A number of cost studies and economic evaluations have been conducted to assess the health-related quality of life and economic impacts of housing improvements. In a recent review of the literature, Fenwick *et al.*[74] identified 45 health economic studies relating to the health impacts of housing. It is clear from the review that only a limited number of health economic evaluations had been conducted during the period considered. Out of the 45 health economic studies, 29 reported cost and/or economic analysis and the majority involved cost studies ($n = 25$). Only four studies involved an economic analysis, although, in the opinion of the authors, 11 of the reported cost studies had sufficient data to conduct an economic evaluation.[74] Three studies stated that a CBA had been conducted but in fact it had not, and only one study was found to have conducted a CEA. Barton *et al.*[51] used the SF-36 to capture change in the health-related quality of life of residents as the basis for the economic evaluation. They concluded that the housing improvements did not produce substantial gains in terms of health-related quality of life, health or more schooling. However, they also recognised that there may have been insufficient time for measurable benefits to have materialised.

In addition to the studies reported by Fenwick *et al.*,[74] a small number of more-recent health economic studies have been conducted. The Gentoo social housing and sustainability group conducted a pilot study[140] ($n = 12$) examining the health economic impact of energy efficiency improvements on people with COPD. The study found that self-reported GP appointments were reduced by 60%, accident and emergency (A&E) attendances by 30%, outpatient appointments by 22% and emergency admissions by 25%. The Warm Homes for Health project[141,142] involved similar improvements, mainly focused on heating and insulation. The study suggests that installation of housing improvements produced cost savings to the NHS worth > £50,000. This would equate to an annual saving of £1B if all 4.8 million substandard homes in the UK receive the same energy efficiency measures. However, these two studies are at an early stage and at the time of writing the full results of their final health economic analyses have not yet been published.

Lawson *et al.*[143] conducted a CUA of a transfer of social and private tenants to new-build social housing rather than regeneration of existing housing stock. The study did not find a significant change in outcomes expressed as utility scores in the intervention group in comparison to a control group over a 2-year period. As a result, they concluded that the intervention was not value for money in health terms, although this was qualified by noting that not all benefits may have been captured and that they may not have been fully realised over the period of the study.[143]

The research reported here builds on these prior studies but extends the body of evidence by using routinely collected health data in addition to self-reported survey data. The use of routinely collected health data allowed the intervention to be evaluated retrospectively using actual health-care utilisation data from the SAIL databank.[82–84,144] The study focuses on utilisation of secondary health-care services, including emergency admissions and contacts with primary care within NHS Wales, by people living in homes that received the intervention.

Objective

The objective of the economic analysis was to evaluate the costs and consequences of the intervention from the perspective of NHS Wales. This was undertaken in the form of a CCA and a CUA.

Method

Study design

The health outcomes utilised in the economic analyses are based on the analyses undertaken using routinely collected data held within the SAIL databank. The methods used for these analyses are described in *Chapter 2*. Based on a literature review and the recommendations of NICE, CCA was considered to be the most appropriate methodological approach for the evaluation as it allows for different types of outcome to be considered. The CCA considers resource use and the related cost impacts of the intervention and benefits of different kinds to be considered and to be reported in a disaggregated form. Health service impacts and costs are thus considered as separate items to enable decision-makers to determine if the intervention represents good value from their perspective.

In addition to the CCA, a CUA was considered as an approach to evaluate the intervention programme. The CUA approach attaches utility values (the 'Q' value in QALYs) over time for study outcomes to provide one single measure (i.e. QALYs). The CUA considers resource use and cost impacts of the intervention and the benefits in terms of QALYs to be established for the intervention. In CUA, the intervention outcomes and the overall costs are compared with the relevant comparator. The intervention can 'dominate' the control (greater effect/lower cost), in which case it will be unambiguously cost-effective, or, in the event of a non-dominance (greater effect/higher cost), results are reported in the form of an incremental cost-effectiveness ratio (ICER) showing the additional cost per QALY gained.

A simple CUA based on QALYs derived from SF-12 responses is reported in *Chapter 3*. However, the utility values collected in the community-based study did not represent specific health states; rather, they were valuations of health experienced before and after the intervention was completed.

The economic analyses utilise the outcomes from the SAIL databank analyses described in *Chapter 2*, and follow a panel analysis approach utilising data available for the study population in the SAIL databank. The data were extracted for the study populations in monthly increments and used to develop a retrospective analysis (see *Chapter 2*). To fully utilise the SAIL databank outcomes, we looked to the literature and prior research to identify utility values for the health states experienced by individuals experiencing COPD-related emergency admissions.

The overall study period is 10 years, from 2005 to 2014. The intervention was delivered in 2010/11. Information collected prior to the intervention was utilised as a baseline to observe any subsequent changes in hospital admissions. The time horizon for the economic evaluation was 4 years post intervention.

As described in *Chapter 2*, the intervention programme included external wall insulation, boiler upgrades and replacements, microgeneration (photovoltaics/solar hot water/heat pumps) and general energy-saving advice. The lifespans of the different elements range from 12 years for boiler upgrades and replacements to 42 years for insulation (see *Table 14*).[91] Considering that the shortest lifespan of an element was 12 years, residents remaining in the property after the improvements will have benefited from the elements installed. Extrapolating beyond the study period seems inappropriate for the base case scenario, given the uncertainty about the health benefits that remain with an individual if they move out of properties over time. We believe that the 4-year time horizon of the study is appropriate and generalisable. To explore this element of uncertainty further, we undertook a sensitivity analysis, using threshold analysis to explore a range of durations of residency. We assumed that the impact was constant and the benefit continued after the observed study period. As the follow-up period after the intervention was completed was longer than 12 months, the costs and benefits beyond 1 year were discounted at a standard rate for public health interventions, currently 3.5%, to bring them into 2013 prices and a sensitivity analysis with 1.5%.[139]

Setting

The economic analysis focused on the first phase of the intervention programme that took place in 2010 and 2011, in which a total of £68M was invested, including leveraged funding. The programme improved the energy efficiency of existing homes in low-income areas. LAs and RSLs submitted project plans to improve thermal efficiency of homes in Wales. The majority of homes were social housing. This study was undertaken using data for the intervention group providing their own historical controls. Individually reported baseline and follow-up periods in the intervention cohort were used to calculate the duration of the intervention for each resident and/or household.

Participants

The study participants within this study were individuals who lived within one of the intervention or comparator homes during the period under consideration. Anonymised housing codes were used to link the homes and individuals within the SAIL databank. All individuals who were a resident within a study home for ≥ 60 days were included in the analysis. Baseline data were collected for several years prior to the intervention.

Variables

A range of explanatory variables was collected for each individual and/or household. The variables utilised within this study were chosen for their theoretical power in explaining the levels of emergency admissions experienced. Information was collected at the individual level for age (in 5-year bands), sex and comorbidity (0, 1). Housing-level data were collected for area income deprivation (ordinal scale) and a measure of rurality (urban or rural). Given the seasonal trend observed within the dependent variables, an identifier for seasonality was also included. All outcome variables were grouped into the composite count measure of cardiovascular and respiratory emergency hospital admissions. To account for the variability in the duration over which individuals were observed, each of the count measures is transformed into a yearly rate. Data for each of these emergency admission variables were collected from PEDW. The PEDW data are structured into ICD-10 diagnosis chapters, described in *Chapter 2*.

Costs

The comparisons in health service resource use related to the study outcomes for the study population were made between the baseline and follow-up intervention period. The resource changes for the health system as a result of changes in health service use were calculated using the methods described in *Chapter 2* and standard NHS unit costs. The costs associated with the resources in secondary care health services used by the recipients of the intervention include secondary care admissions for cardiovascular and respiratory conditions. The total cost of the intervention was estimated from the cost of implementing the programme, plus changes in health-care resource costs over the follow-up period. The comparison is made with the pre-intervention period for the study population and no intervention costs and so the total costs are derived solely from the changes in health-care resource use. The overall budget allocated to the intervention programme was derived from records received from the Welsh Government and the 28 LAs and RSLs involved in the scheme. The evaluation was undertaken from a NHS costing perspective; only costs and benefits to NHS Wales were considered. We used 2015 as the base year for costs.

Outcomes

The health outcomes for the CCA were changes in emergency hospital admissions for cardiovascular and respiratory conditions.

The intervention was expected to have an impact on the health-related quality of life of the residents who received the intervention over the follow-up period. As reported in *Chapter 3*, the results of the community-based study showed no difference in either health-related quality of life or utilities within 12 months of the delivery of the intervention. These results reflect those of similar studies evaluating housing interventions and the subsequent impact on health-related quality of life, in which the authors suggest that the relatively short time period of the follow-up did not allow the full impact of the interventions to be reflected in health-related quality-of-life status.[51,143]

In order to undertake a meaningful CUA, we used an economic modelling approach, which instead used literature-based utility values for the health states related to the primary and secondary health outcomes to evaluate the probable impact of the intervention on QALYs. The CUA conducted here used only outcomes relating to COPD. The reason for that is that there is a relative wealth of literature on utility values for hospital admissions for exacerbations of COPD in comparison with the other reasons for hospital admissions. A number of prior studies have examined the impacts of housing interventions on COPD, and COPD forms an important part of the overall burden of disease.[118,145,146] In order to identify utility values for COPD to enable contextualisation of the results, a systematic approach was taken to reviewing the literature. The literature review is provided in *Appendix 12*.

Economic analysis

Two types of economic analysis were conducted: CCA and CUA.

Cost–consequences analysis

The primary outcome measure for the CCA was the change in cardiovascular or respiratory emergency hospital admissions and utilised the financial costs of the intervention. The findings are reported as the ratio of the cost per person per year and the changes in primary outcome. The statistical approach undertaken to calculate the impact of the intervention on the primary outcome initially assessed the presence of trends over the study period. The data were observed as a monthly count of emergency admissions. In the absence of an evident trend, the data were conflated into a two-period comparison. Our analysis compares the outcome rates before and after the intervention. To account for different exposure durations and data containing incomplete years, the aggregated count data is transformed into annualised rates when possible (see *Chapter 2*). The resulting annualised rates were compared using a mixed multilevel linear model, which incorporates the covariates and explanatory variables.

The covariates included were age, sex, overall comorbidity score, a seasonality adjustment and area-based deprivation. The age variable takes an average age for each of the two periods. In the event of clustering, random effects modelling was used. Clustering was based on a person's unbroken residence within a study property. When an individual was observed inhabiting multiple properties within the study period, the data are assumed to be independent owing to the influence of unobserved factors. The independence of residential durations extends to individuals returning to an intervention property they previously inhabited.

A 'bottom-up' costing approach was undertaken as part of the economic analyses; details are provided in *Appendix 11*. The rationale behind this costing approach was the desire to report figures that represent the financial implications of replicating the intervention and enable both bottom-up and top-down costing in the analysis, which may have inflated values owing to the inclusion of managerial, planning and data collection components that may not be required in a replication intervention. The total bottom-up cost of delivering the intervention was £32,484,900 for the 4968 households in the analysable data set (i.e. with complete data on the property intervention and inhabitants). The Welsh Government intervention top-down spend was reported to be between £60M and £68M (personal communication with Welsh Government). However, these figures include additional properties and leveraged funding that were not reported in the initial data set. The top-down costing approach was used for the sensitivity analysis.

Costs were initially estimated on a per-household basis and later adjusted to a per-person per-year level to standardise the outcome measure. Given the range in effective duration for the different components of the intervention, a time-dependent costing approach was adopted. *Table 14* shows the frequency of each intervention component alongside the effective duration and cost. Costs are reported at 2013 prices. The resulting cost per household was calculated according to the average overall cost and then adjusted to create a per-year figure. The intervention cost was spread across the effective lifetime using a straight-line depreciation method given the assumption of zero residual value.

TABLE 14 Frequency, duration and cost of the intervention

Intervention measure	Number delivered	Estimated lifetime (years)[147]	Indicative cost (£) (WG report)[148]	Average cost (£) per year
External wall insulation	2709	36	7300	202.78
Photovoltaics	1458	25	5400	216.00
Solar water heating	928	25	2600	104.00
Air source heat pumps	401	15	6000	400.00
Loft/rafter insulation	172	42	100	2.38

WG, Welsh Government.

The bottom-up costing approach provided a per-property per-year cost of £225.76. Given that all the intervention elements have a life expectancy of > 4 years, the cost per household can be assumed to be consistent across all the years included in the analysis. The data suggest an average occupancy of 2.7 individuals, resulting in an average per-person per-year cost of £83.61.

The CCA compared the cost of the intervention with the range of reported outcomes. The primary outcome is the rate of combined cardiovascular and respiratory emergency hospital admission. The secondary outcomes are the contributing subgroups of the primary outcome. The primary and secondary outcomes are illustrated alongside their mean annualised change rates in *Table 15*.

The annualised prevalence rates reported here show that, without accounting for covariates, the primary outcome rate increases by 0.0034 following the intervention. Changes in emergency admissions represent an important component of the cost in CCA as a change in rate represents a change in cost. Using an 'average duration' approach and the reported emergency admissions, alongside NHS reference costs,[149] results in a representative cost per event of £2734.29.

Cost–utility analysis

We developed the event profile for COPD-related emergency hospital admission based on a structured literature review (see *Appendix 12* and the search strategy reported in *Appendix 13*). The decline and partial recovery profile that characterises a COPD exacerbation was modelled to include five distinct phases as described by Seemungal *et al.*[150]

The baseline utility value was sourced from a systematic review[151] that reported UK-based utility scores derived from the EuroQol-5 Dimensions (EQ-5D) instrument for each of the four international severity levels for COPD.[152] The distribution of COPD in UK general practice using the Global Initiative for Chronic Obstructive Lung Disease (GOLD) classification was described in a study by Haughney *et al.*,[153] in which the combination of the EQ-5D and weighting data provided the baseline COPD utility. The GOLD stages represent varying forced expiratory volumes (FEVs). The baseline COPD utility score represents the value that individuals with COPD experience before an exacerbation occurs, whether severe enough to cause a hospital admission or otherwise. *Table 16* reports the combination of the distribution of GOLD COPD stages and the utility scores representing the valuation of the health state. The resulting weighted baseline value was a utility score of 0.750.

TABLE 15 Primary and secondary outcomes' mean annualised rates before and after the intervention

Outcome	Before, M (SD) [*n*]	After, M (SD) [*n*]	Change in rate
Cardiovascular or respiratory	0.0543 (0.4788) [22,209]	0.0577 (0.7079) [18,527]	0.0034
COPD	0.0062 (0.1468) [22,209]	0.0069 (0.1150) [18,527]	0.0007
Cardiovascular	0.0179 (0.2709) [22,209]	0.0171 (0.4377) [18,527]	–0.0008
Respiratory	0.0324 (0.3720) [22,209]	0.0371 (0.5430) [18,527]	0.0043

M, mean.

TABLE 16 The utility scores for COPD GOLD stages

GOLD stage of COPD	Distribution of COPD population (%)	Utility score
1	17.1	0.806
2	52.2	0.767
3	25.5	0.704
4	5.2	0.616

An emergency hospitalisation attributable to an exacerbation of COPD represents a detrimental impact on an individual's short-term and possibly long-term health-related quality of life, represented here by health state utility scores. The literature search identified three papers that included utility valuations for individuals on admission and on discharge from a hospital stay for a COPD admission.[154–156] The utility scores for use in this analysis were created using a weighted average of all those reported in these papers, taking into account the number of individuals that the publication reported. *Table 17* shows the number of individuals, utility value and publication from which the value was derived. The average utility score, derived from the literature for the COPD patients who experienced a hospital stay, is 0.504.

The COPD events that are serious enough to require hospital admission carry a risk of mortality. To account for this within this model, an inflated relative mortality measure was calculated. The data on COPD hospital admission mortality come from Esteban *et al.*[157] Given the average hospital stay duration of 7 days, all-cause mortality for this duration provides a baseline rate. The average age of patients in the literature was 72.6 years, whereas the data for COPD events utilised within this analysis show a mean age of 69.2 years. The relative all-cause mortality for these two ages was used to deflate the mortality observed in the literature to a rate representative of COPD hospitalisations for the data used in our analysis. The all-cause mortality was calculated to be 0.031% for the 7-day period, whereas those experiencing a COPD-related hospitalisation had a mortality rate calculated to be 2.507%. The net increase in mortality attributable to COPD hospitalisation is 2.476%. Taking into account this increased mortality when estimating the utility value for a COPD admission for an exacerbation, we estimated a utility value of 0.492.

The estimation of a discharge utility score follows the same approach as estimating the admission value. Hospital discharge values were obtained from the same three papers as the admission figures.[155–157] The data sourced from the literature report 1289 individuals with a mortality-adjusted average utility score of 0.613. As previously mentioned, COPD events are characterised by an initially large reduction of health-related quality of life followed by a recovery phase to prior health. However, some individuals may ultimately never fully recover to the same health and FEV levels they had prior to the exacerbation.

The post-discharge recovery phase was estimated using the recovery statistics reported by Seemungal *et al.*[150] The duration of an event that began with a hospitalisation attributable to COPD was estimated by Seemungal *et al.*[150] to be a total of 91 days. Given a 7-day hospital stay, the remaining 84 days are characterised by two phases: first, 28 days following discharge, during which 75.2% of individuals were found to make a full recovery; and, second, the subsequent 56 days, during which 79.8% of those remaining not fully recovered were reported as still experiencing a negative residual impact of their event. The utility score of these two recovery points is calculated according to the percentage of individuals recovering from the discharge utility value back to the initial baseline value. The utility score for individuals 28 days post discharge was calculated as 0.720, increasing to 0.726 at 84 days. The figure of 0.726 is assumed to be the long-term utility score.

Figure 22 plots the five COPD health states and the related utility values, illustrating the sharp decline caused by the hospitalised exacerbation event followed by the gradual recovery that ultimately never reaches the initial baseline value. The area under the curve approach was used to estimate the short- and long-term reduction in QALYs. The short-term calculation assumes that the hospitalisation occurs in the middle of the year with a within-year QALY reduction of 0.022. The long-term impact of a COPD event is a reduction of 0.240 QALYs.

TABLE 17 Reported utility valuations for individuals on admission and on discharge from a hospital stay for a COPD admission

Research paper	Number of patients	Utility value
Esteban *et al.*[157]	1421	0.600
Menn *et al.*[155]	117	0.446
O'Reilly *et al.*[156]	222	–0.077
Average		0.504

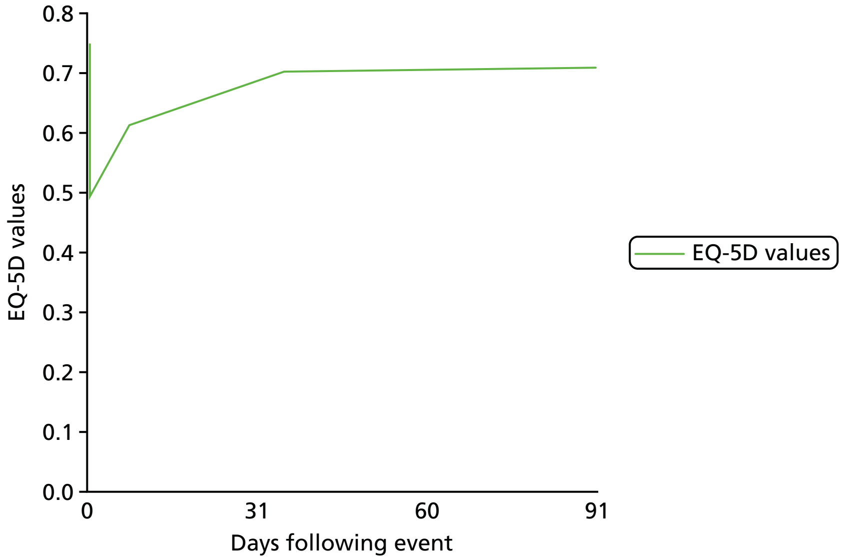

FIGURE 22 Time course and utility values for a COPD exacerbation event.

Although commonly used for estimating health valuation over time, utility decrements may fail to account for the full detrimental impact of a COPD event when used to estimate a structured event pathway for a COPD patient. Rutten-van Mölken *et al.*[158] sought to capture the broader holistic impact of a serious COPD exacerbation using an isolated time trade-off valuation approach. This time trade-off study estimated a single serious exacerbation to reduce health state utility by 0.042. This study viewed an event within the context of 1 year as opposed to the modelling undertaken in this analysis. The extended time frame obtained from the five-point calculation aligns well with the panel data analysis in that it accounts for the longer-term impact of reductions in FEV.

To inform our CUA and economic model, each adverse health event resulting in a hospital admission had a curve mapped from the utility values across the study period. This approach incorporates the initial impact of the event and a time-variable component. The analysis utilised cost associated with the intervention and the improved health following a reduction in COPD events to generate an ICER.[159]

Sensitivity analysis

To address uncertainty in our findings, a number of deterministic one-way sensitivity analyses were carried out based on a number of variables that we were aware introduced uncertainty and/or had a substantive impact on the health outcomes, resource use and costs. The CCA results offer a concise package of findings on which a best-case and worst-case scenario evaluation is undertaken for the sensitivity analysis. The uncertainty in the outputs of the CUA was explored using one-way sensitivity analysis, a threshold analysis and a probabilistic sensitivity analysis (PSA).

The threshold analysis estimates the level of reduced COPD hospitalisations required to make the intervention cost-effective at a £30,000 per incremental QALY gained level. Given the importance of the time frame of the analysis, a range of different time horizons were taken. The PSA enabled a range of variables with inherent uncertainty to be investigated to determine the impact on the results.

Uncertainty exists for two main components of the analysis:

1. costs
2. change in adverse health events resulting in hospital admissions.

Probabilistic sensitivity analysis was conducted to assess the uncertainty of each of these two areas. The approach takes into account the uncertainty inherent in the Welsh Government top-down cost estimate of approximately £60M–68M and models the uncertainty using a uniform distribution. The uniform distribution was chosen in line with good practice because there is no centralised tendency and all figures within the distribution are assumed to be as likely as any other. The change in hospitalisation event values are estimated using normally distributed random samples. The normal distribution takes into account the central point estimate used in the deterministic analysis and the SD from this position.

The PSA approach estimates 1000 resamples, which are calculated as individual ICERs (see *Equation 1*). Findings from the PSA are reported in a cost-effectiveness plane (CEP). The 95% CIs calculated from the PSA samples are reported alongside the main ICER finding. The ICER, CEP and cost-effectiveness acceptability curve (CEAC) were evaluated relative to the NICE willingness-to-pay threshold values. NICE generally considers that interventions costing the NHS < £20,000 per QALY gained are cost-effective. Interventions costing between £20,000 and £30,000 can be deemed cost-effective, depending on the level of uncertainty about the ICER, the impact on health-related quality of life of the intervention, the degree of innovation and level of benefits that may arrive that are not easily quantifiable in terms of health gain:[139]

$$\text{ICER} = \frac{\text{Difference in costs between intervention and control}}{\text{Difference in health effects between intervention and control}}. \quad (1)$$

Results

Cost–consequence analysis

The CCA outcomes are presented in *Table 18*. The outcomes for the primary objective are reported separately from the costs. The average change in emergency admissions by year is weighted according to the prevalence levels within each of the 4 post-intervention years. *Table 18* reports the primary objective alongside the intervention costs. The costs and outcomes are discounted to present-day values at 3.5%.

Table 18 reports four data columns and totals. The 'weighting' column offers the calculation needed to transform the overall impact into a yearly value, which is based on the prevalence of the measure in each year. The change in admissions (B) and SD are reported in the second data column; the fourth data column reports the discounted effects and attached treatment costs. The third column includes the cost of the intervention, which is combined with the changes in treatment costs to offer the final cost component. The total effect value is a simple summation of the four yearly changes in admissions.

TABLE 18 Costs and consequences for the primary outcome (combined cardiovascular and respiratory emergency admissions)

Year	Weighting	Change in admissions post intervention, B (SD)	Cost per person per year for the intervention (£)	3.5% discounted event (discounted event cost, £)
Overall		0.0010 (0.006)		
1	1.078	0.0012 (0.006)	83.61	0.0012 (3.20)
2	0.919	0.0010 (0.005)	83.61	0.0010 (2.64)
3	1.011	0.0011 (0.006)	83.61	0.0010 (2.81)
4	0.992	0.0011 (0.006)	83.61	0.0010 (2.66)
Total			345.75	0.0041

The results suggest a non-significant increase in hospital admissions for the primary outcome: over the 4 years, the cumulative impact is 0.0041 events per person. The per-person cost over the post-intervention period amounts to £345.75, which is driven by an intervention cost of £334.44 and an increase in treatment costs of £11.31. Given the increase in the primary outcome following the intervention and the positive intervention costs, the intervention is not deemed as cost-effective.

The results using the secondary outcomes are reported in *Tables 19–21*. The approach is the same as with the primary outcome but leaves out the intervention costs. The intervention costs are not included in the tables to avoid double counting. *Table 22* reports the combined outcomes and costs for the four measures.

Table 19 reports the impact on the COPD-related hospital admissions per person. The reduction in COPD emergency admissions is not significant at a 95% confidence value; the summation of these event reductions over the 4 years totals to –0.0006 per person. The scale of this reduction is very small and suggests a reduction in NHS treatment costs of £1.64. The reduction of 0.0006 events should be considered alongside each of the following impacts. The weighting levels in *Table 20* show that COPD events were increasing over the 4-year period.

Table 20 reports the impact on the cardiovascular-related emergency hospital admission events per person. As with the COPD results, the cardiovascular event levels have reduced non-significantly. The scale of the reduction is 0.0053 and the discounted amount saved is £14.56. The first year following the intervention saw the lowest levels of cardiovascular emergency admissions.

TABLE 19 The COPD-related emergency admissions

Year	Weighting	Undiscounted change, B (SD)	3.5% discounted event (discounted event cost, £)
Overall		–0.0002 (0.001)	
1	0.7724	–0.0001 (0.001)	–0.0001 (–0.34)
2	0.8666	–0.0001 (0.001)	–0.0001 (–0.36)
3	1.2057	–0.0002 (0.001)	–0.0002 (–0.49)
4	1.1554	–0.0002 (0.001)	–0.0002 (–0.45)
Total			–0.0006 (–1.64)

Note
Discount rate = 3.5%.

TABLE 20 The cardiovascular-related emergency admissions

Year	Weighting	Undiscounted change, B (SD)	3.5% discounted event (discounted event cost, £)
Overall		–0.0014 (0.004)	
1	1.1196	–0.0016 (0.004)	–0.0016 (–4.28)
2	0.9067	–0.0013 (0.003)	–0.0012 (–3.35)
3	0.8947	–0.0013 (0.003)	–0.0012 (–3.20)
4	1.0790	–0.0015 (0.004)	–0.0014 (–3.74)
Total			–0.0053 (–14.56)

Note
Discount rate = 3.5%.

TABLE 21 The respiratory emergency admissions

Year	Weighting	Undiscounted change, B (SD)	3.5% discounted event (discounted event cost, £)
Overall		0.0042 (0.005)	
1	1.0083	0.0042 (0.005)	0.0042 (11.48)
2	0.9460	0.0040 (0.004)	0.0039 (10.57)
3	1.0918	0.0046 (0.005)	0.0043 (11.74)
4	0.9540	0.0040 (0.004)	0.0036 (9.84)
Total			0.0160 (43.66)

Note
Discount rate = 3.5%.

TABLE 22 Costs and consequences

Secondary outcomes emergency admissions	Change in emergency admission events	Net financial cost overall per person (£)
COPD	–0.0006	Effect –85.96
Cardiovascular	–0.0053	Intervention 334.44
Respiratory	0.016	Net cost 248.48

Table 21 reports the impact on the respiratory-related emergency admission events per person. The respiratory emergency admission event changes following the intervention are positive but do not achieve statistical significance. However, the scale is much greater than that for either the COPD or the cardiovascular results. Given that the overall respiratory and cardiovascular findings show an increase in frequency, the two relatively small decreases and the finding that one component was positive and dominating are not surprising.

The combinations of each of the secondary outcome measures alongside the intervention costs are reported in *Table 22*. The intervention reduces COPD and cardiovascular emergency admissions but increases the number of respiratory-related admissions. This is at a net cost of £248.48 per person over a 4-year period.

Cost–utility analysis

The CUA utilises the data from the CCA and develops the analysis further into an economic evaluation using the data identified in the literature review (reported in *Appendix 12*). Our analysis suggests that a within-year QALY decrease for a single COPD exacerbation hospital admission is 0.022. The residual decrement to utility scores in subsequent years after the initial year of the event results in a reduction in QALYs of 0.024. The inclusion of these QALY valuations in the 4-year model is presented in *Table 23*.

The relatively small decrease in COPD events and the relatively large cost of the intervention programme mean that the ICER is > £10M (£10,485,472.12) per QALY gained. When using a discount rate of 1.5% instead of the base case 3.5%, the ICER reduced to £10,066,540.29. Both of these ICERs are deemed not cost-effective.

Threshold analysis was undertaken to estimate the required reduction in COPD events and related utility scores over the 4-year period to make the intervention cost-effective. The base-case analysis estimates suggest that the intervention is not cost-effective, as it would require a constant yearly per-person

TABLE 23 The QALYs and costs related to COPD emergency admissions

Year	Undiscounted change, B (SD)	3.5% discounted event (discounted event cost, £)	Cost per year for the intervention (£)	QALY gains
1	–0.0001 (0.001)	–0.0001 (–0.34)	83.61	–0.000003
2	–0.0001 (0.001)	–0.0001 (–0.36)	83.61	–0.000006
3	–0.0002 (0.001)	–0.0002 (–0.49)	83.61	–0.000010
4	–0.0002 (0.001)	–0.0002 (–0.45)	83.61	–0.000013
Total			332.80	–0.000032

Notes
ICER = £10,485,472.12 per incremental QALY gained.
Discount rate = 3.5%.

reduction in utilities associated with COPD events of 0.028 in order to make the intervention appealing in terms of a cost per incremental QALY gained of £20,000–30,000. Given the long-term investment associated with the intervention, a 10-year threshold analysis was estimated. The benefits of the cumulative health-related quality-of-life benefits require a yearly decrease in utility scores of 0.013 for the intervention to be considered cost-effective. The disparity between these two figures highlights the influence of the duration of analysis. With a condition such as COPD, which has a long-term decrement to health-related quality of life, interventions that deliver benefits consistently over an extended period may be perceived more favourably with extended timelines. Given the relative scale of the required benefits estimated by the threshold analysis in the shorter term compared with those reported in *Table 23*, time horizons of > 10 years were not investigated.

The PSA varied the yearly reductions in COPD admissions alongside a uniformly distributed cost of intervention. The 1000 replications are plotted on a CEP (*Figure 23*). Given the scale of reduction observed in the statistical analysis and the costs involved, it is important to note the axis units. The QALY axis reports numbers in the thousandths of a QALY whereas the net cost unit is in hundreds of pounds. The impact of the intervention on COPD events has a 0% chance of the intervention being cost-effective at a £30,000 per incremental QALY gained level. The CEAC is not illustrated owing to the lack of movement at plausible ICERs.

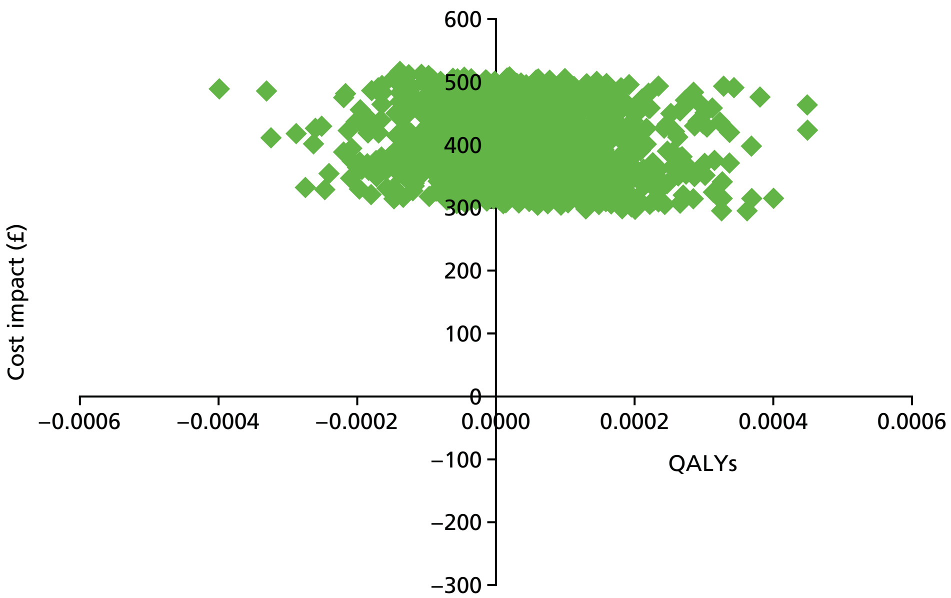

FIGURE 23 Probabilistic sensitivity analysis results on a CEP.

The findings reinforce the uncertainty surrounding the statistical outcomes and highlight the relatively small scale of the impact on COPD event rates in comparison with the intervention costs. The furthest outlier in favour of the intervention saves 0.004 QALYs at a cost of £314.14.

The PSA estimations are also reported as a CEAC in *Figure 24*. The relatively small-scale impact on the effectiveness of the intervention in terms of improvement of utility scores and relatively high costs of the intervention resulted in a 0% chance of cost-effectiveness using a threshold of £30,000 per QALY gained. The scale of the CEAC relates to the relative cost and effectiveness levels and provides an illustration of the positions where the likelihood of cost-effectiveness changes. The upper left-hand quadrant of the CEP in *Figure 23* shows the occurrence of dominated observations (higher costs and worse health outcome), which accounts for 36.1% of the estimations. The maximum percentage of estimations that could be considered cost-effective (i.e. < £30,00 per QALY gained) is 65.9%; the CEAC illustrates up to 54% of these.

Discussion

Key results

As with all economic evaluations, the outcomes of the analyses are driven by the effects of an intervention as well as the costs. In the case of this analysis, the costs incurred by the intervention are large, overwhelming the benefits. The disaggregated outcomes derived from the intervention were balanced against the costs in the CCA. As shown in *Chapter 2*, the change in emergency admissions following the intervention was non-significant. This could be interpreted to mean that the investments, whether the lower bottom-up or the higher top-down reported cost, have not delivered identifiable health benefits in terms of reduced costs to the health service. Similarly, in the CUA, which explored the impacts of the intervention on QALYs relating to the change in rate of emergency admissions for people with COPD, the small, non-significant reduction in emergency admissions is overpowered by the cost of the intervention. Therefore, the intervention cannot be considered cost-effective using commonly accepted norms, with or without discounting costs and benefits to present-day values in line with best practice. It is important to consider that this does not mean that the intervention is without benefit, but rather it may be that the benefits were not able to be identified and measured through the approaches we utilised.

Strengths and limitations

A strength of the current study was the use of routine data held within the SAIL databank. Unlike other health economic studies that focused on affordable warmth interventions, this study was able to use actual health-care utilisation data with near-complete data for the study population (see *Chapter 2*).

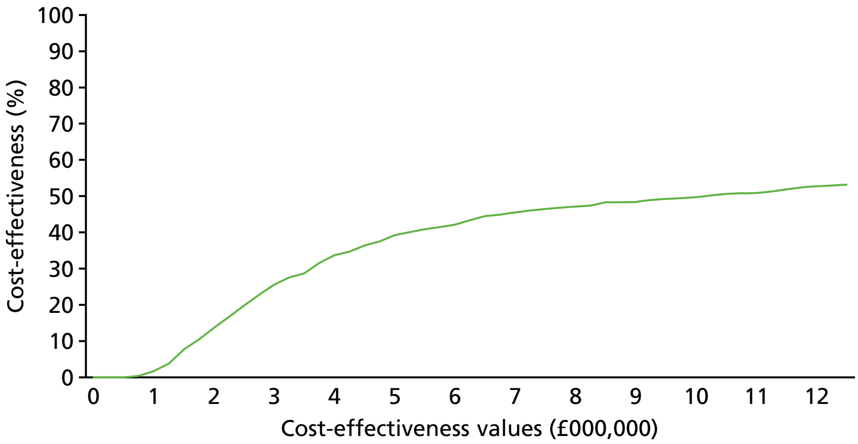

FIGURE 24 Cost-effectiveness acceptability curve for the intervention.

However, the data set will have included people with a wide range of health problems of different stages of severity and no information was available regarding the initial quality of housing and, therefore, the relative improvement resulting from the intervention.

Another strength of the study was that data were used from both the data linkage and the community-based field study. Although routine data allow calculations to be based on actual health-care utilisation, emergency hospital admissions are only a proxy measure for health status. This type of contact with the health-care system can provide a signal that health is changing but will only be one part of the overall story. The community-based field study provided a more detailed understanding of the health, well-being and health-related quality-of-life impact of the intervention, and was used as a basis for a CUA. The results of that analysis are reported in *Chapter 3*.

It was not possible to undertake a CBA, an approach recommended by NICE as an option for evaluating public health interventions, because the available data did not facilitate identification and valuation of all of the impacts of the intervention to society and the full societal cost and consequences of the intervention. It could be useful to conduct such analyses in the future, considering that a housing intervention is likely to have a wide range of benefits beyond health improvements alone. The community-based study showed that the intervention provided a wide range of psychosocial and economic benefits to residents. It is recognised by NICE, however, that CBA poses challenges in terms of obtaining all necessary data to undertake analysis. It was beyond the scope of the study to value these benefits.

We explored the impact of the intervention for up to 10 years (i.e. the probable lifespan of the shortest-lived elements of the intervention), but the effects of the intervention are plausibly longer. A study using longer-term data and a longer-term time horizon may deliver different results.

Interpretation

When trying to determine whether or not an intervention delivers good value for money, the intervention does not necessarily have to be cost-sparing or cost-effective in terms of what would be acceptable for a clinical intervention. Public health decision-makers and budget holders may feel that the goals of the intervention – in this case the delivery of affordable warmth, alleviation of fuel poverty and reduction of CO_2 emissions – justify the costs of the intervention. The fact that our economic analysis suggests that the intervention incurred major costs but did not lead to detectable cost reductions to the health service or improvements in QALYs for people with COPD does not mean that the intervention is without benefit. Indeed, the community-based study showed that the intervention provided a range of social benefits and made it easier and cheaper for households in low-income areas to heat their homes. In addition, the health benefits may emerge over a longer period than the 4-year horizon used in this study, especially as a prevention intervention. A child growing up in a property may not have health impairments that he or she may otherwise have had without the improvements.

The Gentoo[140] and Warm Homes for Health studies,[141] which found health improvements and cost savings after housing improvements, were studies that targeted people with poor housing and the capacity to benefit healthwise. The CUA undertaken with the COPD subpopulation may have been limited by a similar problem. COPD that is sufficiently severe enough to present a risk of hospital admission is defined as moderate to severe.[160] People with moderate to severe COPD are prone to frequent exacerbations (three or more exacerbations per year is part of the definition) and these are an important cause of hospital admission and readmission and, therefore, have a considerable impact on health-related quality of life and daily activities.[150] Reducing exacerbation frequency through improved housing for these people might be more valuable than for others with less-severe COPD, and might spare more health-care resources. However, a hospital admission may be precipitated by a lack of social support and comorbidities rather than severity, which our study data were not able to reveal, but an exacerbation avoided by someone who might fall into this category may have additional value. Focusing an analysis on all such patients may reveal a different picture to the one our present analysis suggests.

Generalisability

This economic study and our findings would be generalisable to a developed country in a temperate region where a national health service exists founded on the principles of solidarity and tax-funded health care.

Chapter 6 Conclusion

Introduction

Improving the energy efficiency of existing housing stock not only has the potential to reduce fuel poverty and carbon emission but it can also help to improve the health of residents.[6] Research has shown that housing quality is associated with a range of health and psychosocial outcomes, and that provision of adequate, affordable warmth can lead to health improvements. However, a recent systematic review of warmth and energy efficiency studies concluded that evidence of the effectiveness of housing improvement is inconclusive, and that more robust research is needed to fill existing gaps in the literature.[48] In particular, limited follow-up periods have made it difficult to determine the long-term health impacts of housing interventions, few studies have focused on psychosocial outcomes that may be part of pathways to better health and only limited research has been conducted to determine whether or not affordable warmth interventions produce better indoor hydrothermal conditions.

In this project, we took the opportunity afforded by a major energy performance investment programme in Wales. The core objectives of the investment programme were to deliver affordable warmth, alleviate fuel poverty and reduce CO_2 emissions through area-based energy efficiency improvements. We examined whether or not these investments provided additional health benefits to residents living in low-income areas in Wales. This was done through a mixed-methods programme of work, including data linkage (see *Chapter 2*), a community-based study (see *Chapter 3*), household monitoring (see *Chapter 4*) and a health economic assessment (see *Chapter 5*). In addition, reconvened focus groups were conducted as part of the wider resident engagement in the project (see *Appendix 2*).

In this final chapter, we will summarise the principal findings of the different studies, followed by a discussion of the main contributions and implications of these findings, as well as the strengths and limitations of the research. The chapter will be concluded with recommendations for further research.

Key findings

The research provided empirical evidence regarding the health and psychosocial impacts of energy performance investments. The key findings of the different studies are reported in the following sections.

The community-based study and the reconvened focus groups

The community-based study found no evidence that the improvements in energy efficiency lead to better mental and physical health in the short term. The intervention was associated with neither improvements in key mental and physical health outcomes nor changes in self-reported respiratory and asthma-related symptoms. However, quantitative evidence was found that the intervention led to improved subjective well-being during the study period, as well as to improvements in a number of psychosocial outcomes that may be part of pathways to better health. This included increased thermal satisfaction, fewer reported financial difficulties, increased satisfaction among participants with the repair of their homes, fewer reported housing-related problems and more social interactions.

These findings were reflected in the focus group discussions that were conducted as part of the resident engagement. The longitudinal focus groups showed the importance of improving the energy efficiency of houses in low-income neighbourhoods.[161] According to residents, the intervention made a great difference to the comfort and warmth of their homes, opened up spaces within the home and reduced their heating bills substantially. This not only helped to relieve financial stress and fuel poverty but made them feel less socially isolated. This confirms that the benefits of the improvements were, at least in the short term, more closely linked to better well-being owing to improved socioeconomic conditions than to physical health outcomes. Experiences with the delivery of the intervention were mixed, which some residents found disempowering and stressful.

The household monitoring study

The household monitoring study demonstrated that the improvements in energy efficiency raised indoor air temperatures and helped households to reduce their energy use. The increase in air temperature was consistent across different heating demand conditions. Although no evidence was found that the intervention reduced the duration of substandard temperatures within the homes, there was a small decrease in the cumulative amount of substandard temperatures (i.e. the time intensity integral of substandard temperatures). However, this reduction was small in absolute terms.

The different energy efficiency measures were not equally effective in raising indoor air temperatures. External wall insulation and connection to the gas mains network were the most effective, whereas new windows and doors or a new heating system did not lead to significant changes in indoor air temperature. The greatest increases in indoor air temperatures were found in British steel-framed (BISF) buildings and buildings with solid walls, which had the lowest energy performance ratings before the intervention. That indoor air temperatures increased most in the evening and at night, as well as in the living room and main bedroom, suggests that the intervention makes the biggest difference when spaces are in use.

Overall, no evidence was found that the intervention increased indoor RH levels. However, some evidence was found that the intervention decreased the duration and cumulative amount of substandard temperatures. Although no evidence was found that the intervention increased indoor RH levels overall, some evidence indicated that individual measures did. Both a connection to the gas mains network and the installation of new windows and doors were associated with small increases in indoor RH levels. However, the increases were small in absolute terms.

The data linkage study

The data linkage study found no evidence that the intervention reduced emergency admissions for either the primary outcome (combined cardiorespiratory emergency hospital admissions) or most secondary outcomes (emergency hospital admissions for cardiovascular, respiratory and COPD conditions, and excess winter admissions) for people of all ages living in an intervention home. The study also did not find evidence of a significant intervention effect on our primary outcome when focused only on residents aged $\geq$ 60 years at the mid-point of their residence in an intervention home. However, the study did find a statistically significant intervention effect on cardiovascular-related emergency admissions: there was an increase in emergency cardiovascular admissions post intervention for those aged $\geq$ 60 years. Although we controlled for age in our analyses, it is possible our analyses have not taken all effects of ageing into account. It may be that age does not have a linear response and the older people in this group are increasingly frail, having had poor health conditions set in motion at an earlier age, working to outweigh the potential for reduced admissions as a result of a single thermal efficiency intervention.

The economic evaluation

The CCA undertaken as part of the economic analysis did not find evidence that the intervention delivered explicit reductions in cardiorespiratory-related emergency admissions. The costs of achieving this outcome relate to the costs of delivering the intervention unmodified by savings in emergency admissions. However, the purpose of undertaking CCA is to present costs and benefits separately, allowing the reader or decision-maker to make their own decision about the relative value of the benefits compared with the costs. As reported previously, there were social benefits from the intervention, albeit not demonstrably seen in emergency admissions. The increased warmth and well-being derived from housing improvements may well be considered worthwhile irrespective of the impact on health-care activity.

The CUA explored, through modelling methods, the impact on QALYs of the change in rate of emergency admissions for people with COPD. However, the impact on COPD-related emergency admissions is overpowered by the cost of the intervention and, therefore, cannot be thought of as cost-effective using commonly accepted norms.

Implications of the research

The research found no demonstrable effects of the intervention on health or health service utilisation in the short and medium term. As a result, the health economic analysis concluded that the intervention might not be considered cost-effective in a traditional sense. These findings appear to be in line with a recent systematic review conducted by Thomson *et al.*[48] in that area-based programmes are less likely to produce improvements than interventions that specifically target at-risk populations. Emerging findings of other research suggest that Nest – the more targeted part of the Welsh Government Warm Homes programme – provides greater health benefits than the broader Arbed scheme that was evaluated in this programme of work.[162] It is nevertheless surprising that no apparent effects were found, given that the intervention programme targeted low-income neighbourhoods with poor-quality housing and where, as a result, residents were at a higher risk of living in fuel poverty.

However, that does not mean that the intervention was without substantial benefit. The main purpose of the programme was to deliver affordable warmth, alleviate fuel poverty and reduce CO_2 emissions. The research found clear evidence that this was the case. The research showed that the investments in energy efficiency provide a wide range of benefits to the lives and well-being of residents. It is not unlikely that this may produce value in terms of benefits to the NHS and social services in the longer term. The time horizon of 4 years may still be insufficient for the health benefits of the investments to have materialised.[48] However, even without such demonstrable health improvements, it may be worth investing in the energy efficiency of substandard homes if it provides better living conditions and quality of life for low-income communities. Although it was not possible to undertake a full CBA, future research may consider the wider social benefits of delivered affordable warmth to low-income households, reduced fuel poverty and reduced CO_2 emissions.

The project trialled a new approach to analyse household monitoring data, which can serve as a useful model for further evaluations of housing improvement programmes. Variants of interrupted time series analysis can be used to make robust assessments with relatively small sample sizes. It is often unclear whether residents receiving energy efficiency improvements use them for extra warmth or benefit in a different way.[133,134] Researchers have observed greater temperature increases following energy efficiency improvements among low-income groups, most likely because low-income groups may have a greater unmet demand for space heating.[163] The household monitoring study found evidence that the rebound effects following the intervention were relatively small. The benefits of energy efficiency improvements were taken as energy saving as well as extra warmth, suggesting that the potential long-term health effects of energy efficiency improvements may work via the two main pathways of improved thermal living conditions and more-affordable heating.[54–56]

The focus groups study highlighted the importance of involving residents in the decision-making regarding affordable warmth interventions. Although residents were overwhelmingly positive about the intervention programme, and felt that it had made a big difference to their lives, they were more critical about its delivery. In line with previous research, some residents reported feelings of disempowerment and stress, which may have partly offset any potential benefits.[39,53,61] Extensive consultation and involvement throughout a housing improvement programme may help to minimise disruption to residents.[91]

Strengths and weaknesses of the research

One of the strengths of the research is that it provided a comprehensive evaluation of a policy-led affordable warmth programme through a longitudinal multimethod investigation comprising data linkage, a field study, household monitoring, qualitative focus groups with residents and a health economic assessment. The different elements were combined to highlight areas in which results converge and supplement each other. Although each method has its own strengths and weaknesses, as discussed in the different empirical chapters, together they provide a more complete picture than could be obtained from a single method alone.[164]

This research demonstrates the need for detailed assessment of policy-led interventions in order to fully understand their impacts, and provides a toolkit for how this might be done in the future. Although data linkage can be used to link the intervention to actual health service utilisation, the field study covers more-subjective aspects resulting from the intervention. The household monitoring has helped to assess the differential impacts depending on construction type and intervention measure. Furthermore, the research has shown that more-qualitative research methods can help to improve our understanding of the choices people make following affordable warmth interventions.

The research has a number of limitations. Most notably, it was not possible to randomise participation into intervention and control groups and, as with any observational study, the potential for unmeasured confounding remains. Both the community-based and household monitoring data relied on the responsiveness of residents and were therefore subject to a number of biases. Response rates and retention rates were particularly low for the field study. This was countered by the data linkage study, which minimised selection and attrition biases with near-complete follow-up. However, data quality was also an issue. The effort required to validate and clean intervention records received from data providers was considerable, and there were missing data for many intervention homes. Furthermore, the data linkage study was only able to investigate emergency hospital admissions. The lack of association with emergency hospital admissions may indicate that the focus of the research was too narrow and the follow-up time too short. It is possible that the health benefits will emerge over a longer period than the 4-year horizon used in this study, especially as a preventative intervention. The finding that the intervention provides a wide range of psychosocial outcomes suggests that a full CBA needs to be conducted to fully appreciate the benefits of affordable warmth improvements.

The research has highlighted the challenges of evaluating complex social interventions.[116,117] Evaluators generally do not have control over the content and delivery of the programme, nor the resources and costs relating to the programme and data regarding the timing may not be in the format or of the quality that is needed. There are added complexities of house moves and non-standard delivery of the intervention. Early involvement may help to address these challenges by developing designs and data collection that would provide the best quality of evidence. Equally, understanding of the resources deployed, their costs and how they could be influenced or changed might improve the balance of costs and benefits of the programme. Early consideration of evaluation methods may also help to increase response and retention rates.

Recommendations for further research

Evaluating housing interventions is challenging owing to a number of factors that affect their quality. We make the following recommendations for future research.

- Our research suggests the importance of incorporating health and economic evaluations as part of housing improvement programmes from the start. A stepped wedge randomisation in the delivery of a programme, together with improved reporting standards regarding the timing, delivery and costs of the intervention, would help to improve the quality of both prospective and retrospective evaluations.
- In the research, each component covered a different aspect of the evaluation. Data linkage in combination with a field study, household monitoring and qualitative work can be used as a model for the evaluation of future housing interventions to provide a comprehensive overview of their impact. Process evaluation should become a core part of testing complex social interventions.[116,165]
- The lack of results in the research presented here may, as suggested by Thomson *et al.*,[48] indicate that area-based programmes are less likely to produce measurable health improvements than those that

specifically target at-risk populations. A direct comparison between different types of programmes, for example between the area-based Arbed and the demand-led Nest schemes, would help to determine which approach leads to the greatest health improvements.

- The research found no evidence for changes in emergency admissions associated with the intervention. One explanation is that the health benefits of housing interventions do not appear in hospital statistics. Future research may therefore need to focus on lower-level health conditions as recorded in primary health-care consultations.
- Future evaluations should ideally have longer follow-up periods and use CBA to fully capture the range of benefits resulting from affordable warmth intervention, including both health and non-health outcomes.
- Long-term monitoring of internal and external hydrothermal conditions, in combination with detailed monitoring of energy consumption and household behaviours, would help to improve our understanding of adaptive responses following energy efficiency investments.[166,167]

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Contributions of authors

Wouter Poortinga (Professor of Environmental Psychology) conceived the research, managed the overall project, supervised the statistical analyses for the community-based and household monitoring studies and led the writing of the report.

Sarah E Rodgers (Associate Professor in Spatial Epidemiology) conceived the research, led the SAIL data linkage part of the research and contributed to the writing of the report.

Ronan A Lyons (Professor of Public Health) conceived the research and contributed to the use of the record-linked data sets and the writing of the report.

Pippa Anderson (Associate Professor in Health Economics) led the economic evaluation of the project and the writing of *Chapter 5*.

Chris Tweed (Professor of Sustainable Design, Head of School of the Welsh School of Architecture) conceived the research and provided expert advice on the household monitoring component of the research.

Charlotte Grey (Research Assistant in Public Health) co-ordinated and conducted the fieldwork for the community-based study, contributed to the data collection of the household monitoring study, conducted the statistical analysis of the community-based study and led the writing of *Chapter 3*. She collected the housing intervention records from the 28 LAs and RSLs that were used for the data linkage, led the reconvened focus group study that was a component of the resident engagement and organised the drop-in dissemination meetings.

Shiyu Jiang (Research Assistant in Household Monitoring) co-ordinated and conducted the fieldwork for the household monitoring study, contributed to the data collection of the community-based study, conducted the statistical analysis of the household monitoring study and led the writing of *Chapter 4*. He collected the housing intervention records from the 28 LAs and RSLs that were used for the data linkage, contributed to the reconvened focus group study that was part of the resident engagement and organised the drop-in dissemination meetings.

Rhodri Johnson (Data Analyst) contributed to the preparation and coding of the PEDW data sets used for the SAIL data linkage and health economic components of the project and contributed to the writing of the report.

Alan Watkins (Associate Professor in Medical Statistics) led the statistical analyses of the SAIL data linkage, contributed to the preparation and coding of the PEDW data sets and led the writing of *Chapter 2*.

Thomas G Winfield (Research Assistant in Health Economics) conducted the health economic analyses and contributed to the writing of the report.

Publications

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Data sharing statement

All data queries and requests should be submitted to the corresponding author for consideration in the first instance. Please note that data collected as part of the community-based study, household monitoring study and reconvened focus group study can be supplied from the corresponding author directly. However, access to data held within the SAIL databank is governed by the SAIL IGRP and data access requests should be submitted to saildatabank@swansea.ac.uk referencing 'Arbed 0273'. Access to the intervention data will require approval from the appropriate data custodians. The corresponding author can advise as appropriate. In all cases, access to available anonymised data may be granted following review.

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Appendix 1 Resident engagement: focus group protocol

Introduction

Introduction (moderator): thank people for coming, introduce self, briefly outline goals for research, reasons for recording the session given, 'rules': only one person to talk at a time, all data are treated confidentially and will be anonymised, the session is open and everyone's views are important, amount of time that will be taken up. Aim for people to talk to each other, not moderator.

- Tell me a little bit about how long you have lived in this area, and what are the good and bad things about living here.
- What are the good and bad things about living in your home?
- Tell me a little bit about your home – do you have any problems with it (e.g. condensation/mould)?

Before intervention (round 1, 2014)

1. **THERMAL COMFORT:** I'd like to talk to you about what conditions are like in your home (before any Arbed measures were installed). Would you tell me what a typical winter's day is like in your home? Probe differences between household members (especially very young and very old): what was it like getting up in the morning, washing/bathing, doing housework, going to bed, use of rooms/house space, draughty/cold parts of the house, warmth and comfort. What would you like your home to be like? What changes would you make if you had the resources?
2. **KEEPING YOUR HOUSE WARM:** How adequate is the heating system that you use to warm your house (before Arbed)? How do you use it? What would you change about your home in order for you to be comfortable in winter? What are the factors stopping you from doing this?
   Probe: timing, warmth, cost/affordability, convenience, efficiency, ease of use. Have you put up with feeling cold because of cost? Are there any rooms you do not heat?
3. **USE OF LIVING SPACE:** Does your ability to keep your house warm enough affect your use of different rooms in your house? Does it ever stop you going out or inviting people home during the coldest days in the winter?
4. **FUEL POVERTY:** Do you feel that paying for heating your home in winter is difficult? What would you spend money on if fuel was less expensive? What is more important, eating well or warmth?
   Probe (written on board): rent/mortgage; repairs to home; telephone bill; food and other necessities; going out/treats; credit payments; occasional bills (e.g. insurance); stress; heat or eat.
5. **HEALTH AND WELL-BEING:** How do you think that living in a home that is not warm enough in winter would affect a person's feeling of health and well-being? (generally)
   How do you think it affects different people: elderly, children, people with pre-existing health problems, fit adults? Probe: effects on mood, state of mind, overall well-being, physical health? Respiratory health: colds/flu?
   Alternative: if you are cold in your home what effect has that on your life in general? AND do you think being cold is connected to your health?
6. **EXPECTATIONS AND EXPERIENCES OF ARBED UP TO DATE:** What did you think the benefits of Arbed might be? Do you think it will have a particularly big effect for any particular family member?
   Probe: physical health and mental/well-being issues for self and other family members, use of home (e.g. increase in living space), social interactions, effects of cold home as age, financial benefits
   Imagine that this Arbed Scheme did not exist and the government would send you a cheque of the same value for you to spend on absolutely anything you would like. How would you have spent it?

Just say the first thing that comes into your mind. Why that? Probe: the money or having the work done: which do you think would benefit you more and why? If you had to spend it on improving your home, what would you spend it on?

End (moderator): thank everyone for their participation, explain what will happen to the data they have given, tell them about further session next year.

After intervention (round 2, 2015)

1. **THERMAL COMFORT:** I'd like to talk to you about what conditions are like in your home (after any measures were installed). Would you tell me what a typical winter's day is like in your home now? Are you satisfied with the temperature of your home?
   Probe: differences between household members (especially young and old): what was it like getting up in the morning, washing/bathing, doing housework, going to bed, use of rooms/house space, draughty/cold parts of the house, convenience, efficiency, warmth and comfort.
2. **KEEPING YOUR HOUSE WARM:** How adequate is the heating system that you use to warm your house (after Arbed)? Do you use the heating/hot water any differently now? If yes, how and why?
   Probe: timing, warmth, cost/affordability, convenience, efficiency, ease of use. Have you put up with feeling cold because of cost?
3. **USE OF LIVING SPACE:** After Arbed, do you use/heat your home differently? Are there any rooms you do not heat? Have you changed your habits of going out or inviting people into your home?
4. **FUEL POVERTY:** What difference has the Arbed work had on your energy bills? Do you find it easier affording to heat your home? Have you changed the way you heat your home? What do you spend any saved money on?
5. **HEALTH AND WELL-BEING:** After the Arbed work have there been any changes in the way you and your family feel in terms of health or well-being?
   In what ways do you think the new heating/hot water has affected your health/illness? Other household member's health/illness?
   Has it affected your/their use of health services (GP visits and callouts; A&E, NHS Direct)? Probe: colds, flu, asthma, other, feelings of well-being? Probe: effects on mood, state of mind, overall well-being, physical health? Respiratory health – colds/flu?
6. **EXPECTATIONS AND EXPERIENCES OF ARBED:** Now you have had the Arbed work done, would you say it has made a difference? To you? To other members of the household? In what ways?
   Probe: the difference made by the most recent work, relative to the effects of any other previous work (damp proofing, cavity wall insulation, loft insulation, double glazing etc.)? What made the biggest difference?
   Overall, would you say your experiences with Arbed were positive? Have you had any problems since the work was carried out? If yes, what and how did you deal with it? If no, who would you contact if you did have a problem? Probe: how contacted, choice, control, implementation, core components everyone received.
   Can you think of any other benefits from Arbed? Probe: what about in relation to the environment? How important is it to you that your new heating is less harmful to the environment?
   Imagine that this Arbed Scheme did not exist and the government would send you a cheque of the same value for you to spend on absolutely anything you would like. How would you have spent it? Just say the first thing that comes into your mind. Why that?

End (moderator): thank everyone for their participation, explain what will happen to the data they have given.

Appendix 2 Resident engagement: summary results of the reconvened focus group study

This appendix contains material from Grey *et al.*[161] This article is distributed under the terms of the Creative Commons Attribution 3.0 License (http://www.creativecommons.org/licenses/by/3.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

Introduction and aims

A reconvened focus group study was conducted as part of the wider residents' engagement with the research project. Three focus groups were held with residents before and again after they received energy efficiency improvements under the second phase of the intervention programme. The aims of the focus groups were to obtain a better understanding of the views and experiences of residents living in energy inefficient (hard-to-heat, hard-to-treat) houses, and then to explore in what way the intervention may have improved these experiences. The qualitative approach used in the study allows the residents to express experiences in their own words and in greater detail than is possible in a quantitative survey. To date, only a small number of qualitative studies have been conducted to examine psychosocial aspects of warmth and energy efficiency improvement.[39,53,61] This reconvened focus group study adds to the evidence of residents' experiences of living in cold homes, the stresses and consequences of living in fuel poverty, and the ways that energy efficiency improvements may change those experiences.

Methods

The focus groups were conducted in three geographically distinct communities in South Wales that had been selected to receive energy efficiency measures under the programme.

Box 2 provides details of the three communities, as well as specifics of the different schemes. The first round of focus groups was held in March 2014 and lasted just under 1.5 hours. In total, 28 people took part in the study (8 in Caerau, 9 in Brynamman and 11 in Hollybush). Participants were recruited from 30 households whose homes were being monitored as part of the project (see *Chapter 4*). They were contacted by telephone to invite them to take part in the discussions. Therefore, one of the researchers (SJ) had been in contact with the participants a number of times before the start of the focus groups. The participants were made aware of the goals of the focus groups as well as the overall project. The focus groups were held at a convenient location and took place either at lunchtime or in the early evening. In one of the focus groups, three participants had already received energy efficiency improvements under the intervention programme. Another three participants had recently received external wall insulation, but not through the intervention programme.

The second round of focus groups was held in March and April 2015 after all improvement work was complete in the three communities. The focus groups again lasted just under 1.5 hours. All participants who took part in the first round were invited to attend. In total, 22 people took part in the reconvened focus groups (5 in Caerau, 3 in Brynamman and 14 in Hollybush). This included three additional residents from the Hollybush area who expressed interest in attending the discussions. A number of previous participants were not available for the second round owing to other commitments or relocation.

BOX 2 Focus group locations

Caerau (Cardiff) is a suburb located 3 miles to the west of Cardiff city centre. Housing is a mixture of housing association flats, bricked terraced houses, traditionally built semi-detached houses and semi-detached BISF houses. The work that took place was external wall insulation and boiler/heating system upgrades. Caerau has a WIMD rank of 170 and is part of the Cardiff West Communities First regeneration cluster.

Brynamman (Carmarthenshire) is a village located on the south-facing side of the Black Mountain in an old coal mining area within the Brecon Beacons National Park boundaries. Housing is predominantly small, stone terraces. Before the first focus group was held, the area was not connected to the mains gas network. The mains gas network was extended to homes in the village and boiler and central heating upgrades were provided. The area has a WIMD rank of 651.

Hollybush (Caerphilly) is an old coal mining village situated between Blackwood and Tredegar, above the Sirhowy Valley. Before the first focus group was held, the village was not connected to the mains gas network. Housing is a combination of older small stone terraced houses (pre 1919) and post-1965 and 1980s detached homes. The work extended the mains gas network to homes in the village and provided boiler and central heating upgrades. The area has a WIMD rank of 565 and is located within the Mid Valleys East Communities First regeneration cluster.

Out of the 31 residents who participated in the focus group discussions, 14 were male and 17 female; 24 owned their home and 7 rented; 4 were aged between 18 and 40 years, 9 were aged between 40 and 60 years and 18 were aged > 60 years. Eighteen residents occupied the home on their own, 19 occupied the home as a couple and 4 could be considered a family (i.e. a couple plus children).

Topics for the focus group discussions were based on the themes from the household survey used for the community-based study (see *Chapter 3*). The same themes were discussed in the before and after focus groups. These included the topics of (1) health and well-being; (2) thermal comfort, staying warm and the use of living space; (3) fuel poverty; and (4) experiences with the intervention programme (see *Appendix 1* for the focus group protocol).

The discussions were led by two researchers (CG and SJ) and supported by Gabriela Zapata-Lancaster and Martina Stefani (see *Acknowledgements*). All focus group discussions were recorded and fully transcribed. The resulting discussions were analysed thematically, using the identified themes as organising concepts. Ethics approval was received from the Welsh School of Architecture's Research Ethics Committee on 15 March 2014 (EC1403.184). Participants were given a £30 voucher as compensation for their time.

Analysis

A structured approach was applied for the analysis. The focus groups were recorded, transcribed and coded using computer-assisted qualitative data analysis software. NVivo 11 (QSR International, Warrington, UK) was used to code the transcripts using the key topics, described above, which were based on identified themes within the context of the existing fuel poverty literature and policies. Transcripts were coded separately by two researchers (CG and Tina Schmieder-Gaite) to ensure consistency. *Figure 25* shows the coding tree that was used to analyse the focus group transcripts. After coding, each parent and child node was analysed thematically and emerging patterns were refined and cross-compared. The results are described according to these themes.

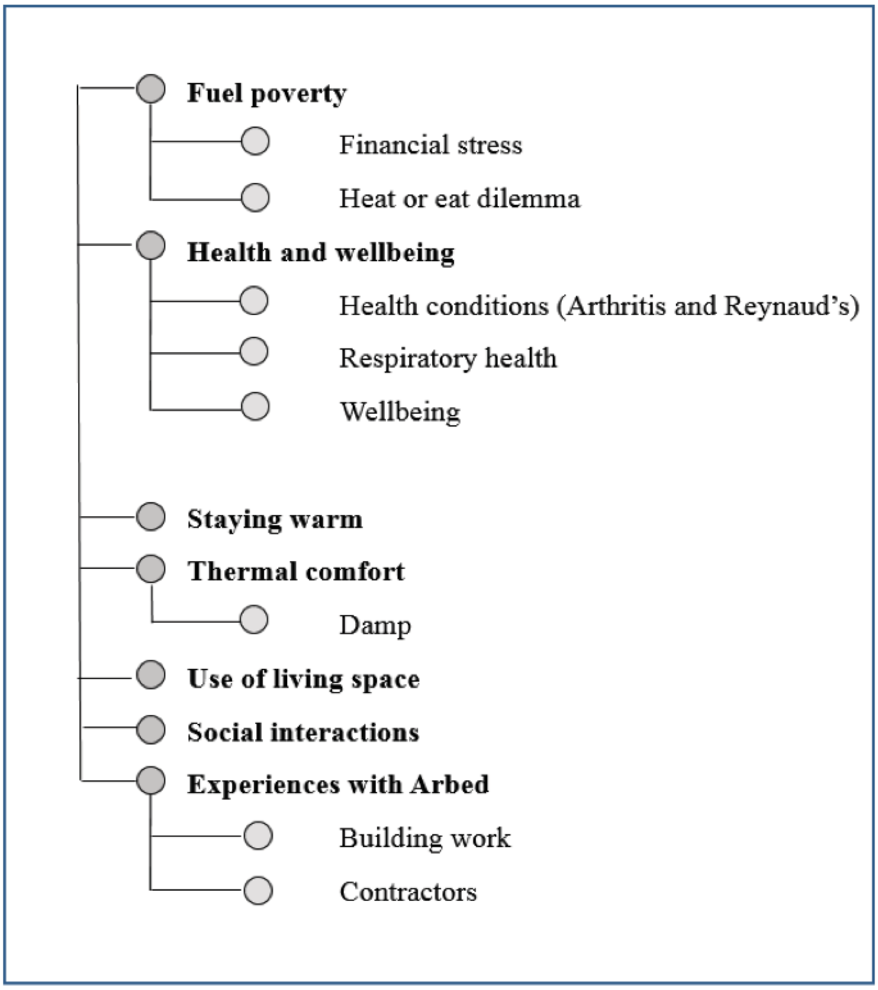


FIGURE 25 Coding tree with coding parent nodes and child nodes.

Results

The main findings of the focus groups are presented here under the key themes investigated. The results for the before and after focus groups are discussed separately. A more detailed description of the results can be found in Grey *et al.*[161]

Round 1: before installation (2014)

Health and well-being

There was strong agreement among the focus group participants that living in a cold home is depressing and detrimental to both mental and physical health. In line with the findings of Harrington *et al.*,[39] participants thought that living in a cold home exacerbates ill health rather than causes it; in particular, that a cold home may make it more difficult to live with or recover from pre-existing chronic conditions. Many described how living in the cold affected their respiratory health and it was felt that the cold environment exacerbated a range of conditions, including diabetes, arthritis and circulatory problems. A cold home was thought to increase both the length and severity of illness. In addition, participants felt that living in a cold home contributes to poor emotional well-being. The physical effects of exposure to poor internal conditions and psychological stress resulting from fuel bills were felt to trigger feelings of depression and anxiety. It was generally believed that a warmer home environment would contribute to better mental and physical well-being.

Thermal comfort, staying warm and use of living space

Participants commented on how unpleasantly cold their homes could be during the winter and expressed concerns about the lack of thermal comfort and the negative consequences this may have for their health. They described how difficult it is to stay warm in an energy inefficient house, in particular if it is non-traditional housing (e.g. a steel frame construction). Respondents used a number of strategies to stay warm and avoid turning on the heating. This included the use of heaters, hot water bottles and blankets, or only heating a limited number of rooms. Similar strategies were reported in Harrington *et al.*,[39] Gilbertson *et al.*[61] and Shortt and Rugkåsa.[53] However, these strategies were seen as temporary stopgaps and were considered unsustainable in the longer term. The lack of thermal comfort and living space was thought to put a strain on social interactions within the households and, as a result, participants' enjoyment of their home. This also meant that some householders tried to avoid being at home for certain periods of time.

Fuel poverty

The focus group participants repeatedly mentioned how expensive it is to heat their homes and discussed how easy it is for low-income households living in an energy inefficient house to fall into fuel poverty. High fuel bills are not only stressful but also force householders to make difficult choices in their daily lives. Participants frequently had to make compromises on how to spend their limited household budget. Just as reported by Harrington *et al.*,[39] households either economised on fuel or refrained from other activities or expenditures in order to stay warm. Many considered the 'heat-or-eat' dilemma a reality in their own lives as well as in their wider community. Some participants reported episodes in which they would not eat because they had to heat their home. The findings support the conclusion of Harrington *et al.*[39] that the health impacts of fuel poverty involves more than the direct physical effects of exposure to poor internal conditions. The cumulative stresses associated with fuel poverty were found to be particularly damaging. Living in a cold, damp house is more depressing when you are not able to eat properly or go out. An inadequate diet may not only lead to problems associated with food poverty but can also worsen feelings of poor well-being in a cold home. Furthermore, the discussions showed how socially isolating fuel poverty can be. Some of the participants described how friends and family were reluctant to come and visit them in their homes because of the cold, even in summer.

Experiences with the intervention programme

All participants of the focus groups welcomed the energy efficiency measures they were expecting to receive under the intervention programme. The participants who had already received some of the measures felt grateful for them, not only because they were provided for free, but also because they had made a noticeable difference to their comfort, finances and overall quality of life. These results are in line with the findings of previous qualitative studies. Gilbertson *et al.*[61] reported that recipients of Warm Front energy efficiency work were generally positive about the upgrades and felt that the upgrades had improved thermal comfort, use of living space and feelings of well-being. They also found that greater warmth and comfort further enhanced emotional security and social relations within the home and eased symptoms of chronic illness.

Although the participants of the first round of focus groups were generally positive about the intervention programme and the provided energy efficiency upgrades, they felt that the communication with the recipients could be improved and households themselves should have a greater say in the delivery of the programme. The 'one-size-fits-all' approach was generally disliked and many questioned the motives for taking this approach and the usefulness of some of the measures.

Round 2: after installation (2015)

Health and well-being

Improvements to health and well-being were discussed again in the second round of focus groups after all improvement work was complete. The participants generally felt that the improvements had had some effect on their health, in particular their respiratory health. However, participants did not discuss the topic in as much detail as in the first round of focus groups. It appeared that health had become a lower priority, and it proved quite difficult to sustain discussion on the topic. Participants did feel that better thermal comfort and aesthetic aspects of the improvements had had a positive effect on their general well-being. The results of the focus groups suggest that the health benefits of the improvements were, at least in the short term, more closely linked to psychological well-being – resulting from better thermal comfort, having more control over of the heating in their homes and reduced stress from financial pressure – than to the physical effects of exposure to improved internal conditions.

Thermal comfort, staying warm and use of living space

Participants of the second round of focus groups agreed that their homes were warmer and more comfortable following the energy efficiency upgrades to their homes, which meant that they no longer needed to find ways to economise on their fuel bills, for example by restricting their use of heating or finding alternative ways of keeping warm. They discussed that they could now more easily afford to maintain their whole house at a more comfortable temperature using their central heating. This negated the need to use alternative 'stay warm' strategies such as the use of blankets. The energy efficiency work not only improved the overall quality of the indoor environment but also opened up space that was previously used less, effectively increasing the amount of usable living space within the home. Similar to the findings of Harrington *et al.*,[39] participants attached a great importance to their increased ability to keep their homes warm. Most of the participants stated that their homes were now much warmer during the winter and cheaper to heat. A few participants discussed how they now felt more comfortable inviting family or friends into their homes, making them feel less socially isolated.

Fuel poverty

In contrast to Gilbertson *et al.*,[61] who found that many participants had difficulties assessing whether or not their fuel bills were lower, our study found that participants were generally aware of their reduced fuel bills. Indeed, participants spent a large amount of time discussing their financial savings in detail and how much easier it was to pay their fuel bills; particularly being able to pay a competitive dual-fuel energy tariff, allowing for further discounts and savings. Gilbertson *et al.*[61] stated that in the Warm Front programme it was likely that householders were experiencing warmer homes but generally not also the dual benefit of reduced bills. This is likely owing to differences in the two energy efficiency schemes: Arbed 2 invested more financially into each home within the scheme, taking a whole-house approach, and the criteria for eligibility to the programmes were different. Shortt and Rugkåsa[53] further found that, although energy efficiency measures helped to improve warmth, some households remained in fuel poverty after the measures were installed, suggesting that, although homes might become easier to heat, this does not always translate to lifting households out of fuel poverty and thereby potentially concealing possible health gains from such an intervention. Post intervention, the 'heat-or-eat' dilemma was not discussed except by one participant who mentioned that savings made on fuel costs meant they did have more money now to spend on a specialised health diet, although this also meant that the savings did not make them feel better off.

Experiences with the intervention programme

Participants in the second round of focus groups appreciated that the energy efficiency improvements were provided for free and were generally happy about the results. According to the participants, the improvements made a big difference to the warmth of their homes. One occupant, who had received energy efficiency measures through a different scheme, felt that the work had been much more effective in making their home warmer. The work was not only seen to be beneficial in terms of providing affordable warmth but it was also felt that the external wall insulation had improved the aesthetics of their homes and the local environment. Participants discussed in detail how this improved their general sense of well-being and pride. Participants in one focus group discussed the importance of energy efficiency schemes for Wales and, in particular, for local communities such as theirs.

The participants were more critical of the delivery of the energy efficiency measures themselves. They expressed some dissatisfaction about the quality of communication, work conducted by contractors and a lack of involvement in the selection of energy efficiency measures that they felt would be the most beneficial. Participants discussed that regular public meetings both before and during the improvement programme, as well as more personal contact between households and scheme managers, could have improved communication. This would have helped to clarify the aims of the programme, reduced misunderstandings about the measures households were to receive and enabled them to report issues with contractors more easily. Finally, participants discussed that they felt that they had too little say over the measures they would receive and expressed some frustration over the fact that they were expected to simply accept the measures because they were free. In particular, participants who rented their home privately or socially felt that they had little or no control over the whole process.

The results regarding the delivery of the programme resonate with previous research. Gilbertson *et al.*[61] also found that recipients of a similar warm homes programme expressed frustration about the delivery of the work. Some found the process of installation disempowering and stressful, which could undermine the well-being of an already vulnerable population. Harrington *et al.*[39] argued that people in fuel poverty should not be viewed as passive targets for benevolence and that government-funded interventions will confer far greater benefit if recipients are made to feel empowered. A greater emphasis on partnership with the community could help address individual concerns, improve feelings of control and, as a result, alleviate stress associated with the delivery of a housing improvement programme.[168] Marmot *et al.*[6] argued in their review that it is important for programmes to create opportunities for individuals and communities to set the agenda for change and identify local solutions. Indeed, participants of the reconvened focus groups felt that the benefits of the programme would have been greater if they had been more closely involved in the decision-making process.

Discussion

The reconvened focus group study that was conducted as part of the residents' engagement proved to be a useful addition to the research project. The study provided a better understanding of the views and experiences of residents undergoing energy efficiency improvements, which resonated with the results of the research project. The study also gained from resident involvement in the research project itself. A number of participants were recruited to a resident panel to provide feedback and contribute to the SSC of the research project. This helped to ensure that the views of residents were represented in the research.

The reconvened focus groups showed the importance of structural energy performance investments of hard-to-heat, hard-to-treat houses in low-income neighbourhoods. The study found that living in a cold home was generally viewed as depressing, stressful and detrimental to both mental and physical health. According to the participants, the energy efficiency work made great improvements to the comfort and warmth of their homes, opened up spaces within the home and substantially reduced their heating bills. This not only helped to relieve financial stress and fuel poverty but also made them feel less socially isolated. Participants felt that physical health improvements following the work were secondary to improvements in thermal comfort and their ability to invite friends and family into their homes. The lack of discussions about physical health following the completion of the work suggests that adverse physical conditions inside the home are no longer experienced as urgent.

Although the improvements were, for the most part, positively received by occupants and clearly fulfilled the goal of the programme to make homes warmer and cheaper to heat, there were some complaints about the delivery of the work itself. This adds weight to the need to consider community engagement and communication to involve residents more closely in the decision-making and delivery of affordable warmth programmes.

Appendix 3 Consolidated criteria for reporting qualitative research checklist

Item	Guide questions/description	Reported on page
Domain 1: research team and reflexivity		
Personal characteristics		
1. Interviewer/facilitator	Which author/s conducted the interview or focus group?	104, *Methods*
2. Credentials	What were the researcher's credentials? (e.g. PhD, MD)	NA
3. Occupation	What was their occupation at the time of the study?	NA
4. Gender	Was the researcher male or female?	NA
5. Experience and training	What experience or training did the researcher have?	NA
Relationship with participants		
6. Relationship established	Was a relationship established prior to study commencement?	104, *Methods*
7. Participant knowledge of the interviewer	What did the participants know about the researcher? (e.g. personal goals, reasons for doing the research)	104, *Methods*
8. Interviewer characteristics	What characteristics were reported about the interviewer/ facilitator? (e.g. bias, assumptions, reasons and interests in the research topic)	104, *Methods*
Domain 2: study design		
Theoretical framework		
9. Methodological orientation and theory	What methodological orientation was stated to underpin the study? (e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis)	104, *Analysis*
Participant selection		
10. Sampling	How were participants selected? (e.g. purposive, convenience, consecutive, snowball)	103–4, *Methods*
11. Method of approach	How were participants approached? (e.g. face-to-face, telephone, mail, e-mail)	104, *Methods*
12. Sample size	How many participants were in the study?	103, *Methods*
13. Non-participation	How many people refused to participate or dropped out? Reasons?	104, *Methods*
Setting		
14. Setting of data collection	Where were the data collected? (e.g. home, clinic, workplace)	103, *Box 2*
15. Presence of non-participants	Was anyone else present besides the participants and researchers?	NA
16. Description of sample	What are the important characteristics of the sample? (e.g. demographic data, date)	104, *Methods*

Item	Guide questions/description	Reported on page
Data collection		
17. Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	*Appendix 1*, 101–2
18. Repeat interviews	Were repeat interviews carried out? If yes, how many?	104, *Methods*
19. Audio/visual recording	Did the research use audio or visual recording to collect the data?	104, *Methods*
20. Field notes	Were field notes made during and/or after the interview or focus group?	NA
21. Duration	What was the duration of the interviews or focus group?	Pages 103 and 104, *Methods*
22. Data saturation	Was data saturation discussed?	NA
23. Transcripts returned	Were transcripts returned to participants for comment and/or correction?	NA
Domain 3: analysis and findings *Data analysis*		
24. Number of data coders	How many data coders coded the data?	104, *Analysis*
25. Description of the coding tree	Did authors provide a description of the coding tree?	105, *Figure 25*
26. Derivation of themes	Were themes identified in advance or derived from the data?	104, *Methods*
27. Software	What software, if applicable, was used to manage the data?	104 (NVivo)
28. Participant checking	Did participants provide feedback on the findings?	NA
Reporting		
29. Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? (e.g. participant number)	NA, see page 104 for a reference to Grey *et al.*[161]
30. Data and findings consistent	Was there consistency between the data presented and the findings?	105–8, *Results*
31. Clarity of major themes	Were major themes clearly presented in the findings?	105–8, *Results*
32. Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	108, *Discussion*

NA, not applicable.

Appendix 4 Resident engagement: key findings brochure

[redacted]

ARBED & HEALTH

Results from a study by Cardiff University

Household survey results

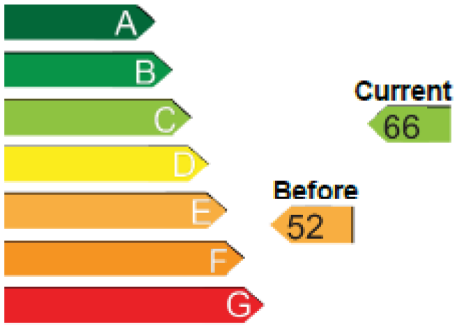
Over the past few years, a number of communities across Wales have had energy-efficiency work done to their homes through the European and Welsh Government funded Arbed programme. Measures included external wall insulation, new boilers and radiators, and connecting homes to the mains gas network.

Cardiff University conducted a study to find out how these improvements would make a difference to residents. The study found that the Arbed programme:

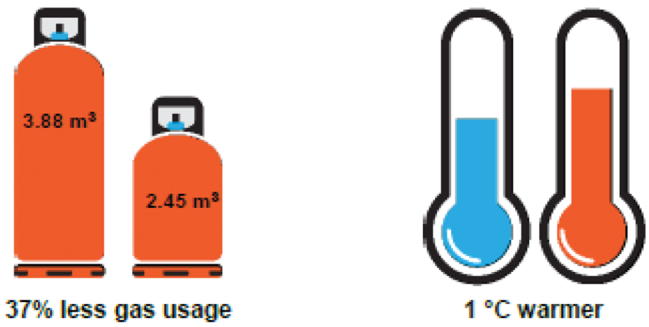
- ✓ Improved overall wellbeing
- ✓ Improved satisfaction with the temperature inside the home
- ✓ Made it less of a struggle to pay heating bills
- ✓ Made people happier to invite friends into their homes

Household monitoring results

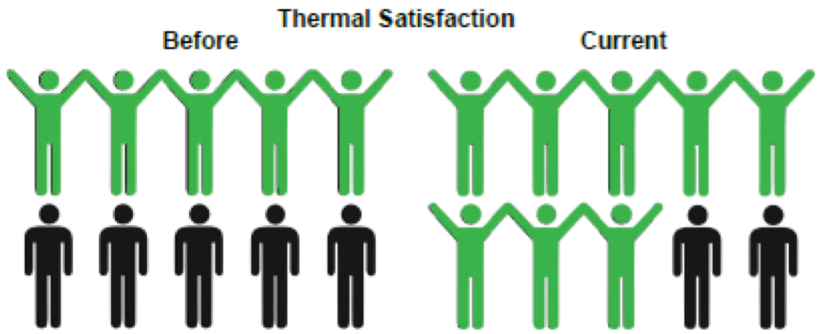
Having energy efficiency work helped to improve the energy rating of homes from E to C on average.



This means savings of up to £39 per month while homes become 1 °C warmer during winter.



Residents are more satisfied with indoor air temperature.



Further information

[redacted]

Seeking information and help

Resource Efficient Wales is a single point of contact within the Welsh Government for information on improving the energy efficiency of your home, generating renewable energy, saving water and reducing waste. They are there to help you find the right support to become more efficient. Call the Resource Efficient Wales helpline on

0300 123 2020

Thank you to all residents who kindly gave their time to help with our survey.

If you have any questions please contact us at:
Cardiff University, Welsh School of Architecture
Bute Building, King Edward VII Avenue, Cardiff, CF10 3NB
Email: arbed2@cardiff.ac.uk

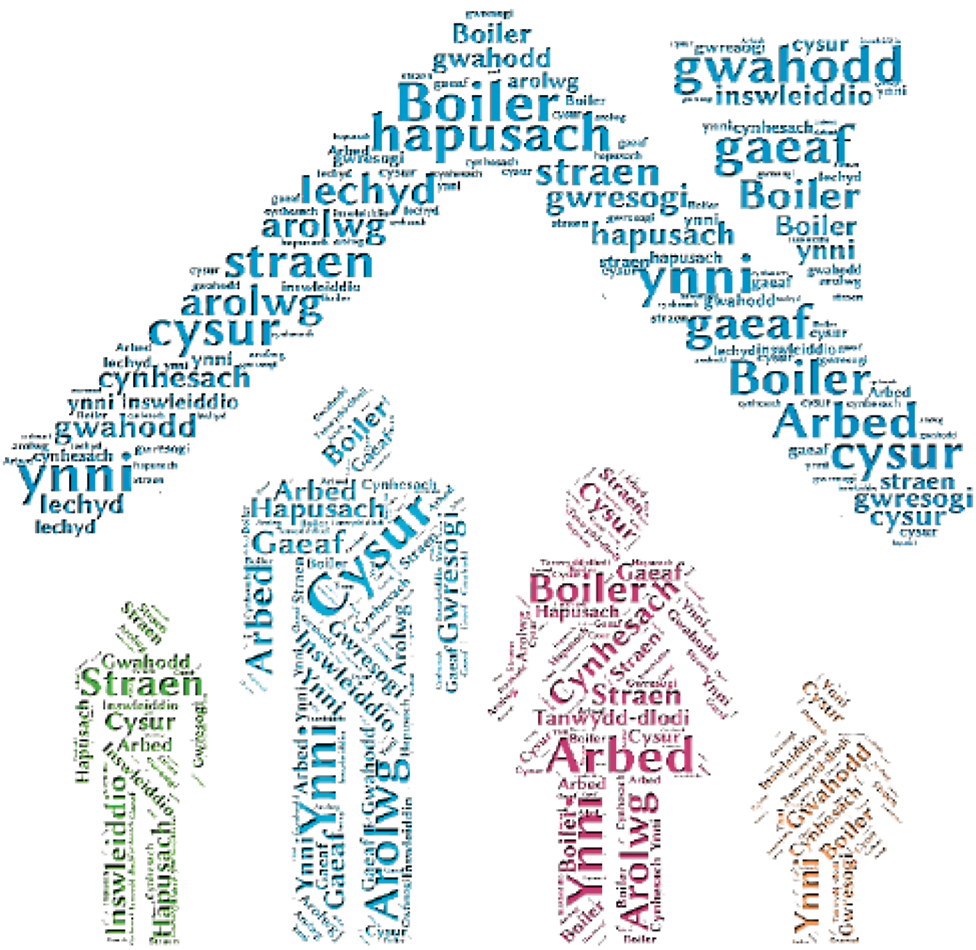
This brochure presents emerging results from independent research funded by the National Institute for Health Research (NIHR). The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

DOI: 10.3310/phr06050 PUBLIC HEALTH RESEARCH 2018 VOL. 6 NO. 5

[redacted]

ARBED AC IECHYD

Canlyniadau astudiaeth gan Brifysgol Caerdydd



Canlyniadau arolwg cartrefi

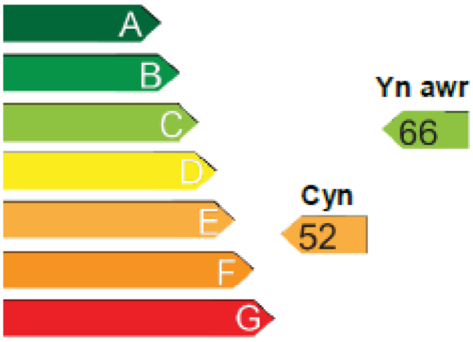
Dros y blynyddoedd diwethaf, mae gwaith gwella effeithlonrwydd ynni cartrefi wedi'i wneud mewn cymunedau ledled Cymru drwy raglen Arbed a ariannwyd gan Ewrop a Llywodraeth Cymru. Roedd y gwaith yn cynnwys insiwleiddio waliau allanol, gosod boeleri a rheiddiaduron newydd, a chysylltu cartrefi â'r prif rwydwaith nwy.

Cynhaliodd Prifysgol Caerdydd astudiaeth i weld sut byddai'r gwelliannau hyn yn gwneud gwahaniaeth i breswylwyr. Yn ôl yr astudiaeth, mae rhaglen Arbed wedi:

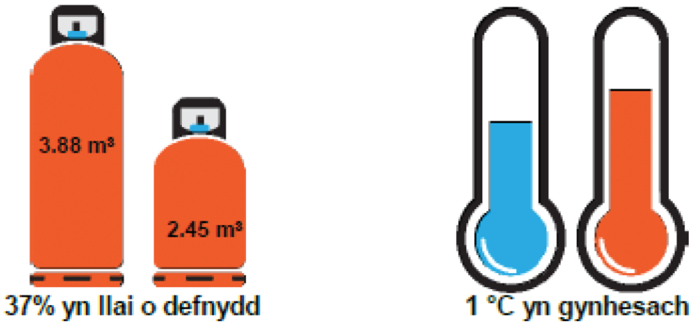
- ✓ Gwella lles yn gyffredinol
- ✓ Gwella bodlonrwydd ar y tymheredd y tu mewn i'r cartref
- ✓ Gwneud talu biliau gwresogi yn fwy fforddiadwy
- ✓ Gwneud pobl yn fwy parod i wahodd ffrindiau i'w cartrefi

Canlyniadau monitro cartrefi

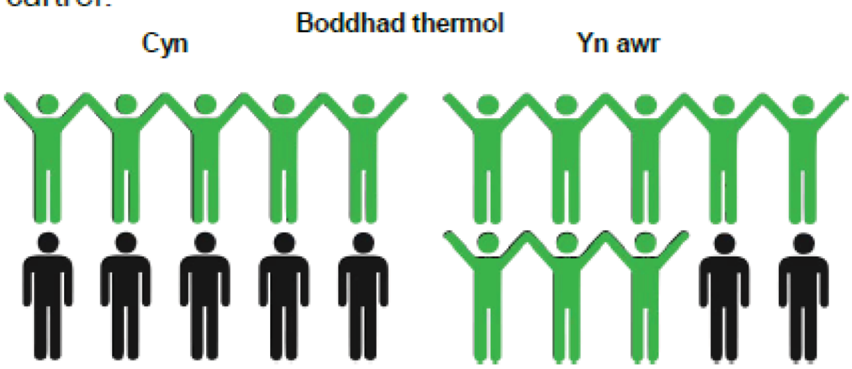
Roedd gwneud gwaith gwella effeithlonrwydd ynni yn helpu i wella sgôr ynni cartrefi o E i C ar gyfartaledd.



Mae hynny'n golygu bod hyd at £39 yn cael ei arbed bob mis tra bod cartrefi 1 °C yn gynhesach yn ystod y gaeaf.



Mae trigolion yn fwy bodlon ar dymheredd yr aer yn y cartref.



Rhagor o Wybodaeth

[redacted]

Gofyn am ragor o wybodaeth a chymorth
Adnodd Effeithlon Mae Cymru yn un pwynt cyswllt o fewn Llywodraeth Cymru i gael gwybodaeth ar wella effeithlonrwydd ynni eich cartref, cynhyrchu ynni adnewyddadwy, arbed dŵr a lleihau gwastraff. Maent yno i'ch helpu i ddod o hyd i'r cymorth iawn i ddod yn fwy effeithlon. Ffoniwch y llinell gymorth Adnoddau Effeithlon Cymru ar:

0300 123 2020

Diolch i'r holl breswylwyr a roddodd o'u hamser i lenwi ein harolwg.

Cysylltwch â ni ar bob cyfrif os oes gennych unrhyw gwestiynau:
Prifysgol Caerdydd, Ysgol Pensaernïaeth Cymru
Adeilad Bute, Rhodfa'r Brenin Edward VII, Caerdydd, CF10 3NB.
Ebost: arbed2@caerdydd.ac.uk

Mae'r llyfryn hwn yn rhoi'r canlyniadau sy'n dod i'r amlwg mewn ymchwil annibynnol a ariennir gan y Sefydliad Cenedlaethol ar gyfer Ymchwil Iechyd (NIHR). Barn yr awdur(on) a fynegir, ac nid yw'r GIG, y Sefydliad Cenedlaethol ar gyfer Ymchwil Iechyd na'r Adran Iechyd o reidrwydd yn rhannu'r un farn.

Appendix 5 Resident engagement: pull-up banner

[redacted]

Living in cold homes that are hard to keep warm can lead to poor health and fuel poverty. We evaluated a national scheme to improve the energy-efficiency of Welsh homes, to see what impact the work had on conditions inside the home, and the health and wellbeing of the people living there.

Health and Wellbeing

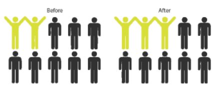
People living in homes which had energy-efficiency work undertaken through the arbed scheme, felt:

✓ That their feelings of wellbeing had improved.

✓ They were less likely to put up with feeling cold to save costs.

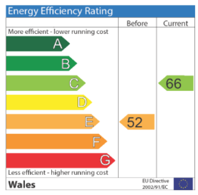
✓ They were more likely to invite friends or family home during the winter.

✓ They were more satisfied with the state of repair of their home.



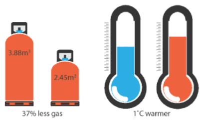
Temperature and comfort

Having energy-efficiency work helped to improve the energy rating of homes from E to C on average.



During the winter this meant savings of up to £39 per month, while the home.

✓ Residents were more satisfied with the temperature inside their homes.



✓ They were more satisfied with indoor air temperature.

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welsh-school-of-architecture-cardiff-university-156027

Appendix 6 Template for Intervention Description and Replication checklist

Item number	Item	Page number	Further details
	BRIEF NAME		
1	Provide the name or a phrase that describes the intervention	3	
	WHY		
2	Describe any rationale, theory or goal of the elements essential to the intervention	3	
	WHAT		
3	Materials: describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL)	4	There was a large amount of variation in materials in the two phases of the intervention programme; a list of materials may be available from the scheme managers of the different schemes
4	Procedures: describe each of the procedures, activities and/or processes used in the intervention, including any enabling or support activities	4–5	
	WHO PROVIDED		
5	For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given	5	
	HOW		
6	Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group	5	
	WHERE		
7	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features	4	
	WHEN and HOW MUCH		
8	Describe the number of times the intervention was delivered and over what period of time, including the number of sessions, their schedule and their duration, intensity or dose	4–5	
	TAILORING		
9	If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when and how	5	
	MODIFICATIONS		
10	If the intervention was modified during the course of the study, describe the changes (what, why, when and how)	NA	

Item number	Item	Page number	Further details
	HOW WELL		
11	Planned: if intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them	NA	
12	Actual: if intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned	NA	

NA, not applicable.

Appendix 7 Emergency-hospital-admission-based outcome classification

The method of classifying hospital admissions in PEDW as primary outcomes, and as COPD outcomes for a subanalysis, is shown in *Figure 26*. Emergency admissions were identified using the admission method of the first episode within a person spell (representing continuous periods of inpatient care for a single patient), with primary diagnosis of cardiovascular or respiratory conditions contained within chapters 'I' ('Diseases of the Circulatory System') or 'J' ('Diseases of the Respiratory System') of the ICD-10.[85] Episodes representing symptoms and signs involving the circulatory and respiratory systems (R00–R09) in the first diagnostic position with no subsequent secondary diagnosis codes were also classified as a primary outcome.

The COPD outcomes using ICD-10 codes as a subgroup of the primary outcome emergency admissions were selected, measured separately for people of all ages and those aged > 60 years. The codes and age-based rules are shown below.

All admissions for any age for codes

- J40 (bronchitis, not specified as acute or chronic).
- J41 (simple and mucopurulent chronic bronchitis).
- J42 (unspecified chronic bronchitis).
- J43 (emphysema).
- J44 (other chronic obstructive pulmonary disease).

Admissions for which age at admission is > 40 years for codes

- J45 (asthma).
- J46 (status asthmaticus).

All admissions for any age for codes

- R06 primary code, with any ICD-10 code starting with J4.

Subgroups of the primary outcome were created for cardiovascular (codes J00–J99) and respiratory (codes I00–I99) admissions.

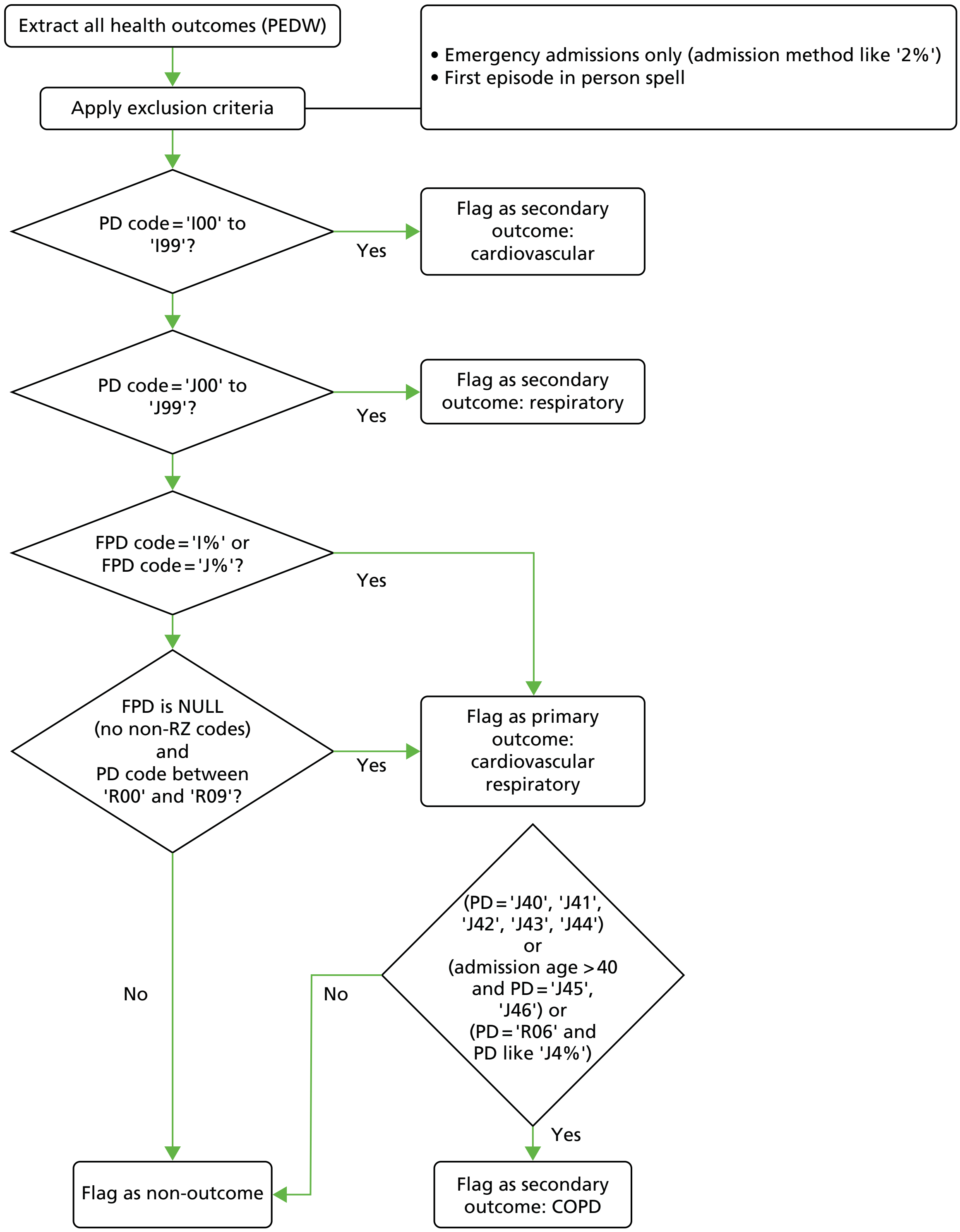

FIGURE 26 Flow chart to define emergency hospital admission outcomes. FPD, first non-RZ, missing diagnosis code; PD, first diagnosis code (position 1); RZ, R or Z codes (from ICD-10 Chapters 18 or 21, respectively); SD, second to fourteenth position diagnosis code.

Appendix 8 Data for the two comparator groups

The data on the two comparator groups are potentially useful in assessing trends in the study window, following the usual assumption that trends are common across groups. *Figures 27* and *28* show the monthly emergency admission rates per person across the study window for the intervention groups, and for the social housing and the top 10% deprivation groups, respectively. These time plots provide evidence of little or no trend in these rates across the study window data; the corresponding correlations between rates across the study window are 0.296 for intervention and social housing groups (conventionally regarded as weak) and 0.506 for intervention and the top 10% deprivation groups (somewhat stronger but conventionally only regarded as moderate).

The time plots and correlations offer only limited support for using data from either comparator group in the analysis of the intervention group rates.

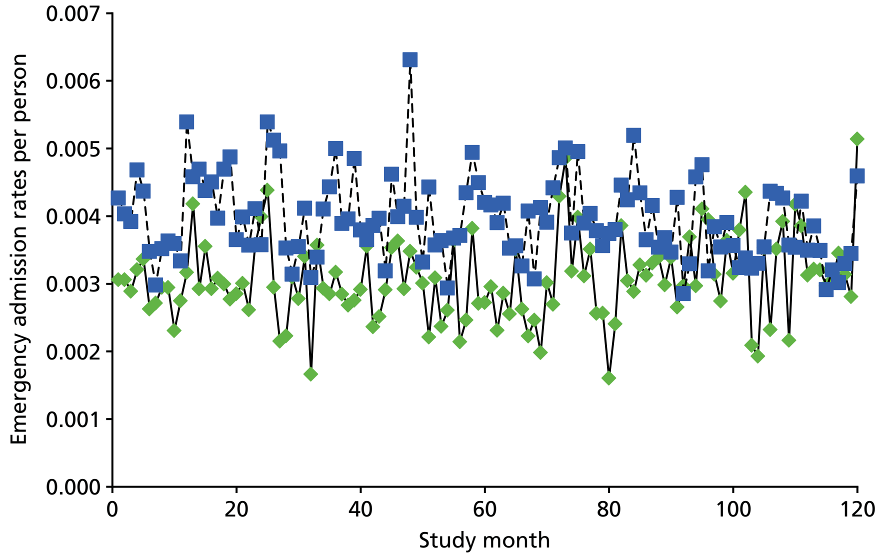

FIGURE 27 Monthly emergency admission rates per person for intervention and social housing groups (study month 1 is January 2005).

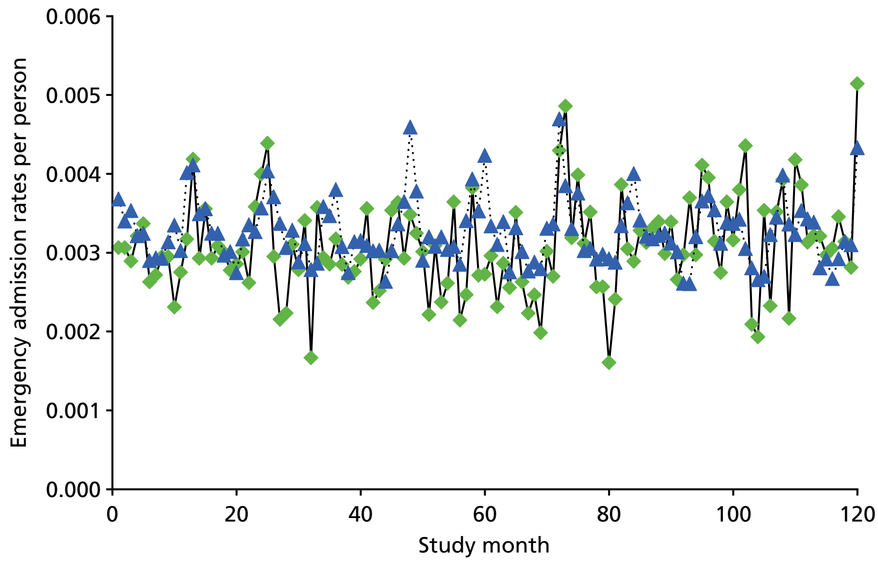

FIGURE 28 Monthly emergency admission rates per person for intervention and top 10% deprivation groups (study month 1 is January 2005).

Appendix 9 Community-based study: the health questionnaire

Questions 1–7 were from the SF-12 version 2 and have been redacted from this appendix.

Your Health and Well-Being

This survey asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. ***Thank you for completing this survey!***

For each of the following questions, please tick the one box that best describes your answer.

We would like to ask you about your health, your use of NHS services, and how you feel

8. **In the past month have you had any of the following symptoms?**

Please tick all that apply

- Coughing ☐
- Bring up phlegm ☐
- Shortness of breath ☐
- Wheezing attack ☐
- Chest tightness ☐
- Runny nose ☐
- Blocked nose ☐
- Sinus swelling ☐
- Sneezing ☐
- Sore throat ☐
- Cold/Flu ☐
- None of the above ☐

9. **Have you had wheezing and whistling in your chest at any time in the last 12 months?** Yes ☐ No ☐

   (a) If yes, Have you been at all breathless when the wheezing noise was present? Yes ☐ No ☐

   (b) If yes, Have you had this wheezing or whistling when you have not had a cold? Yes ☐ No ☐

10. **Have you woken up with a feeling of tightness in the chest at any time in the last 12 months?** Yes ☐ No ☐

11. **Have you been woken up by an attack of shortness of breath at any time in the last 12 months?** Yes ☐ No ☐

12. **Have you been woken up by an attack of coughing at any time in the last 12 months?** Yes ☐ No ☐

13. **Have you had an attack of asthma in the last 12 months?** Yes ☐ No ☐

14. **Are you currently taking any medication (including inhalers, aerosols or tablets) for asthma?** Yes ☐ No ☐

15. **Do you have any nasal allergies including hay fever?** Yes ☐ No ☐

16. **Are you currently being treated by your GP or hospital for any of these conditions?**

Please tick all that apply

- Angina ☐
- Heart failure ☐
- High blood pressure (or hypertension) ☐
- Another heart condition ☐
- Asthma ☐
- Emphysema ☐
- Bronchitis ☐
- Another respiratory illness ☐
- Depression ☐
- Anxiety ☐
- Another mental illness ☐
- Arthritis ☐

17. **During the past 2 weeks, how many times did you visit a family doctor (GP) to talk about your own health?**	**Please write in number**
18 **During the past 12 months, how many times did you go to Casualty/A&E as a patient?**	**Please write in number**
19. **During the past 12 months, how many times did you visit a hospital as an in or out patient?**	**Please write in number**

20. **Overall, how satisfied are you with your life nowadays?** Please give your answer on a scale of 0 to 10, where 0 is 'not at all satisfied' and 10 is 'completely satisfied' (tick one only)

Not at all satisfied										*Completely satisfied*
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

21. **Overall, to what extent do you feel that the things you do in your life are worthwhile?** (tick one only)

Not at all worthwhile										*Completely worthwhile*
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

22. **Overall, how happy did you feel yesterday?** (tick one only)

Not at all happy										*Completely happy*
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

23. **On a scale where 0 is 'not at all anxious' and 10 is 'completely anxious', overall, how anxious did you feel yesterday?** (tick one only)

Not at all anxious 0	1	2	3	4	5	6	7	8	9	*Completely anxious* 10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

We would like to ask you some questions about your home and energy use in winter

	Very satisfied	Fairly satisfied	Neither satisfied nor dissatisfied	Fairly dissatisfied	Very dissatisfied
24. **On a typical winter day, how satisfied are you with the temperature in your home**	☐	☐	☐	☐	☐

25. **In the past 12 months have you put up with feeling cold to save heating costs?** Yes ☐ No ☐

26. **How would you describe the overall level of warmth in your home during the winter? Is it…**

Tick one only

- ☐ Much colder than you would have liked
- ☐ A bit colder than you would have liked
- ☐ About right
- ☐ A bit warmer than you would have liked
- ☐ A lot warmer than you would have liked
- ☐ Both too warm and too cold

27. **Do you have central heating?** Yes ☐ No ☐

28. **How do you heat your home?** **Please tick all that you use**

- ☐ Electric central heating (e.g. storage heater)
- ☐ Mains gas (central heating)
- ☐ Oil (central heating)
- ☐ Solid fuel (e.g. coal, wood)
- ☐ Bulk LPG (liquid petroleum gas)
- ☐ Gas portable heater
- ☐ Electric portable heater
- ☐ Oil filled radiator
- ☐ Other

	Please state the figure easiest for you		
	£ per week	**£ per month**	**£ per quarter**
29. **How much do you pay for your total gas and electricity utility bills?**		OR	OR
How much do you pay for oil or solid fuels (coal, wood)?		OR	OR

30. **How do you pay for your gas/electric bills?**

	Gas	Electric
pre-payment meter	☐	☐
quarterly bills (standard credit)	☐	☐
direct debit	☐	☐
other	☐	☐

31. **On a typical winter day, which of the following rooms are heated?**

Kitchen	Main living area/room	Hallway	Main bedroom 1	Bedroom 2	Bedroom 3	Bathroom	Other rooms
☐	☐	☐	☐	☐	☐	☐	☐

32. **On a typical winter evening, which of the following rooms are heated?**

Kitchen	Main living area/room	Hallway	Main bedroom 1	Bedroom 2	Bedroom 3	Bathroom	Other rooms
☐	☐	☐	☐	☐	☐	☐	☐

33. **In the last year have you ever felt reluctant to invite friends or family to your home because of difficulties keeping it warm?** Yes ☐ No ☐

In the past 2 weeks, how many times have you…	Not at all	Once or twice	3-6 times	More than 6 times
34. **Gone out to visit family or friends?**	☐	☐	☐	☐
35. **Had family/friends to visit you in your home?**	☐	☐	☐	☐

Next are some questions about your home

36. **In what type of house are you living?**

- ☐ House – detached
- ☐ House – semi detached
- ☐ House – terraced/end of terrace
- ☐ Bungalow
- ☐ Flat – purpose built
- ☐ Flat or maisonette – conversion
- ☐ Other

37. **How long have you lived here?**

- ☐ Less than one year
- ☐ 1-4 years
- ☐ 5-9 years
- ☐ More than 9 years

38. **Approximately, when was your home first built?**

Before 1919	1919 - 1944	1945 - 1964	1965 - 1979	1980 or later
☐	☐	☐	☐	☐

39. **How many bedrooms are there in your home?**

Please write in the number

40. **Does your household own or rent this accommodation?**

- ☐ Owner occupied
- ☐ Rented from private landlord/agent
- ☐ Rented from local authority (council)
- ☐ Rented from housing association/ cooperative/ trust/ registered social landlord (RSL)
- ☐ Other (e.g. through work/relative)

41. **How satisfied or dissatisfied are you with the current state of repair of your home?**

Very satisfied	Fairly satisfied	Neither satisfied nor dissatisfied	Fairly dissatisfied	Very dissatisfied
☐	☐	☐	☐	☐

42. **Do you currently experience any of the following problems in your home?**

Tick all that apply

- ☐ Condensation
- ☐ Leaking roof
- ☐ Damp walls and/or floors
- ☐ Rot in windows or door frames
- ☐ Draught
- ☐ Mould

We would like to ask you some questions are about how you feel about money

How often is it difficult to meet the cost of…	Very often	Quite often	Only Occasionally	Never
43. The rent or mortgage	☐	☐	☐	☐
44. Repairs or maintenance for your home	☐	☐	☐	☐
45. Gas, electricity and other fuel bills	☐	☐	☐	☐
46. The telephone bill	☐	☐	☐	☐
47. Bills for council tax, insurance etc. that come up from time to time	☐	☐	☐	☐
48. Credit payments (e.g. visa, store cards)	☐	☐	☐	☐
49. Food and other necessities	☐	☐	☐	☐
50. Treats like a night out, or presents for the family	☐	☐	☐	☐

	Better off	Just the same	Worse off
51. Compared to a year ago, do you feel financially…	☐	☐	☐

	None	Slight	Somewhat	Moderate	High
52. What level of financial stress do you feel?	☐	☐	☐	☐	☐

	Very often	Quite often	Only Occasionally	Never
53. In the last 12 months, the food I bought just didn't last, and I didn't have money to get more	☐	☐	☐	☐
54. In the last 12 months, I couldn't afford to eat balanced meals	☐	☐	☐	☐
55. In the last 12 months, did you ever cut the size of your meals or skip meals because there wasn't enough money for food?	☐	☐	☐	☐

We would like to ask you a few questions about you & your household

56. **Which one of these best describes you?**

- ☐ I smoke daily
- ☐ I smoke occasionally, but not every day
- ☐ I used to smoke daily, but do not smoke at all now
- ☐ I used to smoke occasionally, but do not smoke at all now
- ☐ I have never smoked

57. **Are you intending to quit smoking in the next 6 months?** Yes ☐ No ☐

58. **How many members of this household smoke (including yourself)?** **Please write in the number**

59. **What is your sex?** Male ☐ Female ☐

60. **Which age group do you belong to?** **Mark one box only**

Under 18	☐	36-45 years	☐
18-20 years	☐	46-54 years	☐
21-25 years	☐	55-64 years	☐
26-35 years	☐	65 or above	☐

61. **How many children (under 16) usually live in your household?** **Please write in number**

62. **Including yourself, how many adults (16 years or over) usually live in your household?** **Please write in number**

63. **How many of these adults are employed– full or part time?** **Please write in number**

64. **What is your marital status?**

- ☐ Single (never married)
- ☐ Cohabiting/ Living together
- ☐ Married or Civil partnership
- ☐ Separated
- ☐ Divorced
- ☐ Widowed
- ☐ Other

65. **What is your current employment status?**

- ☐ Employed full time
- ☐ Employed part time (less than 30 hours per week)
- ☐ Self employed
- ☐ Unemployed, looking for work
- ☐ Not working because of poor health or disability
- ☐ Full-time house-person
- ☐ Full time student
- ☐ Retired
- ☐ Other

66. **What is the highest qualification you have?**

- ☐ GCSE/O-level/CSE
- ☐ Vocational qualification (=NVQ1+2)
- ☐ A-level or equivalent
- ☐ Degree level or higher
- ☐ No formal qualification
- ☐ Other

67. **Thinking of the income of your household as a whole (including all benefits), which represents the total income of the whole household before deductions for income tax, National Insurance, etc.**

	Weekly	Per Year
☐	£0 - £96	£0 – £4,999
☐	£97 - £144	£5,000 – £7,499
☐	£145 - £192	£7,500 – £9,999
☐	£193 - £288	£10,000 – £14,999
☐	£289 - £385	£15,000 – £19,999
☐	£386 - £577	£20,000 – £29,999
☐	£578 - £769	£30,000 – £39,999
☐	£770 – £962	£40,000 – £49,999
☐	£963 or more	£50,000 or more

68. **Do you receive housing benefits?** Yes ☐ No ☐

Finally, can we just ask...

69.	**Are you having energy efficiency work done to your home this year?**	Yes ☐ No ☐
70.	**If yes, is this work being done through …**	Please tick all that apply

- Arbed ☐
- NEST ☐
- Green Deal/ECO ☐
- Paid for by your household ☐
- Don't know ☐

Thank you for completing this questionnaire!

Appendix 10 Consolidated Health Economic Evaluation Reporting Standards checklist

Section/item	Item number	Recommendation	Page number
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more-specific terms such as 'cost-effectiveness analysis', and describe the interventions compared	XX
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base-case and uncertainty analyses) and conclusions	XX
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study Present the study question and its relevance for health policy or practice decisions	XX
Methods			
Target population and subgroups	4	Describe characteristics of the base-case population and subgroups analysed, including why they were chosen	XX
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made	XX
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated	XX
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen	XX
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate	XX
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate	XX
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed	XX
Measurement of effectiveness	11a	Single study-based estimates: describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data	XX
	11b	Synthesis-based estimates: describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data	XX
Measurement and valuation of preference-based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes	NA
Estimating resources and costs	13a	Single study-based economic evaluation: describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs	XX, *Appendix 12*
	13b	Model-based economic evaluation: describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs	XX

Section/item	Item number	Recommendation	Page number
Currency, price date, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate	XX, *Table XX*, *Appendix 11*
Choice of model	15	Describe and give reasons for the specific type of decision-analytic model used. Providing a figure to show model structure is strongly recommended	XX
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytic model	XX
Analytical methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty	XX
Results			
Study parameters	18	Report the values, ranges, references and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended	XX
Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios	XX
Characterising uncertainty	20a	Single study-based economic evaluation: describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective)	XX
	20b	Model-based economic evaluation: describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions	XX
Characterising heterogeneity	21	If applicable, report differences in costs, outcomes or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information	NA
Discussion			
Study findings, limitations, generalisability and current knowledge	22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge	XX
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct and reporting of the analysis. Describe other non-monetary sources of support	XX
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations	XX

NA, not applicable.

Appendix 11 Costs of intervention measures and their estimated lifetime

Intervention measure	Number delivered	Estimated lifetime-years (DECC)[147]	Cost (£)		
			Indicative (WG)[148]	Intervention measure	Yearly per measure
External wall insulation	2709	36	7300	19,775,700	549,325
Photovoltaics	1458	25	5400	7,873,200	314,928
Solar water heating	928	25	2600	2,412,800	96,512
Air source heat pumps	401	15	6000	2,406,000	160,400
Loft/rafter insulation	172	42	100	17,200	409.52
Total cost				32,484,900.00	1,121,574.52

DECC, Department of Energy and Climate Change; WG, Welsh Government.

The total yearly cost of £1,121,574.52 represents each of the individual measures' totals divided by their estimated lifetime. The per-house yearly cost is the total yearly cost divided by the number of properties ($n = 4968$), which results in a figure of £225.76.

Appendix 12 Chronic obstructive pulmonary disease utilities literature review

Introduction

The review was designed as a structured narrative literature review. It sought to capture and draw conclusions from the main body of literature reporting health state utility values (HSUVs) for patients with COPD in order to build a profile of HSUVs before, during and after admission to hospital with an exacerbation, including the longer-term residual effect.

The focus was on secondary health-care utilisation as the majority of patients with COPD are elderly and thus are at risk of prolonged hospital stays.[169] Hospital admission can have a considerable impact on subsequent quality of life, often disempowering individuals and reducing functional independence.[170,171]

The evidence was compiled following systematic procedures and, when possible, adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; see *Appendix 15*). PRISMA is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. PRISMA focuses on the reporting of reviews evaluating randomised trials, but can also be used as a basis for reporting systematic reviews of other types of research, particularly evaluations of interventions. The protocol for the review was devised and included an initial scoping of the literature to identify existing reviews, a comprehensive search strategy to identify relevant studies and a narrative data synthesis to provide a summary of results in relation to each objective.

Aim and objectives

To review the literature in order to build a profile of HSUVs for patients with COPD before, during and after admission to hospital with an exacerbation of COPD:

i. to quantify HSUVs for stable COPD patients
ii. to quantify the change in HSUV from hospital admission to discharge
iii. to quantify the residual effect of a hospital admission
iv. to identify other confounding variables that cause variation in HSUVs.

Methods

A scoping exercise identified several existing reviews that provided pooled HSUVs for patients with COPD, including three open access reviews and one review of which only the abstract was available.[151,172,173] The scoping search revealed the availability of many recent systematic reviews/meta-analyses in relation to HSUVs in patients with stable COPD (objective i). The focus of this review was to capture any additional reviews relevant to stable COPD (objective i) and to identify studies reporting HSUVs at admission and discharge (objective ii), the residual effect of a hospital admission (objective iii) and confounding variables (objective iv).

The review was designed using a two-stage process. First, a broad overview of HSUV studies for patients with COPD was undertaken to identify the number and type of studies that are currently available in the literature. The second selection process used additional inclusion and exclusion criteria to identify those studies relevant to each objective. Primary inclusion and exclusion criteria were designed to incorporate all studies reporting HSUVs for patients with COPD. The study used the inclusion and exclusion criteria reported in *Table 24*.

TABLE 24 Primary inclusion and exclusion criteria

	Inclusion	Exclusion

Population	• Studies in which either:
	  ○ all or part of the population has a respiratory disease defined by ICD-10 codes J00–J06, J09–J18, J20–J22, J30–J39, J40–J47, J60–J70, J80–J84, J85–J86 or J90–J94 (matching those used in the Arbed study); or
	  ○ a descriptive definition (e.g. COPD) is used if the condition is physician diagnosed (including when reported by a third party or self-reported)
	• Studies in which the population includes adults (aged ≥ 18 years) only
		• Studies in which COPD was not the primary disease state
		• Studies that include patients with other conditions and in which the data for patients with COPD conditions are not distinguishable
		• Studies including data on population in correctional institutions only
		• Studies in which the population has a genetic disorder responsible for COPD
		• Studies in which the study population is < 18 years of age or in which data for adults is not distinguishable

Study type	• Studies published in the English language • Analytical studies including randomised control trials, cohort studies, cross-sectional studies, case–control studies • Studies using empirical data and modelling studies	• Full text not available as an open access source • Non-English-language studies (including those with English abstracts only) • Descriptive studies including case studies and opinion-based literature (editorials/letters, etc.) • Systematic reviews and meta-analyses (eligible for referencing searching only)
Context	• Studies based in primary, secondary or tertiary care	NA
Outcomes	• Studies including a HSUV measured by the EQ-5D, SF-6D, HUI-2, AQoL, 15D or QWB	• Studies based on regression analysis that report beta coefficients only • Studies reporting HSUV graphically when values cannot easily be identified • Studies reporting experience-based HSUV • Studies in which utility values were estimated using mapping values from other instruments or the questionnaire was completed by a third party

15D, 15-dimensional measure of health-related quality of life; AQoL, Assessment of Quality of Life; HUI, Health Utilities Index; NA, not applicable; QWB, Quality of Well-Being.

Secondary inclusion and exclusion criteria were developed to extract studies relevant to each objective (*Table 25*). Based on the results of the first-stage search, it was established that the majority of studies used EQ-5D-generated utility values; therefore, this was included in the secondary inclusion criteria in order to ensure consistency and validity of the HSUV profile.

The review was restricted to articles published in academic journals. These were sourced from both electronic databases and reference searching of relevant review papers. Searches were conducted on 27 July 2016. Advice was sought from subject librarians with regard to relevant electronic databases and search terms for the review.

The following electronic databases were searched: (1) PubMed (via NCBI), (2) Web of Science (via Thompson Reuters), (3) Scopus (via Elsevier), (4) The Cochrane Library (via Wiley Online Library), which includes the Cochrane Database of Systematic Reviews, the Database of Abstracts of Reviews of Effectiveness, the Cochrane Central Register of Controlled Trials and the Cochrane Methodology Register, (5) ProQuest Health Management and (6) Cumulative Index to Nursing and Allied Health Literature (CINAHL) (via EBSCO*host*).

TABLE 25 Secondary inclusion and exclusion criteria

Objective	Inclusion	Exclusion
Change in HSUV during hospital admission	• Studies in which patients were admitted to hospital with an exacerbation of COPD • Studies based on the EQ-5D	• Studies in which exacerbations were recorded in primary and community care (including outpatient clinics)
Residual HSUV post hospital admission	• Studies reporting change in HSUV from hospital admission/discharge to a later time point • Studies reporting change in HSUV in relation to the number of hospital admissions for COPD • Studies based on the EQ-5D	NA
Confounding variables	• Studies reporting HSUVs for subgroups of patients with COPD • Studies based on the EQ-5D	• Studies reporting a single HSUV for patients with COPD without subgroups for comparison • Studies reporting HSUVs when the comparison group is patients without COPD

NA, not applicable.

Search strategy

The search strategy was developed around the main themes of the review aim: 'chronic obstructive pulmonary disease' and 'HSUV'. Therefore, the search focused on all generic instruments for measuring health-related quality of life that produce HSUVs [EQ-5D, SF-6D, Health Utilities Index (HUI)-2, HUI-3, Quality of Well-Being (QWB), Assessment of Quality of Life (AQoL), AQoL2] and related terms (i.e. EuroQol and Health Utilities Index), as well as all terms that could represent COPD.

The final search terms were:

COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis

AND

"health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR "utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional"

A combination of title, abstract or topic searches were adapted for use with each database depending on the options available. Limitations included papers published in the English language and no date restrictions were set. The full, unedited search strategies for each database can be found in *Appendix 13*. All studies that were identified via electronic database searches were exported into EndNoteWeb [Clarivate Analytics (formerly Thomson Reuters), Philadelphia, PA, USA] and duplicates removed. The remaining references were then exported to Microsoft Excel® (Microsoft Corporation, Redmond, WA, USA).

Study selection

A multistage selection process was undertaken by the reviewer. First, all titles and abstracts were screened against the inclusion criteria with a preference towards overinclusion in cases that were unclear. The reviewer was not blinded to author and journal details. Next, full papers were obtained and, owing to time constraints, those that were not available as open access sources were excluded from the review. Following this, full studies were assessed against both the inclusion and exclusion criteria. Many of the studies include duplicate data sets and these were therefore grouped together to ensure that information was not reported twice.

Seventy-eight studies were accepted after the primary inclusion and exclusion criteria were applied (see *Table 24* and *Figure 29*). An overview of these studies was given, including country of origin, instruments used to measure HSUVs, tariff values used and data sets used (*Table 26*). Subsequently, secondary

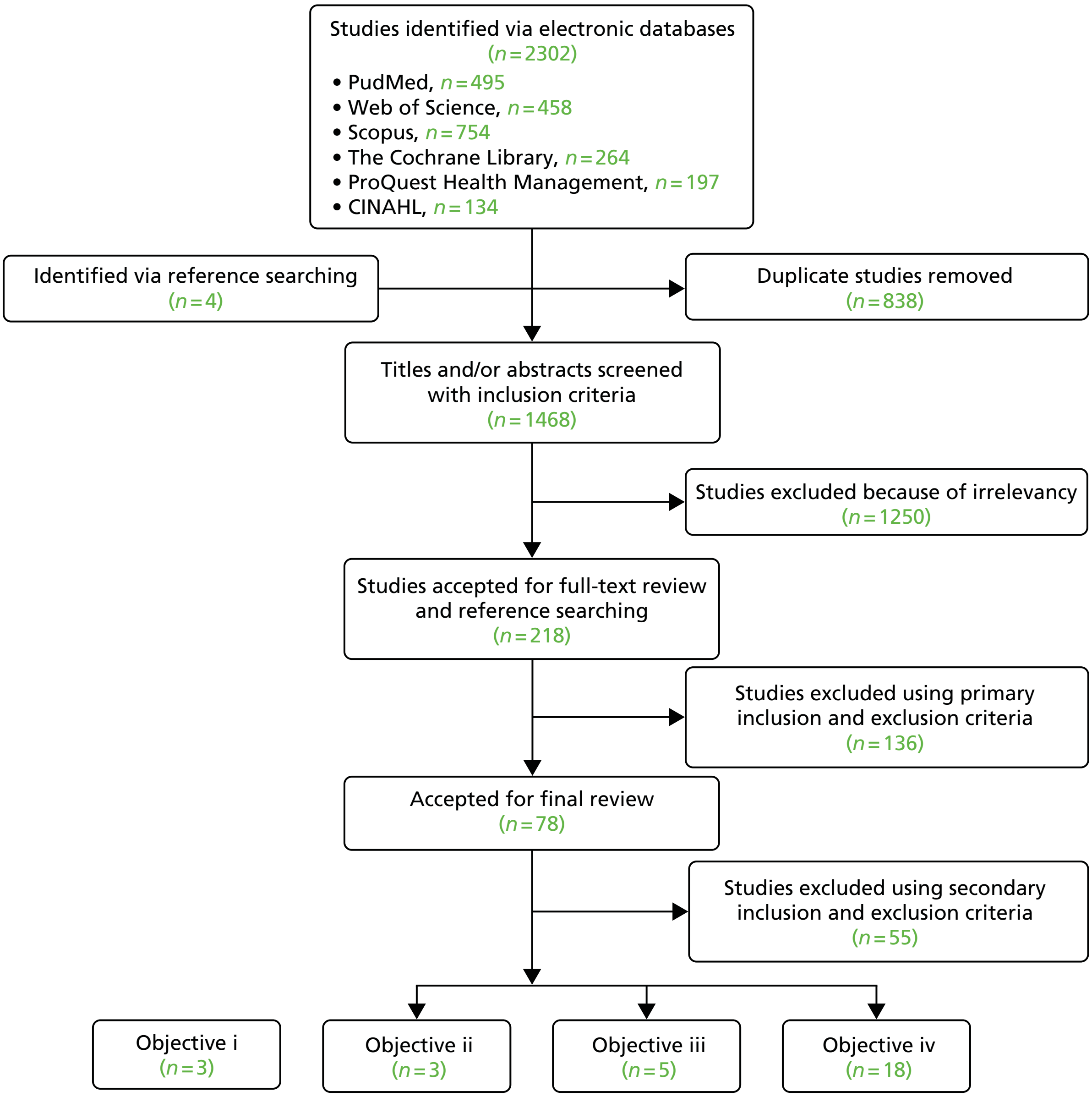

FIGURE 29 Flow diagram: study selection process following PRISMA guidelines.

TABLE 26 All studies accepted after primary inclusion and exclusion criteria were applied

Author	Country	Instrument	Tariff values	Data set
Boland *et al.*[174]	The Netherlands	EQ-5D	–	RECODE trial[175,176]
Burns *et al.*[177]	UK	EQ-5D	UK	Wilson *et al.*[178]
Cramm and Nieboer[179]	The Netherlands	EQ-5D	–	Zichtbare visible link programme[180,181]
Ding *et al.*[182]	China	SF-36v2 (SF-6D), SF-12v2 (SF-6D)	–	CNHW survey[183]
Dritsaki *et al.*[184]	UK	EQ-5D	UK	SPACE trial[185,186]
Eklund *et al.*[187]	Canada, Spain, Sweden, UK	EQ-5D	–	SPARK[188] and UPLIFT[189] trial
Esteban *et al.*[154]	Spain	EQ-5D	–	IRYSS-CAS[190]
Hoyle *et al.*[191]	UK	EQ-5D	UK	ClinicalTrials.gov and GlaxoSmithKline studies[192]
Jia *et al.*[193,194]	USA	EQ-5D	–	NHANES 2005–2008[195,196]
Kwon and Kim[194,197]	South Korea	EQ-5D	South Korean	KNHANES 2007–2012[198,199]
Lee *et al.*[194,200]	South Korea	EQ-5D	–	KNHANES 2007–2012[194]
Lee *et al.*[194,201]	South Korea	EQ-5D	South Korean	KNHANES 2007–2012[194]
Martinez Rivera *et al.*[202]	Spain	EQ-5D	–	Original data[203,204]
Roncero *et al.*[205]	Spain	EQ-5D	–	Original data[206]
Selya-Hammer *et al.*[207]	Italy	EQ-5D	–	Rutten-van Mölken *et al.*[208]
Wacker *et al.*[209]	Germany	EQ-5D	German	Rutten-van Mölken *et al.*[210]
Zanaboni *et al.*[211]	Norway	EQ-5D	–	Original data[211]
Boland *et al.*[212]	The Netherlands	EQ-5D	Dutch	RECODE trial[175,176]
Boland *et al.*[213]	The Netherlands	EQ-5D	–	RECODE,[175,176] GO-AHEAD,[214] MARCH[215] trials
Fishwick *et al.*[216]	UK	EQ-5D	UK	Original data[217]
Hong *et al.*[194,218]	South Korea	EQ-5D	South Korean	KNHANES 2007–2010[199]
Kim *et al.*[194,219]	South Korea	EQ-5D	South Korean	KNHANES 2007–2010[199]
Miravitlles *et al.*[220]	Spain	EQ-5D	Spanish	Original data – same data as Miravitlles *et al.*[221]
Miravitlles *et al.*[221]	Spain	EQ-5D	Spanish	Original data – same data as Miravitlles *et al.*[220]
Stoddart *et al.*[222]	UK	EQ-5D	UK	Original data[223,224]
Sundh *et al.*[225]	Sweden	EQ-5D	UK	Original data[225]
Wilson *et al.*[178]	UK	EQ-5D	–	Original data[178]
Wu *et al.*[226]	China	EQ-5D	–	Original data[226]
Abdin *et al.*[227]	Singapore	EQ-5D	UK	SMHS[228]
van Boven *et al.*[229]	UK, Sweden	EQ-5D	–	PHARMACOP[230]
Chen *et al.*[231]	Hong Kong	EQ-5D	UK	Original data[231]
García-Rio *et al.*[232]	Spain	EQ-5D	–	EPI-SCAN study[233,234]
Karabis *et al.*[235]	USA	EQ-5D	–	Rutten-van Mölken *et al.*[210]

continued

TABLE 26 All studies accepted after primary inclusion and exclusion criteria were applied (*continued*)

Author	Country	Instrument	Tariff values	Data set
Kim *et al.*[236]	South Korea	EQ-5D	South Korean	Original data[236]
Lin *et al.*[237]	USA	EQ-5D	USA	CONCERT study[238]
Miravitlles *et al.*[239]	Spain	EQ-5D	Spanish	Original data[239]
Miravitlles *et al.*[206]	Spain	EQ-5D	Spanish	Original data – DEPREPOC study[206]
Miravitlles *et al.*[240]	Spain	EQ-5D	Spanish	Original data – INSEPOC study[241,271]
Mullen *et al.*[242]	Canada	EQ-5D	USA	Combined data set[243]
Peters *et al.*[244]	UK	EQ-5D	–	Original data – same data as Peters *et al.*[245]
Peters *et al.*[245]	UK	EQ-5D	–	Original data – same data as Peters *et al.*[244]
Samyshkin *et al.*[246]	UK	EQ-5D	–	Studies M2–124 and M2–125, Rabe[247] and Rutten-van Mölken *et al.*[158]
Tsiachristas *et al.*[248]	The Netherlands	EQ-5D	Dutch	Original data[249]
Gillespie *et al.*[250]	Ireland	EQ-5D	UK	PRINCE trial[251]
Samyshkin *et al.*[252]	Switzerland	EQ-5D	–	Rutten-van Mölken *et al.*[158] and Takeda Pharma AG (Pfäffikon, Switzerland)
Solem *et al.*[253]	USA	EQ-5D	USA	Original data[253]
Asukai *et al.*[254]	UK	EQ-5D	UK	INVOLVE,[255] INHANCE[256] and INLIGHT-2[257] trials
DiBonaventura *et al.*[258]	USA	SF-12v2 (SF-6D)	–	NHWS[259]
Goodacre *et al.*[260]	UK	EQ-5D	UK (using pilot-study data)	Original data[260]
Taylor *et al.*[261]	UK	EQ-5D	UK	Original data[261]
Fletcher *et al.*[262]	Brazil, China, Germany, Turkey, USA, UK	EQ-5D	Germany, UK and USA	Original data[262]
Goosens *et al.*[263]	USA	EQ-5D	USA	CASA-Q[264]
Janssen *et al.*[265]	The Netherlands	EQ-5D	–	Original data[266–268]
Khdour *et al.*[269]	UK	EQ-5D	UK	Khdour *et al.*[270]
Miravitlles *et al.*[271]	Spain	EQ-5D	Spanish	Original data – INSEPOC study[241,271]
Pickard *et al.*[173]	USA	SF-36, EQ-5D	UK and USA	Joo *et al.*[272]
Starkie *et al.*[273]	Worldwide	EQ-5D	UK	TORCH study[274]
Hoogensoorn *et al.*[275]	The Netherlands	EQ-5D	–	Original data[275]
Menn *et al.*[155]	Germany	EQ-5D, SF-12 (SF-6D)	UK	Original data[155]
Rutten-van Mölken *et al.*[158]	The Netherlands	EQ-5D	In-study valuation	Original data[158]
Szende *et al.*[276]	Sweden	EQ-5D	UK	Combined data – Szende *et al.*[277] and OLIN[278]

TABLE 26 All studies accepted after primary inclusion and exclusion criteria were applied (*continued*)

Author	Country	Instrument	Tariff values	Data set
Punekar *et al.*[279]	USA, France, Germany, Italy, Spain, UK	EQ-5D	UK	Original data – the Respiratory Disease Specific Programme III[279]
O'Reilly *et al.*[156]	Germany	EQ-5D	UK	Original data[156]
Rutten-van Mölken *et al.*[208]	Spain	EQ-5D	Spanish	Six clinical trials and pooled data[280–283]
Rutten-van Mölken *et al.*[210]	13 countries (% participants): USA (34.5%), Czechia (17.5%), Spain (11.9%), Denmark (8.4%), Germany (4.9%), Poland (4.8%), the Netherlands (4.4%), Italy (4.4%), France (3.1%), Hungary (2.5%), the Russian Federation (1.5%), Belgium (1.4%), Australia (0.8%)	EQ-5D	UK and USA	UPLIFT trial[284]
Spencer *et al.*[285]	UK	EQ-5D	–	Prescott-Clarke *et al.*,[286] Brazier *et al.*,[105] Spencer *et al.*[287]
Ståhl *et al.*[288]	Sweden	EQ-5D, SF-36 (SF-6D)	–	OLIN studies[289–291]
Sullivan *et al.*[292]	USA	EQ-5D	USA	MEPS[293]
Borg *et al.*[294]	Sweden, UK	EQ-5D	UK	OLIN studies[289,295,296]
Brazier *et al.*[297]	UK	EQ-5D, SF-6D	UK	Thomas *et al.*[298]
Kaplan *et al.*[299]	USA	SF-36 (SF-6D), QWB-SA	–	NETT[300]
Hazell *et al.*[301]	UK	EQ-5D	UK	Original data[301]
Stavem *et al.*[302]	The Netherlands	EQ-5D	UK	Original data – same data as Stavem[303]
Paterson *et al.*[304]	UK	EQ-5D	UK	Original data[304]
Stavem[303]	Norway	EQ-5D, 15D, SF-36 (SF-6D)	UK	Original data – same data as Stavem *et al.*[302]
Torrance *et al.*[305]	Canada	HUI	–	Original data[305]
Harper *et al.*[306]	UK	EQ-5D, SF-36 (SF-6D)	–	Original data[306]
Jaeschke *et al.*[307]	Canada	QWB	–	Original data[307]

–, unknown; 15D, 15-dimensional measure of health-related quality of life; CASA-Q, Cough and Sputum Assesment Questionnaire; CONCERT, COPD Outcomes-based Network for Clinical Effectiveness and Research Translation; CNHW, China National Health and Wellness Survey; DEPREPOC, Depression in Chronic Obstructive Pulmonary Disease; GO-AHEAD, Assessment Of Going Home Under Early Assisted Discharge; INLIGHT-2, Indacaterol Efficacy Evaluation Using 150-µg Doses with COPD Patients; INVOLVE, Indacaterol: Value in COPD: Longer Term Validation of Efficacy and Safety; IRYSS-CAS, Investigacion en Resultados y Servicios de Salud COPD Appropriateness Study; KNHANES, Korean National Health and Nutrition Examination Survey; MARCH, Health Status Guided COPD Care; MEPS, Medical Expenditure Panel Survey; NHANES, National Health and Nutrition Examination Survey; NETT, National Emphysema Treatment Trial; NHWS, National Health and Wellness Survey; OLIN, Obstructive Lung Disease in Northern Sweden; QWB-SA, QWB self-administered; SF-36v2, SF-36 version 2; SF-12v2, SF-12 version 2; RECODE, Randomised Clinical Trial on Effectiveness of Integrated COPD Management in Primary Care; SMHS, Singapore Mental Health Survey; SPACE, Self-management Programme of Activity, Coping and Education; TORCH, Towards a Revolution in COPD Health.

inclusion and exclusion criteria (see *Table 25*) were applied to filter these further, so that papers relevant to each objective only were selected. The full review process was documented using the PRISMA flow diagram (see *Figure 29*).

Data collection process

Data were extracted from the final selection of papers in a systematic manner in which each study was scanned for the same fields. When multiple papers reported the same data set(s), only one paper was included. Several criteria were used to prioritise the paper chosen in the following order: first, studies using patient-reported data were prioritised (as opposed to secondary data used in modelling studies); second, the papers with the most-recent data set were chosen (e.g. a study reporting 2014–16 data instead of 2013–15 data); and third, the study reporting the largest sample size and/or most information was selected.

Data items

The data items extracted included the following: author, year, country of origin (data), sample size, age, sex, COPD GOLD stage/severity level, study type, time of measurement of EQ-5D, data source, EQ-5D tariff value and HSUVs. Risk of bias was assessed at outcome level only. The primary outcome was HSUV.

Overview of all health state utility values studies for patients with chronic obstructive pulmonary disease

After the initial search, 79 studies were identified to include HSUVs for patients with COPD. The studies incorporated data from the UK, Spain, France, the Netherlands, Germany, Switzerland, Italy, Norway, Sweden, Turkey, Brazil, China, the USA and Canada. In addition, several studies involved multicountry data sets in which individual countries were not identified.[210,273]

The majority of studies reported HSUVs based on the EQ-5D (73 studies[154–156,158,173,174,177–179,184,187,191,193,194,197,200–202,205–213,216,218–222,225–227,229,231,232,235–237,239,240,242,244–246,248,250,252–254,260–262,265,269,271,273,275,276,279,285,288,292,294,297,301–304,306]); some studies also reported utility values based on the SF-36/SF-12/SF-6D (nine studies[155,173,182,258,288,297,299,303,306]). In addition, one study used HUI,[305] one study used QWB[307] and one study used the 15-dimensional measure of health-related quality of life.[303]

Eighteen studies[177,178,184,191,216,222,244–246,254,260,261,269,286,297,301,304,306] were UK based (UK data set or, if secondary data were used, UK lead authors), five studies included UK data in pooled analysis and 27 studies[155,156,173,177,184,191,210,216,222,225,227,231,250,254,260–262,269,273,276,279,294,297,301–304] used UK tariff values. Not all studies explicitly stated the tariff values used so instead, when possible, this was deduced by the references used.

Although a large number of studies were identified, many used overlapping data sets that were not always initially obvious. For instance, modelling studies often used secondary data from the same clinical trials; for example, Eklund *et al.*[187] and Karabis *et al.*[235] used data from the UPLIFT trial.[308] Other studies also reported secondary data in other studies; for example, Wacker *et al.*[209] report data from Burns *et al.*[177] and Rutten-van Mölken *et al.*[210] report data from Wilson *et al.*[178] Many studies used pooled data from several trials; for example, Boland *et al.*[212] used pooled data from the Randomised Clinical Trial on Effectiveness of Integrated COPD Management in Primary Care (RECODE),[175,176] the Assessment Of Going Home Under Early Assisted Discharge (GO-AHEAD) trial[214] and the Health Status Guided COPD Care (MARCH) trial.[215] Other studies used data from the same national surveys for different and/or overlapping years; for example, Kwon *et al.*,[194,197] Lee *et al.*,[194,201] Hong *et al.*[194,218] and Kim *et al.*[194,219] use data from the Korean National Health and Nutrition Examination Survey (KNHANES).[199]

The initial scan found three review papers with full-text availability in relation to COPD patients with stable COPD[151,172,309] and the full search did not identify any additional reviews (*Table 27*).

TABLE 27 Overview of reviews reporting HSUVs for stable COPD

Author	Country	Population	Methods	Instrument	HSUV
Pickard *et al.*[309]	All countries considered	COPD and asthma	Papers published from January 1988 to January 2007 COPD	EQ-5D	Mean EQ-5D-generated utilities using UK tariff and GOLD stages (SD) • 1 (mild) = 0.74 (0.62–0.87) • 2 (moderate) = 0.74 (0.66–0.83) • 3 (severe) = 0.69 (0.60–0.78) • 4 (very severe) = 0.61 (0.44–0.77)
Petrillo *et al.*[172]	All countries considered	COPD	Papers published from 1997 to August 2009 COPD	All instruments considered (generic and specific)	Range EQ-5D-generated utilities based on GOLD stages for UK studies • 1 (mild) = 0.90–0.77 • 2 (moderate) = 0.79–0.68 • 3 (severe) = 0.81–0.62 • 4 (very severe) = 0.72–0.52
Moayeri *et al.*[151]	All countries considered	COPD	Papers published before 2014 COPD English-language studies	EQ-5D (UK tariff)	Mean EQ-5D-generated utilities using UK tariff and GOLD stages (95% CI) • 1 (mild) = 0.806 (0.747 to 0.866) • 2 (moderate) = 0.767 (0.740 to 0.795) • 3 (severe) = 0.704 (0.670 to 0.739) • 4 (very severe) = 0.616 (0.556 to 0.676)

Pickard *et al.*[309] estimated average HSUVs by disease severity based on pooled data from 1988 to 2007. Petrillo *et al.*[172] updated the search by Pickard *et al.*[309] and provided HSUV ranges by disease severity and a summary of the HSUV change during an exacerbation (community or hospital based). Moayeri *et al.*[151] conducted a meta-analysis on COPD HSUV studies that were published prior to 2014 using UK tariff values and produced average utilities by disease severity.

Change in health state utility values during a hospital admission for an exacerbation of chronic obstructive pulmonary disease

Three studies considered change in EQ-5D-generated HSUVs from hospital admission to discharge,[154–156] two of which used UK tariff values.[155,156]

There was large disparity in HSUVs between the studies using UK tariff values, particularly in relation to HSUVs on admission. For instance, mean admission and discharge HSUVs for O'Reilly *et al.*[156] were –0.077 and 0.576, respectively; whereas, for Menn *et al.*,[155] the reported weighted average admission and discharge HSUVs were 0.61 and 0.78, respectively. However, differences can be explained by the timing of the measurement; whereas patients in O'Reilly *et al.*[156] completed the EQ-5D 'on admission' (i.e. at the most severe part of their exacerbation), patients in Menn *et al.*[155] completed the EQ-5D 'within 3 days after admission' (i.e. after treatment had started, when it is likely symptoms had improved). Similarly, Esteban *et al.*[154] reported similar values (0.60 on admission and 0.64 on discharge) to those reported by Menn *et al.*,[155] when data were collected 'on the first day after admission', again after treatment had started (*Table 28*).

Residual effect on utility values after an admission to hospital with an exacerbation of chronic obstructive pulmonary disease

Five studies (*Table 29*) report the residual effect of EQ-5D-generated HSUVs after an exacerbation requiring hospital admission,[156,158,246,252,253] three of which used the same data set.[158,246,252] The residual effect was tracked over three timescales: 3 months,[156] 12 months[158] and a varied timescale related to previous exacerbation.[253] Only one study used UK tariff values.[156]

TABLE 28 Change in HSUV during a hospital admission for an exacerbation of COPD

Author	Country	Population	Methods	Instrument	HSUV, mean (SD)
Esteban *et al.*[154]	Spain	1421 COPD (all stages) patients admitted to hospital • mean age, years (SD) = 72.6 (9.6) • sex, male (%) = 90.3 950 COPD (all stages) patients discharged • mean age, years (SD) = 73.0 (9.7) • sex, male (%) = 91.8	Prospective cohort study; patients recruited on admission to hospital. EQ-5D score measured in an interview at admission (24 hours after ED) and discharge (next day or week after)	EQ-5D	Admission ($n = 1421$) = 0.60 (0.28) Discharge ($n = 950$) = 0.64 (0.29)
Menn *et al.*[155]	Germany	117 patients Mean age, years (SD) • GOLD stage 3 (severe) ($n = 34$) = 67 (8) • GOLD stage 4 (very severe) ($n = 83$) = 68 (8) Sex, male (%) • GOLD stage 3 (severe) ($n = 34$) = 59 • GOLD stage 4 (very severe) ($n = 83$) = 66	Prospective observational study, data collected via patient-completed questionnaire during hospital stay within 3 days of admission and discharge	EQ-5D SF-12 (SF-6D) German and UK tariff	German tariff • GOLD stage 3 (severe) ($n = 34$): admission = 0.62 (0.26); discharge = 0.84 (0.20) • GOLD stage 4 (very severe) ($n = 83$): admission = 0.60 (0.26); discharge = 0.75 (0.22) UK tariff GOLD stage 3 (severe) ($n = 34$): admission = 0.46 (0.31); discharge = 0.72 (0.23) GOLD stage 4 (very severe) ($n = 83$): admission = 0.44 (0.31); discharge = 0.61 (0.28) Sensitivity to change • admission = 0.60 (0.26) • discharge = 0.79 (0.21) • absolute standardised difference = 0.69

DOI: 10.3310/phr06050

Author	Country	Population	Methods	Instrument	HSUV, mean (SD)
O'Reilly *et al.*[156]	Germany	All (*n* = 222) GOLD • stage 0 (at risk) or 1 (mild): 6 • stage 2 (moderate): 30 • stage 3 (severe): 52 • stage 4 (very severe): 45 Follow-up (*n* = 40) • stage 0 (at risk) or 1 (mild): 2 • stage 2 (moderate): 5 • stage 3 (severe): 15 • stage 4 (very severe): 11	Prospective observation study, data collected via self-administered EQ-5D and SF-12 during hospital admission, at discharge and at 3-month follow-up	EQ-5D (UK tariff) SF-12	All (*n* = 222) • admission = –0.077 (0.397) • discharge (within 3 days) = 0.576 (0.317) Patients with follow-up data (*n* = 40) • admission = –0.120 (0.366) • discharge (within 3 days) = 0.635 (0.243) • follow-up = 0.389 (0.313) Change in EQ-5D first admissions (*n* = 112) • admission–discharge: 0.653 (0.434)

ED, emergency department.

TABLE 29 Residual effect on utility values after a hospital admission for an exacerbation of COPD

Author	Country	Population	Methods	Instrument	HSUV
Solem *et al.*[253]	USA	Overall (*n* = 314) • mean age, years (SD) = 68.0 (9.6) • sex, male (%) = 51.3 GOLD stage 3 (severe) COPD (*n* = 190) • mean age, years (SD) = 67.4 (9.8) • sex, male (%) = 49.5 GOLD stage 4 (very severe) COPD (*n* = 124) • mean age, years (SD) = 68.8 (9.2) • sex, male (%) = 54	Cohort study, data collected in a patient interview (including EQ-5D), recruitment via primary care physicians/pulmonologists	EQ-5D (USA tariff)	Overall (*n* = 314), mean (SD) • current health = 0.674 (0.204) • last exacerbation = 0.552 (0.283) • incremental disutility = 0.122 (0.213) GOLD stage 3 (severe) COPD (*n* = 190), mean (SD) • current health = 0.707 (0.174) • last exacerbation = 0.590 (0.256) • incremental disutility = 0.117 (0.205) GOLD stage 4 (very severe) COPD (*n* = 124), mean (SD) • current health = 0.623 (0.234) • last exacerbation = 0.494 (0.312) • incremental disutility = 0.128 (0.226) Severity of last exacerbation (GP treated): moderate (*n* = 205), mean (SD) • current health: 0.698 (0.197) • last exacerbation: 0.595 (0.257) • incremental disutility: 0.103 (0.191) Severity of last exacerbation (GP treated): severe (requiring hospitalisation) (*n* = 109), mean (SD) • current health = 0.627 (0.210) • last exacerbation = 0.471 (0.313) • incremental disutility = 0.157 (0.245)

Author	Country	Population	Methods	Instrument	HSUV
Rutten-van Mölken *et al.*[158] (same data as in Samyshkin *et al.*[246,252])	The Netherlands	229 TTO data available • mean age, years (SD) = 45 (16) • male: 47%	Cohort study, recruited via advertisement in local newspaper; health states valued during group session or at home	EQ-5D (Dutch tariff)	Estimated annual utility decrements, mean (SE) • 1 non-serious exacerbation = 0.010 (0.007) • 2 non-serious exacerbations = 0.021 (0.007) • 1 serious exacerbation = 0.042 (0.009) • 1 serious and 1 non-serious exacerbation = 0.088 (0.009)
O'Reilly *et al.*[156]	Germany	Follow-up ($n = 40$), GOLD stages • 0 (at risk) or 1 (mild): 2 • 2 (moderate): 5 • 3 (severe): 15 • 4 (very severe): 11	Prospective observation study, data collected from self-administered EQ-5D and SF-12 during hospital admission, at discharge and at 3-month follow-up	EQ-5D (UK tariff) SF-12	HSUV, mean (SD) • discharge (within 3 days) ($n = 40$) = 0.635 (0.243) • 3-month follow-up ($n = 40$) = 0.389 (0.313)

TTO, time trade-off.

Confounding variables

The studies reported HSUV in a range of different subgroups, the most common being severity level, phenotype, age, sex, number and severity of exacerbations, number and type of comorbidities, smoking history, body mass index (BMI) and socioeconomic status. Tables for the confounding variables can be found in *Appendix 14*.

Phenotype

Two studies reported utility values by phenotype, although each considered different subgroups. Mean utility values in each group ranged from 0.63 to 0.69 in Ding *et al.*[182] and from 0.52 to 0.69 in Miravitlles *et al.*[220]

Ding *et al.*[182] found patients with asthma–COPD overlap syndrome (ACOS) and asthma only to have the lowest HSUVs in comparison with COPD only (COPD, chronic bronchitis or emphysema) or controls (those without asthma, COPD, chronic bronchitis or emphysema). In contrast, Miravitlles *et al.*[220] studied a cohort of COPD patients and found the 'excerbators with chronic bronchitis' group to have the lowest HSUV in comparison with 'excerbators without chronic bronchitis', ACOS or 'non-excerbators'.

Age

Four studies considered HSUV by age, with mean HSUV ranging from 0.42 to 0.94.[194,219,262,279,301] All studies showed a general trend towards a decrease in HSUV with age, with a slightly greater decrease seen in females than in males.[194,219,301] However, this sex difference is particularly pronounced in the South Korean study, which, as mentioned previously, has a high percentage of males, meaning differences may be exaggerated by a small female sample size.[194,219]

Sex

Six studies reported sex differences in HSUV, with overall mean utility values ranging from 0.60 to 0.93.[191,194,219,225,236,262,279] Four out of six of the studies reported that females have a lower HSUV, with differences ranging from 0.03 to 0.11.[191,225] Two studies reported that males have a higher HSUV; however, both studies have male-dominated cohorts [Kim *et al.*[236] (91.5% male) and Kim *et al.*[194,219] (74.0% male)] and are based on a specific population (i.e. South Korean).

Number and severity of exacerbations

Two studies looked at HSUV by number of exacerbations, reporting a reduction in HSUV with an increasing number of exacerbations,[221,279] and one study considered utility decrements by severity of exacerbations, reporting greater decrements in HSUVs with increasing severity.[158]

Number and type of comorbidities

Three studies considered the effect of specific comorbidities on HSUV.[202,206,221] The greatest differences were found between those with and without depression. Both Martinez Rivera *et al.*[202] and Miravitlles *et al.*[206] found that patients with COPD and depression had a lower mean HSUV than patients with COPD only (0.40 and 0.55 vs. 0.76 and 0.83, respectively). Miravitlles *et al.*[221] also found that those with comorbid cardiovascular disease had a lower mean HSUV (0.78) than patients with COPD only (0.82); however, no differences were found for patients with and without diabetes, and patients with comorbid haematological malignancies had similar HSUVs.

One study measured HSUVs in relation to a number of comorbid diseases in patients with COPD and found that HSUV decreased as the number of comorbidities increased.[194,218] In addition, Miravitlles *et al.*[221] also considered HSUV in relation to the Charlson index, with mixed results: those scoring 0, 1 and 3 had similar utility scores (0.82, 0.82 and 0.81, respectively), whereas those scoring 2 had a lower HSUV of 0.74.

Smoking history

Three studies assessed smoking status in relation to HSUV in patients with COPD, with mixed results. The studies report smokers with HSUVs higher than,[194,201] lower than[242] and the same as[221] non-smokers.

Body mass index

Two studies report BMI in relation to HSUV in patients with COPD, with mixed results.[221,232] The lowest HSUV was reported in underweight patients (0.69)[221] and the highest in overweight patients (0.90);[232] however, the general relationship between HSUV and weight was not linear.

Socioeconomic status

Two studies considered HSUV by socioeconomic status for patients with COPD, both reporting that HSUVs increase as socioeconomic status increases.[194,219,271]

Appendix 13 Search strategy

PubMed: 495 (date of search: 27 July 2016).

Web of Science: 458 (date of search: 27 July 2016).

Scopus: 754 (date of search: 27 July 2016).

The Cochrane Library: 264 (date of search: 27 July 2016).

ProQuest Health Management: 197 (date of search: 27 July 2016).

CINAHL: 134 (date of search: 27 July 2016).

PubMed	
Search terms	#1 "Lung Diseases, Obstructive"[Mesh]
	#2 COPD[tiab] OR COAD[tiab] OR "chronic obstructive pulmonary disease"[tiab] OR "chronic obstructive lung disease"[tiab] OR "chronic lung disease"[tiab] OR "chronic respiratory"[tiab] OR "chronic obstructive airway disease" [tiab] OR emphysema[tiab] OR bronchitis[tiab]
	#3 "health state"[tiab] OR "health states"[tiab] OR "health preference"[tiab] OR "health preferences"[tiab] OR "health utility"[tiab] OR "health utilities"[tiab] OR "utility index"[tiab] OR "utilities index"[tiab] OR "utility indices"[tiab] OR "utility measure"[tiab] OR "utility measures"[tiab] OR "utility value"[tiab] OR "utility values"[tiab] OR "utility score"[tiab] OR "utility scores"[tiab] OR "utility outcome"[tiab] OR "utility outcomes"[tiab] OR "utility weight"[tiab] OR "utility weights"[tiab] OR "utility evaluation"[tiab] OR "utility evaluations"[tiab] OR HUI[tiab] OR HSUV[tiab] OR eq5d[tiab] OR euroqol* [tiab] OR "eq 5d"[tiab] OR "euro qol" [tiab] OR "euro qols" [tiab] OR "utility analysis"[tiab] OR "utility analyses"[tiab] OR "cost utility"[tiab] OR "cost utilities"[tiab] OR CUA[tiab] OR QALY[tiab] OR "quality adjusted life year"[tiab] OR "quality adjusted life years"[tiab] OR "time trade off"[tiab] OR "time tradeoff" [tiab] OR "timetrade off"[tiab] OR TTO[tiab] OR "standard gamble"[tiab] OR sf6d[tiab] OR "sf 6d"[tiab] OR "short form 6 dimension"[tiab] OR "short form 6 dimensions"[tiab] OR "short form 6"[tiab] OR AQoL [tiab] OR "assessment of quality of life"[tiab] OR HUI2[tiab] OR HUI3[tiab] OR QWB[tiab] OR QWB-SA[tiab] OR "quality of well-being"[tiab] OR 15D[tiab] OR "15 dimensional"[tiab]
	#4 #1 OR #2
	#5 #3 AND #4
Filters	Species: Human
	Language: English
SCOPUS	
Search terms	**Title-Abstract-Key Words:**
	COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis
	AND
	Title-Abstract-Key Words:
	"health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR

SCOPUS	
	"utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional"
Filters	Language: English
CINAHL	
Search terms	S1 (MH "Lung Diseases, Obstructive+") S2 AB COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis S3 AB "health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR "utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional" S4 S1 OR S2 S5 S3 AND S4 Note: AB = abstract, MH = Cinahl Heading
Filters	Language: English Species: Human
Web of Science	
Search terms	**Topic:** COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis **AND** **Topic:** "health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR "utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional"
Filters	Language: English Databases: Web of ScienceTM Core Collection (SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH, ESCI)

The Cochrane Library	
Search terms	#1 MeSH descriptor: [Lung Diseases, Obstructive] explode all trees
	COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis :ti,ab,kw
	#3 "health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR "utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional" :ti,ab,kw
	#4 #1 OR #2
	#5 #4 AND #3
ProQuest Health Management	
Search Terms	**Anywhere except full text:**
	COPD OR COAD OR "chronic obstructive pulmonary disease" OR "chronic obstructive lung disease" OR "chronic lung disease" OR "chronic respiratory" OR "chronic obstructive airway disease" OR emphysema OR bronchitis
	AND
	Anywhere except full text:
	"health state" OR "health states" OR "health preference" OR "health preferences" OR "health utility" OR "health utilities" OR "utility index" OR "utilities index" OR "utility indices" OR "utility measure" OR "utility measures" OR "utility value" OR "utility values" OR "utility score" OR "utility scores" OR "utility outcome" OR "utility outcomes" OR "utility weight" OR "utility weights" OR "utility evaluation" OR "utility evaluations" OR HUI OR HSUV OR eq5d OR euroqol* OR "eq 5d" OR "euro qol" OR "euro qols" OR "utility analysis" OR "utility analyses" OR "cost utility" OR "cost utilities" OR CUA OR QALY OR "quality adjusted life year" OR "quality adjusted life years" OR "time trade off" OR "time tradeoff" OR "timetrade off" OR TTO OR "standard gamble" OR sf6d OR "sf 6d" OR "short form 6 dimension" OR "short form 6 dimensions" OR "short form 6" OR AQoL OR "assessment of quality of life" OR HUI2 OR HUI3 OR QWB OR QWB-SA OR "quality of well-being" OR 15D OR "15 dimensional"
Filters	Language: English
	Databases: ProQuest Central, Health & Medical Collection, Nursing & Allied Health Database, Public Health Database, Health Management Database, Family Health Database, Research Library, Research Library: Health & Medicine

Appendix 14 Additional tables for objective IV

TABLE 30 Confounding variables: phenotypes

Author	Country	Population	Methods	Instrument	HSUV
Ding *et al.*[182]	China	ACOS = 350 Asthma only = 822 COPD only = 1598 Matched control = 2770 Mean age, years (SD) • ACOS = 43.11 (14.42) • asthma only = 43.47 (14.65) • COPD only = 42.07 (14.69) • matched control = 43.83 (15.11) Sex, male (%) • ACOS = 58.57 • asthma only = 57.54 • COPD only = 59.89 • matched control = 61.19 COPD (%) (*n* = 1602) • mild = 75.59 • moderate = 22.85 • severe = 1.56 ACOS (%) (*n* = 366) • mild = 74.86 • moderate = 22.95 • severe = 2.19	Cross-sectional cohort study. China National Health and Wellness Survey data (self-administered online survey). Data from 2010, 2012 and 2013. Participants recruited using online and offline methods Control = no diagnosis of asthma, COPD, chronic bronchitis or emphysema COPD only = COPD, chronic bronchitis or emphysema	SF-36v2, SF-12v2 (SF-6D algorithm applied to get utility values)	Adjusted mean (SE) • ACOS (*n* = 350) = 0.63 (0.01) • asthma only (*n* = 822) = 0.63 (0.00) • COPD only (*n* = 1598) = 0.66 (0.00) • matched control (*n* = 2770) = 0.69 (0.00) ED visits in the past 6 months, adjusted mean (SE) • ACOS (*n* = 350) = 1.09 (0.13) • asthma only (*n* = 822) = 0.70 (0.04) • COPD only (*n* = 1598) = 1.29 (0.10) • matched control (*n* = 2770) = 0.46 (0.02) Hospitalisations in the past 6 months, adjusted mean (SE) • ACOS (*n* = 350) = 0.32 (0.05) • asthma only (*n* = 822) = 0.48 (0.04) • COPD only (*n* = 1598) = 0.17 (0.02) • matched control (*n* = 2770) = 0.11 (0.01)

Author	Country	Population	Methods	Instrument	HSUV
Miravitlles *et al.*[220]	Spain	3125 patients COPD (1974 primary care, 1151 pneumology departments) ACOS (*n* = 496) • mean age, years (SD) = 64.6 (9.4) • sex, male (%) = 69.8 Non-exacerbators (*n* = 1894) • mean age, years (SD) = 66.6 (9.7) • sex, male (%) = 85.4 Exacerbators with chronic bronchitis (*n* = 602) • mean age, years (SD) = 69.3 (9.2) • sex, male (%) = 85.4 Excerbators without chronic bronchitis (*n* = 133) • mean age, years (SD) = 68.8 (9.8) • sex, male (%) = 73.7	Transversal observational study; 875 primary care physicians, 258 pneumologists recruited 3/4 patients each	EQ-5D (Spanish tariff)	Unadjusted mean (95% CI) • ACOS (*n* = 496) = 0.65 (0.31) • non-exacerbations (*n* = 1894) = 0.69 (0.29) • exacerbations with chronic bronchitis (*n* = 602) = 0.52 (0.35) • exacerbations without chronic bronchitis (*n* = 133) = 0.59 (0.32) Mean adjusted for severity of airflow obstruction, sex and age (95% CI) • ACOS (*n* = 496) = 0.61 (0.58 to 0.64) • non-exacerbations (*n* = 1894) = 0.68 (0.66 to 0.69) • exacerbations with chronic bronchitis (*n* = 602) = 0.54 (0.52 to 0.57) • exacerbations without chronic bronchitis (*n* = 133) = 0.61 (0.56 to 0.66)

ED, emergency department; SF-36v2, SF-36 version 2; SF-12v2, SF-12 version 2.

DOI: 10.3310/phr06050

TABLE 31 Confounding variables: age

Author	Country	Population	Methods	Instrument	HSUV
Kim and Kim[194,219]	South Korea	COPD patients 556 male • aged 19–64 years = 49.3% • aged ≥ 65 years = 50.7% 195 female • aged 19–64 years = 37.5% • aged ≥ 65 years = 62.5%	Data from KNHANES	EQ-5D (Korean tariff)	Male, mean (SE) • aged 19–64 years = 0.94 (0.01) • aged ≥ 65 years = 0.92 (0.01) Female, mean (SE) • aged 19–64 years = 0.92 (0.01) • aged ≥ 65 years = 0.82 (0.03)
Fletcher *et al.*[262]	Brazil, China, Germany, Turkey, USA, UK	2426 participants Age (years) • 45–54 = 1029 • 55–64 = 971 • 65–67 = 426 MRC dyspnoea scale severity • mild = 849 • moderate = 1012 • evere = 521 • missing data = 44	Cross-sectional study, participants recruited by a contract research organisation and data collected in interviews that included the EQ-5D	EQ-5D (German, UK and USA tariff)	Age (years), mean (SD) • 45–54 (*n* = 42) = 0.686 (0.85) • 55–64 (*n* = 40) = 0.605 (0.80) • 65–67 (*n* = 18) = 0.585 (0.79)

DOI: 10.3310/phr06050

Author	Country	Population	Methods	Instrument	HSUV
Punekar *et al.*[279]	USA, France, Germany, Italy, Spain, UK	2703 patients • seen by PCP = 1381 • seen by RS = 1322 Mean age, years (SD) • seen by PCP = 66 (0.29) • seen by RS = 66 (0.31) Sex, male (%) • seen by PCP = 66 • seen by RS = 71 Forced spirometry, mean (95% CI) • seen by PCP = mild: 0.77 (0.73 to 0.81); moderate: 0.68 (0.62 to 0.74); severe: 0.62 (0.56 to 0.68) • seen by RS = mild: 0.68 (0.64 to 0.72); moderate: 0.72 (0.69 to 0.75); severe: 0.64 (0.61 to 0.67)	Cross-sectional survey; physicians recruited and recorded information for six patients during consultations	EQ-5D (UK tariff)	Patient seen by PCP (*n* = 1381) age, mean (95% CI) • < 65 years = 0.77 (0.75 to 0.79) • ≥ 65 years = 0.65 (0.62 to 0.67) Patient seen by RS (*n* = 1322) age, mean (95% CI) • < 65 years = 0.72 (0.70 to 0.75) • ≥ 65 years = 0.64 (0.62 to 0.67)

continued

TABLE 31 Confounding variables: age (*continued*)

Author	Country	Population	Methods	Instrument	HSUV
Hazell *et al.*[301]	UK	10,471 patients (aged ≥ 16 years) • 16–24 years = 1205 • 25–34 years = 1189 • 35–44 years = 1029 • 45–54 years = 908 • 55–64 years = 872 • 65–74 years = 757 • 75–84 years = 721 Mean age, years (SD) = 48.5 (19.4) Sex, male (%) = 45.1 (1054 with likely OAD)	Observational study; data gained from postal questionnaire that includes EQ-5D. Recruitment via two general practices	EQ-5D (UK tariff)	Likely OAD, mean = 0.63 Female, mean (SD) • aged 16–24 years = 0.87 (0.84–0.91) • aged 25–34 years = 0.79 (0.74–0.85) • aged 35–44 years = 0.72 (0.66–0.78) • aged 45–54 years = 0.51 (044–0.59) • aged 55–64 years = 0.48 (0.41–0.56) • aged 65–74 years = 0.44 (0.33–0.55) • aged 75–84 years = 0.42 (0.32–0.53) Male, mean (SD) • aged 16–24 years = 0.87 (0.82–0.92) • aged 25–34 years = 0.84 (0.79–0.88) • aged 35–44 years = 0.63 (0.56–0.71) • aged 45–54 years = 0.55 (0.47–0.63) • aged 55–64 years = 0.46 (0.36–0.55) • aged 65–74 years = 0.57 (0.47–0.67) • aged 75–84 years = 0.44 (0.28–0.59)

KNHANES, Korean National Health and Nutrition Examination Survey; MRC, Medical Research Council; OAD, obstructive airway disease; PCP, primary care physician; RS, respiratory specialist.

TABLE 32 Confounding variables: sex

Author	Country	Population	Methods	Instrument	HSUV
Hoyle *et al.*[191]	UK	COPD patients • baseline (*n* = 1658) • visit 1 (*n* = 1447) • visit 2 (*n* = 1341) Sex, male (%) = 68.8 GOLD stage • 1 (mild) (*n* = 1138) • 2 (moderate) (*n* = 2093) • 3 (severe) (*n* = 1080) • 4 (very severe) (*n* = 135)	Data from two Phase III, longitudinal, randomised controlled trials. All patients randomised to treatment. EQ-5D conducted at baseline and two follow-up visits	EQ-5D (UK tariff)	Baseline of trial, mean (SD) • male = 0.752 (0.212) • female = 0.721 (0.228)
Kim and Kim[194,219]	South Korea	COPD patients 556 male • aged 19–64 years = 49.3% • aged ≥ 65 = 50.7% 195 female • aged 19–64 years = 37.5% • aged ≥ 65 = 62.5%	Data from KNHANES	EQ-5D (Korean tariff)	Sex, mean (SE) • male (*n* = 556) = 0.86 (0.02) • female (*n* = 195) = 0.93 (0.01)

continued

DOI: 10.3310/phr06050

TABLE 32 Confounding variables: sex (*continued*)

Author	Country	Population	Methods	Instrument	HSUV
Sundh *et al.*[225]	Sweden	373 COPD patients • GOLD stage 3 (severe) = 259 • GOLD stage 4 (very severe) = 114 Male (*n* = 165) • mean age, years (SD) = 72.2 (8.11) Female (*n* = 208) • mean age, years (SD) = 70.5 (7.58)	27 hospital-based secondary care respiratory units enrolled ≈10 patients each. EQ-5D completed by patient during visit or later at home	EQ-5D (UK tariff)	Sex, mean (SD) • male (*n* = 165) = 0.71 (0.23) • female (*n* = 208) = 0.60 (0.30)
Kim *et al.*[236]	South Korea	200 COPD patients (GOLD stages 1–4); age, years • < 60 = 25 • 60–69 = 74 • 70–79 = 85 • ≥ 80 = 16 Sex, male (%) = 91.5	Interview, including EQ-5D. Recruitment by respiratory specialists via outpatient departments	EQ-5D (Korean tariff)	Sex, mean (SE) • male = 0.86 (0.02) • female = 0.93 (0.01)

Author	Country	Population	Methods	Instrument	HSUV
Fletcher *et al.*[262]	Brazil, China, Germany, Turkey, USA, UK	2426 patients Age, years • 45–54 = 1029 • 55–64 = 971 • 65–67 = 426 MRC dyspnoea scale severity • mild = 849 • moderate = 1012 • severe = 521 • missing data = 44	Cross-sectional study. Data gained from interviews with participants (including EQ-5D). Recruited by a contract research organisation. Participants recruited to represent wide range of demographics and disease severity	EQ-5D (Germany, UK and USA tariff)	Sex, mean (SE) • male (n = 1178) = 0.678 (0.009) • females (n = 1243) = 0.596 (0.009)
Punekar *et al.*[279]	USA, France, Germany, Italy, Spain, UK	2703 patients • seen by PCP = 1381 • seen by RS = 1322 Mean age, years (SD) • seen by PCP = 66 (0.29) • seen by RS = 66 (0.31) Sex, male (%) • seen by PCP = 66 • seen by RS = 71	Cross-sectional survey. Physicians recruited and recorded information for six patients during consultations	EQ-5D (UK tariff)	Sex (seen by PCP), mean (95% CI) • male = 0.70 (0.68 to 0.72) • female = 0.69 (0.66 to 0.71) Sex (seen by RS), mean (95% CI) • male = 0.69 (0.67 to 0.71) • female = 0.65 (0.62 to 0.68)

KNHANES, Korean National Health and Nutrition Examination Survey; MRC, Medical Research Council; PCP, primary care physician; RS, respiratory specialist.

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TABLE 33 Confounding variables: number and severity of exacerbations

Author	Country	Population	Methods	Instrument	HSUV
Miravitlles *et al.*[206]	Spain	346 COPD patients Mean age, years (SD) = 67.9 (9.7) Sex, male (%) = 85.5	Multicentre observational cross-sectional study; 15 hospitals. Patients recruited at outpatient clinic. All patients in stable condition	EQ-5D (Spanish tariff)	Exacerbations in previous year, median (IQR) • no = 0.87 (0.25) • yes = 0.78 (0.31) • < 2 = 0.84 (0.29) • ≥ 2 = 0.74 (0.54)
Punekar *et al.*[279]	USA, France, Germany, Italy, Spain, UK	2703 patients • seen by PCP = 1381 • seen by RS = 1322 Mean age, years (SD) • seen by PCP = 66 (0.29) • seen by RS = 66 (0.31) Sex, male (%) • seen by PCP = 66 • seen by RS = 71	Cross-sectional survey. Physicians recruited and recorded information for six patients during consultations	EQ-5D (UK tariff)	Exacerbations (seen by PCP), mean (95% CI) • 0 = 0.78 (0.75 to 0.80) • 1–2 = 0.74 (0.72 to 0.77) • ≥3 = 0.61 (0.59 to 0.64) Exacerbations (seen by RS), mean (95% CI) • 0 = 0.75 (0.72 to 0.77) • 1–2 = 0.73 (0.71 to 0.76) • ≥3 = 0.57 (0.54 to 0.60)

IQR, interquartile range; PCP, primary care physician; RS, respiratory specialist.

DOI: 10.3310/phr06050

TABLE 34 Confounding variables: number and type of comorbidities

Author	Country	Population	Methods	Instrument	HSUV
Martinez Rivera *et al.*[202]	Spain	115 COPD patients • mean age, years (SD) = 66.9 (8.8) • sex, male (%) = 93 Patients with depression • mean age, years (SD) = 68.3 (8.1) • sex, male (%) = 96.4 Patients without depression • mean age, years (SD) = 66.5 (9) • sex, male (%) = 92	Multicentre observational cross-sectional study; 13 hospitals. Data also used in Alcazar *et al.*[204] and García-Polo *et al.*[205]	EQ-5D (Spanish tariff)	Mean (SD) • patients with depression (*n* = 28) = 0.40 (0.30) • patients without depression (*n* = 87) = 0.76 (0.29)

Hong *et al.*[194,218]	South Korea	1178 COPD patients
		• mean age, years (SD) = 63.7 (9.5)
		• sex, male (%) = 69
		GOLD stage 1 (mild) COPD (*n* = 497)
		• mean age, years (SD) = 65.1 (9.5)
		• sex, male (%) = 71
		GOLD stage 2 (moderate) COPD (*n* = 612)
		• mean age, years (SD) = 62.4 (9.6)
		• sex, male (%) = 68
		GOLD stage 3 (severe) or 4 (very severe) COPD (*n* = 69)
		• mean age, years (SD) = 64.6 (8.0)
		• sex, male (%) = 75
		1178 control subjects
		• mean age, years (SD) = 63.4 (9.3)
		• sex, male (%) = 69
			Data from KNHANES	EQ-5D (Korean)	Mean (SD)
					• 0 comorbid diseases
					  ○ mild = 0.95 (0.12)
					  ○ moderate = 0.94 (0.12)
					  ○ severe = 0.91 (0.08)
					• 1 comorbid disease
					  ○ mild = 0.91 (0.14),
					  ○ moderate = 0.93 (0.12)
					  ○ severe = 0.91 (0.08)
					• 2 comorbid diseases
					  ○ mild = 0.86 (0.17)
					  ○ moderate = 0.88 (0.15)
					  ○ severe = 0.87 (0.14)
					• ≥ 3 comorbid diseases
					  ○ mild = 0.84 (0.14)
					  ○ moderate = 0.82 (0.19)
					  ○ severe = 0.78 (0.18)

continued

TABLE 34 Confounding variables: number and type of comorbidities (*continued*)

Author	Country	Population	Methods	Instrument	HSUV
Miravitlles *et al.*[221]	Spain	346 COPD patients • mean age, years (SD) = 67.9 (9.7) • sex, male (%) = 85.5	Multicentre observational cross-sectional study; 15 hospitals. Patients recruited at outpatient clinic. All patients in stable condition	EQ-5D (Spanish tariff)	Median (IQR) • cardiovascular disease = 0.78 (0.30) • no cardiovascular disease = 0.82 (0.25) • diabetes = 0.81 (0.25) • no diabetes = 0.81 (0.38) • haematological malignancies = 0.80 (0.16) • no haematological malignancies = 0.81 (0.27)
Miravitlles *et al.*[206]	Spain	713 COPD patients • mean age, years (SD) = 68.3 (9.3) • sex, male (%) = 83 Patients with depression (*n* = 527) • mean age, years (SD) = 68.3 (9.1) • sex, male (%) = 82.1 Patients without depression (*n* = 186) • mean age, years (SD) = 68.3 (9.8) • sex, male (%) = 85.7	DEPREPOC – a multicentre observational cross-sectional study	EQ-5D (Spanish tariff)	Mean (SD) • total patients (*n* = 713) = 0.62 (0.24) • patients with depression (*n* = 527) = 0.55 (0.21) • patients without depression (*n* = 186) = 0.83 (0.16)

DEPREPOC, Depression in Chronic Obstructive Pulmonary Disease; IQR, interquartile range; KNHANES, Korean National Health and Nutrition Examination Survey.

DOI: 10.3310/phr06050

TABLE 35 Confounding variables: smoking history

Author	Country	Population	Methods	Instrument	HSUV
Lee *et al.*[194,201]	South Korea	Non-smoker ($n = 399$) • aged < 65 years (%) = 52.4 • aged ≥ 65 years (%) = 46.6 • sex, male (%) = 25.1 Smoker ($n = 823$) • aged < 65 years (%) = 50.1 • aged ≥ 65 years (%) = 50.4 • sex, male (%) = 93.6	Data from KNHANES	EQ-5D (Korean tariff)	Mean (SD) • smoker ($n = 823$) = 0.91 (0.15) • non-smoker ($n = 399$) = 0.87 (0.16)
Miravitlles *et al.*[221]	Spain	346 COPD patients • mean age, years (SD) = 67.9 (9.7) • sex, male (%) = 85.5	Multicentre, observational, cross-sectional study, 15 hospitals. Patients recruited at outpatient clinic. All patients in stable condition	EQ-5D (Spanish tariff)	Median (IQR) • former smoker = 0.81 (0.25) • current smoker = 0.81 (0.27)
Mullen *et al.*[242]	Canada	956 COPD Smokers = smoked daily in the last 6 months Mean age, years (SD) • usual care = 62.3 (15.4) • OMSC = 65.9 (10.6)	Smokers hospitalised for one of four selected diagnoses. Intervention: OMSC intervention. Comparator: usual care. Utility scores calculated from Sullivan *et al.*[310] and Tillman *et al.*[311]	EQ-5D (USA tariff)	Former smoker = 0.52 Current smoker = 0.50

IQR, interquartile range; KNHANES, Korean National Health and Nutrition Examination Survey; OMSC, Ottawa Model for Smoking Cessation.

TABLE 36 Confounding variables: BMI

Author	Country	Population	Methods	Instrument	HSUV
Miravitlles *et al.*[221]	Spain	346 COPD patients • sex, male (%) = 85.5 • mean age, years (SD) = 67.9 (9.7)	Multicentre observational cross-sectional study; 15 hospitals. Patients recruited at outpatient clinic. All patients in stable condition	EQ-5D (Spanish tariff)	BMI, median (IQR) • underweight = 0.69 (0.51) • normal = 0.80 (0.31) • overweight = 0.82 (0.25) • obese = 0.81 (0.38)
García-Rio *et al.*[232]	Spain	3797 COPD patients, aged 40–80 years Normal weight • mean age, years (SD) = 61 (10) • sex, male (%) = 63.9% Overweight • mean age, years (SD) = 64 (11) • sex, male (%) = 75.6 Obese • mean age, years (SD) = 66 (9) • sex, male (%) = 68.1	EPI-SCAN study – multicentre cross-sectional population-based study	EQ-5D (Spanish tariff)	BMI, mean (SD) • normal weight (*n* = 97) = 0.83 (0.24) • overweight (*n* = 172) = 0.90 (0.19) • obese (*n* = 113) = 0.83 (0.21) • total = 0.86 (0.21)

IQR, interquartile range.

TABLE 37 Confounding variables: socioeconomic status

Author	Country	Population	Methods	Instrument	HSUV
Kim and Kim[194,219]	South Korea	COPD patients 556 male • aged 19–64 years (%) = 49.3 • aged ≥ 65 years (%) = 50.7 195 female • aged 19–64 years (%) = 37.5 • aged ≥ 65 years (%) = 62.5	Data from KNHANES	EQ-5D (Korean tariff)	Mean (SE) • GOLD stage 1 (mild) = 0.90 (0.01) • GOLD stage 2 (moderate) = 0.92 (0.01) • GOLD stage 3 (severe) = 0.95 (0.01) • GOLD stage 4 (very severe) = 0.96 (0.01)
Miravitlles *et al.*[271]	Spain	4574 COPD patients • mean age, years (SD) = 67.06 (10.04) • sex, male (%) = 83.7	Patients recruited from GPs and respiratory specialists	EQ-5D (Spanish tariff)	Socioeconomic status – unadjusted • low = 0.63 • medium = 0.72 • high = 0.75 Socioeconomic status – adjusted for age • low = 0.64 • medium = 0.71 • high = 0.73 Socioeconomic status – adjusted for age and severity • low = 0.66 • medium = 0.70 • high = 0.71

KNHANES, Korean National Health and Nutrition Examination Survey.

Appendix 15 Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist

Section/topic	Number	Checklist item	Reported on page number
Title			
Title	1	Identify the report as a systematic review, meta-analysis or both	The report was identified as a structured narrative literature review, which followed systematic procedures and, where possible, adhered to the PRIMSA checklist (see *Appendix 12*, page 141)
Abstract			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	The literature review was conducted as part of the economic evaluation section (see *Chapter 5*) of the report and thus inclusion of an abstract was not applicable
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known	The rationale for the review was included as part of the methodology of the report on *Chapter 5*, page 61
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS)	Four objectives for the review were stated (see *Appendix 12*, page 141)
Methods			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g. web address) and, if available, provide registration information including registration number	The review protocol is described in *Appendix 12*. No formal registration was made
Eligibility criteria	6	Specify study characteristics (e.g. PICOS, length of follow-up) and report characteristics (e.g. years considered, language, publication status) used as criteria for eligibility, giving rationale	The review was designed using a two-stage process. Eligibility criteria were developed for each stage based around the PICOS format (when relevant) and included language and year of publication (see *Tables 24* and *25*, pages 142 and 143)
Information sources	7	Describe all information sources (e.g. databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched	All information sources were described in *Appendix 12* (page 142) and databases, with access dates were included in *Appendix 13*
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated	Full electronic search strategies are presented in *Appendix 12* (page 143) and all individual database searches are included in *Appendix 13*
Study selection	9	State the process for selecting studies (i.e. screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis)	The process of study selection, including use of inclusion and exclusion criteria, was described in *Appendix 12*, pages 144 and 148
Data collection process	10	Describe method of data extraction from reports (e.g. piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators	The process of data extraction, including how duplicate information was dealt with, was described in *Appendix 12*, page 148

Section/topic	Number	Checklist item	Reported on page number
Data items	11	List and define all variables for which data were sought (e.g. PICOS, funding sources) and any assumptions and simplifications made	The data items extracted were listed in *Appendix 12*, page 148
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level) and how this information is to be used in any data synthesis	Not applicable (risk of bias was not formally assessed, although potential bias was considered when selecting studies for the economic evaluation)
Summary measures	13	State the principal summary measures (e.g. risk ratio, difference in means)	The principal summary measures were differences in HSUVs
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g. I^2) for each meta-analysis	The studies were used individually for the economic evaluation, except in one case in which a weighted average of the results were used (see *Chapter 5*, pages 63–5)
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g. publication bias, selective reporting within studies)	Not applicable (risk of bias was not formally assessed, although potential bias was considered when selecting studies for the economic evaluation)
Additional analyses	16	Describe methods of additional analyses (e.g. sensitivity or subgroup analyses, meta-regression), if done, indicating which were prespecified	Not applicable (no additional analysis was undertaken for this review as it was deemed outside the scope of the project)
Results			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram	The study selection process was presented in a PRIMSA flow diagram (see *Appendix 12*, *Figure 29*, page 144)
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g. study size, PICOS, follow-up period) and provide the citations	Study characteristics for all selected studies were presented in *Table 27–29* (see *Appendix 12*, pages 149–53)
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12)	Not applicable (risk of bias was not formally assessed, although potential bias was considered when selecting studies for the economic evaluation)
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot	For all selected studies, HSUVs (means and SDs) were presented in *Tables 27–29* (see *Appendix 12*, pages 149–53)
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency	Not applicable (meta-analysis was not included as part of the data synthesis, instead results were presented as a narrative summary)
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see item 15)	Not applicable (risk of bias was not formally assessed, although potential bias was considered when selecting studies for the economic evaluation)
Additional analysis	23	Give results of additional analyses, if done [e.g. sensitivity or subgroup analyses, meta-regression (see item 16)]	Not applicable (no additional analyses were conducted)

Section/topic	Number	Checklist item	Reported on page number
Discussion			
Summary of evidence	24	Summarise the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g. health-care providers, users, and policy-makers)	Brief summaries of the results in relation to each objective are provided in *Appendix 12*, pages 148, 149, 154 and 155
Limitations	25	Discuss limitations at study and outcome level (e.g. risk of bias), and at review-level (e.g. incomplete retrieval of identified research, reporting bias)	The purpose of the review was to identify studies to inform the economic evaluation; therefore, it was not written as a full review, so a section on limitations was not applicable. However, risk of bias and limitations of individual studies were considered when selecting studies for the economic evaluation
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research	The review was designed specifically to identify papers to support the economic evaluation; therefore, this section was not applicable
Funding			
Funding	27	Describe sources of funding for the systematic review and other support (e.g. supply of data); role of funders for the systematic review	The literature review was conducted as part of the economic evaluation section (see *Chapter 5*) of the report. Funding details can be found on pages vi and xxvii

PICOS, participants, interventions, comparisons, outcomes and study design.

EME
HS&DR
HTA
PGfAR
PHR

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