The Health Impacts of Household Energy Efficiency Measures

By:

Christopher D. Maidment

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The University of Sheffield
Faculty of Science
Department of Psychology

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Abstract

Living in a cold, damp home is harmful to physical and mental health. Household energy efficiency measures, often installed to reduce carbon emissions, should make it easier and more affordable for residents to maintain a warm, comfortable environment, thereby reducing cold-related illnesses and associated stress. However, the expected health benefits are often not seen and concerns have been raised of unplanned, detrimental effects on health.

A series of studies was conducted to investigate the relationship between household energy efficiency measures and the health of residents using three different approaches. Initially, the mechanisms by which such health benefits may be achieved were investigated via continuous indoor environmental monitoring in a number of case study homes and a questionnaire-based survey of residents following a council retrofit scheme. A meta-analysis of the extant evidence then identified a positive impact from household energy efficiency measures on health. Finally, professionals involved in the planning or implementation of household energy efficiency schemes were interviewed to determine the extent to which health is considered in organisational and individual objectives.

The present research contributes to the design of effective energy efficiency policies and interventions. The presence of household energy efficiency measures was found to have a positive effect on health on average, particularly for residents vulnerable to the impacts of fuel poverty due to their age, health or income. Physical and perceived changes to the home environment were identified as the key consecutive components of the mechanism for this effect. Future research that comprehensively assesses long-term health impacts alongside short-term changes in wellbeing would contribute to the promotion of household energy efficiency measures. The need was recognised, though, for a holistic, collaborative approach to address individual needs and overcome institutional barriers in order to achieve concurrent environmental, economic, social and health benefits.

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Introduction

The present research was initiated as part of the Big Energy Upgrade (BEU) (DECC, 2012b), a large scale programme developed to improve the energy efficiency of homes across Yorkshire and the Humber. Tailored packages of household energy efficiency measures and micro-generation technologies were installed in existing housing to improve insulation and energy control, and energy-efficient behaviour was promoted. The programme received investment from the European Regional Development Fund and was delivered by a partnership of local authorities and providers of housing, housing services, and energy. The University of Sheffield worked closely with the delivery partners to research various technological, behavioural and economic outcomes from the programme in order to inform future energy efficiency improvement and policy.

In addition to reducing energy demand and carbon dioxide emissions, the installation of household energy efficiency measures has been shown to produce co-benefits for residents including improvements in health (Thomson, Thomas, Sellstrom, & Petticrew, 2009). Evidence of the scale and nature of such health changes is not consistent though, while some research also suggests a potential for harmful effects (Bone, 2010). The present research was therefore devised to investigate the relationship between household energy efficiency measures and health so that insight can be gained into how energy efficiency policies and interventions can realise health benefits.

Background - Energy efficiency policy

The global response to climate change

In 2011, the world's largest greenhouse gas producers met in Durban as part of the United Nations Framework Convention on Climate Change and finally agreed to binding emissions reductions, having failed to reach such global agreement at previous conferences in Kyoto, Copenhagen and Cancun. However, as the terms of the agreement were still to be negotiated and would not come into force until 2020, some commentators questioned its timeliness and, therefore, its capacity to address climate change (e.g., Bond, 2012). While China has problems enforcing its ambitious targets at a regional level, it is national policy in the US that has been blocked by conservative, industry-led opposition (Oh, 2012), leaving much of the progress on energy efficiency to individual states. Many provide incentives and enforce residential energy conservation codes, though with varying degrees of success (Doris et al., 2009). Relatively cheap and known energy efficiency technologies are expected to play a vital role in the US, fitting in to the 'green growth' emissions strategy that avoids restricting lifestyle (Sterner & Damon, 2011) and providing social benefits that are not dependent on the still controversial issue of climate change (Rayner, 1993). This direction is reflected globally, with major consumers including USA, EU, China, India and Brazil among the voluntary members of the International Partnership for Energy Efficiency Cooperation (IPEEC, 2012).

Early in 2011 the EC set out a 'roadmap' to achieving unprecedented 80-95% reductions in greenhouse gas emissions by 2050 while remaining competitive (EC, 2011a), and adopted the Energy Efficiency Plan (EC, 2011b) which aims to save up to €1000 per household annually through a strategy that includes building renovation as well as more efficient components and appliances within. The Energy Efficiency

Directive (EC, 2012), which binds member states to requiring end-use energy savings from utility companies and financing facilities for energy efficiency measures, was approved in September 2012.

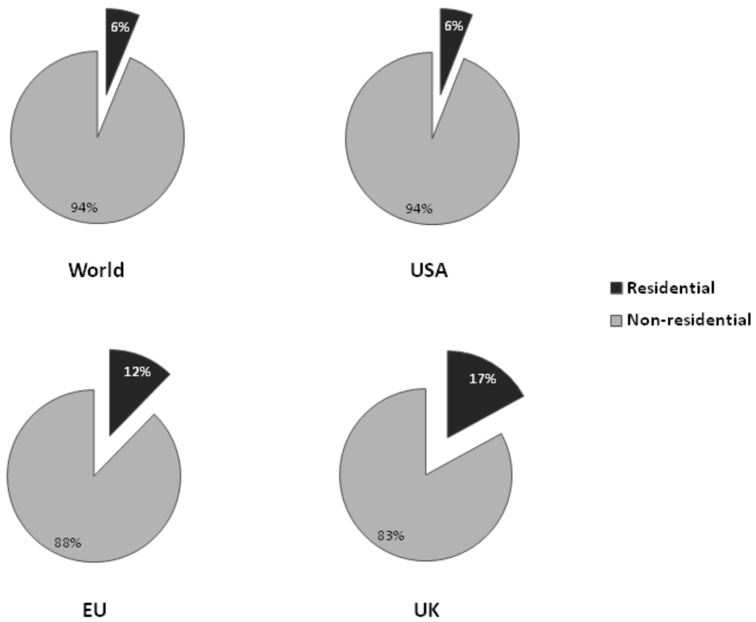

Figure 1: Estimated emissions of carbon dioxide from fuel combustion in 2010, by sector (data from IEA, 2012)

UK policy

In the UK in particular, the residential sector accounts for a significant portion of carbon dioxide (CO_2) emissions (IEA, 2012, Figure 1) due in part to the climate but also to the construction and condition of the housing stock[1]. Alongside being subject to stringent carbon targets however, the UK has a statutory duty to eradicate fuel poverty. Cutting emissions primarily through taxation would not only be unpopular while energy prices are high but would disproportionately affect the poorest households (Boardman, 2004), which are often among the least thermally efficient. Originally launched as the Home Energy Efficiency Scheme in 2000, the Warm Front scheme (DECC, 2012c)

[1] While climate might be expected to be the key predictor for heating energy demand, the low proportion of emissions from residential sources in some Scandinavian countries demonstrates the influence of thermally-efficient housing.

provided grants to improve insulation and heating in English households that receive certain benefits - a crude method of targeting the fuel poor - while the Decent Homes programme concurrently sought to ensure that public sector housing would meet basic standards of health, safety and comfort by 2010. From 2008 the Carbon Emissions Reduction Target (DECC, 2012d) and the Community Energy Saving Programme (DECC, 2012e) required large energy companies to encourage uptake of low carbon measures by their customers. These policies have now been replaced by the Green Deal and the Energy Company Obligation (DECC, 2011). The Green Deal allows individuals and companies to finance installations through loans recouped via the projected energy savings. The Energy Company Obligation requires suppliers to subsidise measures not economically viable through the Green Deal alone, aiming to target the homes most needing or benefitting from improvement. Although the energy efficiency market has grown since the oil crisis in the early 1970s, domestic energy use has continued to rise (Faiers, Cook, & Neame, 2007), partly because most UK homes at the beginning of the new millennium were thought to be under-insulated compared to new builds, for which standards in air-tightness, thermal insulation and carbon emissions have been raised significantly since (HM Government, 2010). Various retrofit schemes, such as the BEU (DECC, 2012b) in Yorkshire and the Humber region, have been implemented to try to narrow this gap. The University of Sheffield collaborated with the BEU partners to assess the economic and energy performance of the measures installed through the programme, using remote monitoring and life cycle analysis for instance, and to investigate the expected co-benefits such as job creation and improved health.

Energy efficiency and health

The Hills Fuel Poverty Review (2012) highlighted serious health implications for the millions of people in England and Wales struggling to heat their homes adequately because of low incomes and high energy costs. Living in cold or thermally-inefficient homes has been linked to a variety of detrimental health effects (Liddell & Morris, 2010; Marmot, 2011) including excess winter deaths (Healy, 2003), respiratory conditions such as chronic obstructive pulmonary disease (Osman et al., 2008), and increased risk of heart attacks and strokes due to raised blood pressure (Lloyd, 1991). The damp or mould that can accumulate in cold homes has been shown to affect allergic or respiratory conditions including asthma (e.g. Fisk et al., 2007) and respiratory tract infections (Emond, Howat, Evans, & Hunt, 1997), and, in general, stress, depression, and low levels of wellbeing have all been linked with cold or damp housing (Shortt and Rugkasa, 2007). Social problems can also arise from energy inefficient housing with residents becoming isolated, too embarrassed by their housing conditions to accept visitors, or children's education suffering where only the main living areas are heated, leaving no suitable place for undisturbed study (Richardson and Eick, 2006).

Household energy efficiency measures like insulation, double glazing and heating improvements aim to reduce energy demand, making it more affordable to keep homes warm. Given the evidence linking cold housing to poor health, it could be assumed that energy efficiency measures should beneficially affect the health of householders. Consistent with this idea, household energy efficiency interventions have been shown to result in a diverse range of positive health impacts (Thomson et al., 2009; 2013), including children’s respiratory health, weight and susceptibility to illness, the mental health of adults (rarely assessed for children) (Liddell and Morris, 2010), better self-reported health, and reduced respiratory symptoms and school absences due to asthma (PHIS, 2006). Indirect evidence was also provided by Sandel and Wright (2006) who noted that stress caused by housing problems including damp and mould can exacerbate asthma in children. There is also evidence that improved domestic space heating can reduce school absences and health service use for children with asthma (Preval et al., 2010). Given that financial strain may worsen both mental and physical health (Gilbertson, Grimsley, & Green, 2012), improving the energy efficiency of homes can also contribute to a better quality of life by reducing energy bills.

However, further research is needed because despite the introduction of interventions designed to improve household energy efficiency, the extent of any resulting health benefits remains in question. Key reviews in the field to date, for example, have covered wider issues, like the health impacts of fuel poverty (Liddell and Morris, 2010) or housing standards (Thomson et al., 2009), without solely focussing on the impact of household energy efficiency interventions. The Cochrane Review (Thomson et al., 2013), which did investigate the health effects of various physical improvements to housing, called specifically for more reviews devoted to energy efficiency and warmth improvements. Thomson et al. (2013) concluded that despite the increasing evidence base in this area, potential improvements to data collection and reporting still exist, as do key knowledge gaps, for example, in relation to the relative impacts of interventions on particular population subgroups and/or from particular measures.

Household energy efficiency interventions may also have negative effects on health and wellbeing. For instance, formaldehyde was commonly used in insulation until the 1980s but has since been identified as carcinogenic and is now considered a major harmful pollutant (Frey, Destaillats, Cohn, Ahrentzen, & Fraser, 2014). Insulating and sealing homes may also have indirect repercussions for occupants' health though as the resultant increases in airtightness affect the indoor environment. In reviewing the wide range of impacts from energy efficiency improvements, Shrubsole, Macmillan, Davies, & May (2014) described a number of adverse health impacts that could result from reduced ventilation rates. Firstly, raised relative humidity levels can lead to increases in dust mite levels, mould growth, and microbiological pathogens and, therefore, potentially cause or worsen allergic symptoms and asthma. Secondly, energy efficiency interventions that limit ventilation may expose occupants to increased concentrations of pollution from cleaning, cooking, decorating or other indoor sources; pollutants such as particulate matter, volatile organic compounds (VOCs) and environmental tobacco smoke (ETS), or naturally occurring pollutants like radon. As lower ventilation rates may conversely protect occupants against external pollution, Shrubsole et al. (2014) noted both positive and negative potential health effects related to changes in indoor air quality. While there is still some uncertainty concerning the impacts of indoor air chemistry on health (Weschler, 2011), adverse health effects from certain pollutants are well documented (Sharpe, Thornton & Osborne, 2014) and the likelihood that failure to compensate for reduced ventilation rates results in more harmful home environments is highlighted by Milner et al.'s (2015) examination of retrofit energy efficiency interventions.

The relationship between housing and health

It is apparent from the range of health impacts described above, both positive and negative, that the relationship between housing and health is complex and that the impact that a particular housing improvement will have on residents’ health is therefore difficult to predict. For instance, while general housing improvements have been shown to improve mental health in a number of studies (Egan et al., 2013; Macintyre et al, 2003), there is conflicting evidence (Clark & Kearns, 2012). Previous research has shown that health changes resulting from interventions such as household energy efficiency measures can depend on perceptual or attitudinal factors, not just the tangible physical or financial benefits. Mental wellbeing is influenced by perceptions of the worth of the home compared to others (Ellaway, McKay, Macintyre, Kearns, & Hiscock, 2004), of the relative standard of living, the status of the home and reputation of the neighbourhood among peers (Kearns, Whitley, Bond, Egan, & Tannahill, 2013), and by factors such as aesthetics and security (Bond et al., 2012).

The range of perceptions and attitudes regarding the home that can affect wellbeing suggests deeper-lying reasons for the connection between housing and health. For example, the relationships tenants have with landlords can affect the benefits they derive from household improvements (Clark & Kearns, 2012), tenants often feeling that a disproportionate power to affect their lives lies with the landlords (Dillahunt, Mankoff, & Paulos, 2010). This suggests that a lack of control over changes to the home environment may influence the derived benefits. As control, along with continuity and distinctiveness, is a key element of identity and self-esteem (Breakwell, 1993), the attitudes and behaviours regarding energy efficiency measures may be explained to some extent by social identity theory (Tajfel & Turner, 1986). Identity can be closely linked to the place or community in which one lives (Jacquet & Stedman, 2013) so residents may feel that their wellbeing has been impaired if household improvements are deemed to harm their control over their environment, for instance those involving unfamiliar technology such as renewables or even new central heating controls. Social identity theory also suggests that a person wanting to belong to a particular group will be driven to share certain views and attitudes (Mumford & Gray, 2010). Consequently, opinions of changes to the home may depend on whether residents want to fit in with or be distinct from their neighbours, or simply maintain continuity. Whether a household energy efficiency measure will be adopted and, if so, how it will be used can therefore be difficult to predict. For example, although new energy efficiency measures can help demonstrate an 'early adopter' or environmentally-conscious lifestyle, consumption (e.g., of energy) is traditionally linked with status and valued social practices such as providing for the family, therefore a conspicuously low energy lifestyle may have a stigmatising effect (Hards, 2013). While such stigma may reduce as energy conserving behaviours and technologies become normalised, Hards (2013) also noted that the level of energy consumption considered normal has tended to increase over time.

As residents must purchase, volunteer for, or accept an intervention (or adopt a new behaviour) for a scheme to be successful, their priorities are likely to be important considerations in its planning and implementation. Organ, Proverbs, and Squires, (2013) identified money, comfort, and environmental impact as the key motivators for residents to undertake energy efficiency refurbishments. Such decisions may be skewed towards resistance to change though by the tendency to place more importance on upfront costs than on future savings (Christie, Donn, and Walton, 2011), or by distrust of the authority promoting or providing the intervention. Mumford and Gray (2010) found that energy companies tend to be perceived as acting only in self interest, therefore placing suspicion on any help or advice they offered. Such stereotypical images and emotional responses are known to influence or even outweigh rational decision-making, so that distant, intangible benefits like health are undervalued (Taylor-Gooby, 2004). In theory this could affect the thinking not just of the recipients of household energy efficiency measures but also of those involved in their provision, so that appraisals of residents' needs are biased towards achieving immediate, measureable impacts rather than long-term health changes.

Thesis narrative

The existing evidence of the relationship between energy efficiency and health presented a convoluted picture of multiple connected and conflicting outcomes, influenced by a variety of factors. The primary aim of the present research, therefore, was to determine whether or not household energy efficiency measures tend to improve health. The identification and measurement of the typical change in health, if any, attributed to a household energy efficiency measure would not only help inform energy efficiency and health policies but would provide a platform for further research. Given the varied health outcomes − both positive and negative − discussed in the preceding sections though, a greater understanding of the mechanisms by which household energy efficiency measures affect health changes was also needed.

Two connected studies were developed to collect empirical data, via both physical measurement and self-reporting by residents, in Scunthorpe, North Lincolnshire where over one hundred homes had received energy efficiency measures as part of a council retrofit programme the previous year. The case studies research, which is described in Chapter 2, involved collecting primary data from participating households via continuous monitoring of the temperature, relative humidity and level of carbon dioxide in their living room and bedroom over a 3 month winter period. This indoor environmental data was captured alongside outdoor temperature readings, household energy usage measurements, and perceptions of the home environment and health, self-reported regularly by the participants. The purpose was to build a clearer picture of the direct impacts resulting from the installation of household energy efficiency measures in a home. The use of objective measures to assess health, such as medical tests or health records, was considered but rejected on both practical and ethical grounds as discussed in the following chapter.

The second study, described in Chapter 3, was developed to survey a larger number of residents in the same location in order to investigate the mechanisms by which any direct impacts of installing household energy efficiency measures might lead to changes in the health. This study used a questionnaire to investigate the health of residents and the characteristics of their homes, including the house type and construction and the energy efficiency measures present. The questionnaire also gathered data regarding the indoor environment or energy usage of the home including problems experienced (e.g., with damp or paying energy bills), feelings of satisfaction (e.g., with temperature and air quality), and related behaviours (e.g., heating and ventilation). Using this information, the research sought to investigate the negative influence of physical factors (e.g., cold and damp) and psychological factors (e.g., financial stress, discomfort and dissatisfaction) on health and wellbeing, and the extent to which they are addressed by household energy efficiency measures. Such analysis would both benefit from and contribute to insight into the particular circumstances − characteristics of the resident, property and intervention, for instance − that induce or prevent health changes and, therefore, would aid in the design of interventions and how they are targeted to maximise health benefits.

Difficulties were encountered during the data collection process, principally in identifying and engaging with local authority retrofit schemes that would allow baseline data (prior to installation) and follow-up data (at least a year later) to be collected within the timescale of the research project. Due to delays in local authority schedules, the research plans were altered to conduct the data collection independently but retrospectively. This prompted the consideration of alternative research approaches.

To help answer the question of whether and to what extent household energy efficiency measures improves or impairs the health of residents, a review of the extant evidence examining this relationship was conducted, as described in Chapter 4. Meta-analysis was chosen for this purpose as the process would result in a single value to quantify the impact by extracting effect sizes from relevant studies, weighting by sample size and calculating the average effect. The process would also provide the opportunity for further investigation into what factors moderate this effect. Overall the meta-analysis conducted highlighted the complexity of the relationship between household energy efficiency measures and health, and provided some explanation for the disparity between the predicted and measured effects. To provide further insight into this disparity and give context to the findings of the first three studies, a qualitative approach was needed.

Given the enthusiasm of many of the public-sector staff consulted when planning and conducting the studies described in Chapters 2 and 3, a study was developed to utilise this resource and gain insight from their experience of implementing household energy efficiency schemes and dealing with vulnerable people. Professionals working in the fields of housing, energy, health, and fuel poverty were interviewed, as described in Chapter 5. To inform effective energy efficiency policy and interventions, the research sought to go beyond the performance and impact of individual household energy efficiency measures and investigate their implementation. Each interviewee was asked about their motivations for, and experiences of, conducting energy efficiency improvement work; the people they had helped (or tried to help), the barriers they had faced and the successes they had achieved, and the role that health played in driving, promoting, targeting, and evaluating this work. Understanding the characteristics of a successful energy efficiency scheme and the practical, institutional and individual barriers that prevent household energy efficiency measures from being installed or used effectively would help to identify the best promotion and implementation strategies, and therefore deliver the greatest health benefits.

The use of a variety of methods to address the research question was made possible, perhaps necessitated, by the multidisciplinary nature of the project. In order to fully utilise the range of psychology, engineering and local authority expertise available a triangulation approach (Jick, 1979) was used to draw together and validate the findings of the studies. This enabled the individual studies to be compared constructively, using the empirical results to both test and add to the existing evidence base on energy efficiency and health. The quantitative analysis was therefore used to test and support the anecdotal evidence, and conversely the qualitative evidence was used to examine and explain the quantitative findings. This exploration and comparison of the key findings is discussed in Chapter 6.

Exploring potential routes between energy efficiency improvements and health changes in residents: Case studies

The evidence of complex, contradictory relationships between housing, energy efficiency and health described in the previous chapter suggests that more detailed study of the health outcomes of energy efficiency improvements is required. In the UK, local authorities are under increasing pressure to support investment decisions with quantitative evidence (e.g., Curtis, 2011), while a lack of support for energy policy reform in the US has left individual states with the task of incentivising and regulating housing standards, and in need of guidance (Doris et al., 2009). A better understanding of the circumstances and factors that boost, diminish or reverse the impacts, positive or negative, of energy efficiency measures on health and wellbeing would therefore help inform the design of interventions and the direction of policy.

Figure 2: Model of the expected route from the installation of household energy efficiency measures to improved health for residents, via improvements to the home environment

Figure 2 describes the simple mechanism by which energy efficiency measures might be expected to affect health, namely protecting residents from the harm associated with cold living environments (Liddell & Morris, 2010). However, as stated above the review of the existing literature on housing conditions and residents' health in Chapter 1 found the relationship to be complex and identified a range of factors that may influence the effect of energy efficiency interventions on health. For example, residents may fail to use the new technologies optimally, may consequently alter their behaviour in harmful ways, e.g., lead a more 'indoor' sedentary lifestyle or ventilate their homes less (Shrubsole, Macmillan, Davies, & May, 2014), or may opt to take financial benefits rather than improve their home environment (e.g., using less heating to maintain the same temperature rather than keeping the same heating patterns and seeing temperatures increase due to the greater thermal efficiency). Many of these factors are interconnected in a complex manner that makes the behaviour of residents difficult to predict (Critchley, Gilbertson, Grimsley, Green, & Warm Front Study, 2007). For instance, financial savings could be spent on products for healthy or unhealthy lifestyles, on other home improvements (Scott, Jones, & Webb, 2014) or kept to meet household bills and therefore reduce anxiety. Consequently the model in Figure 3 was proposed to broadly capture and illustrate these factors, providing a starting point for their study. The model is arranged so that the upper row concerns objective changes in both the home and residents while the lower row concerns changes in the subjective perceptions held by residents, again regarding their homes and themselves.

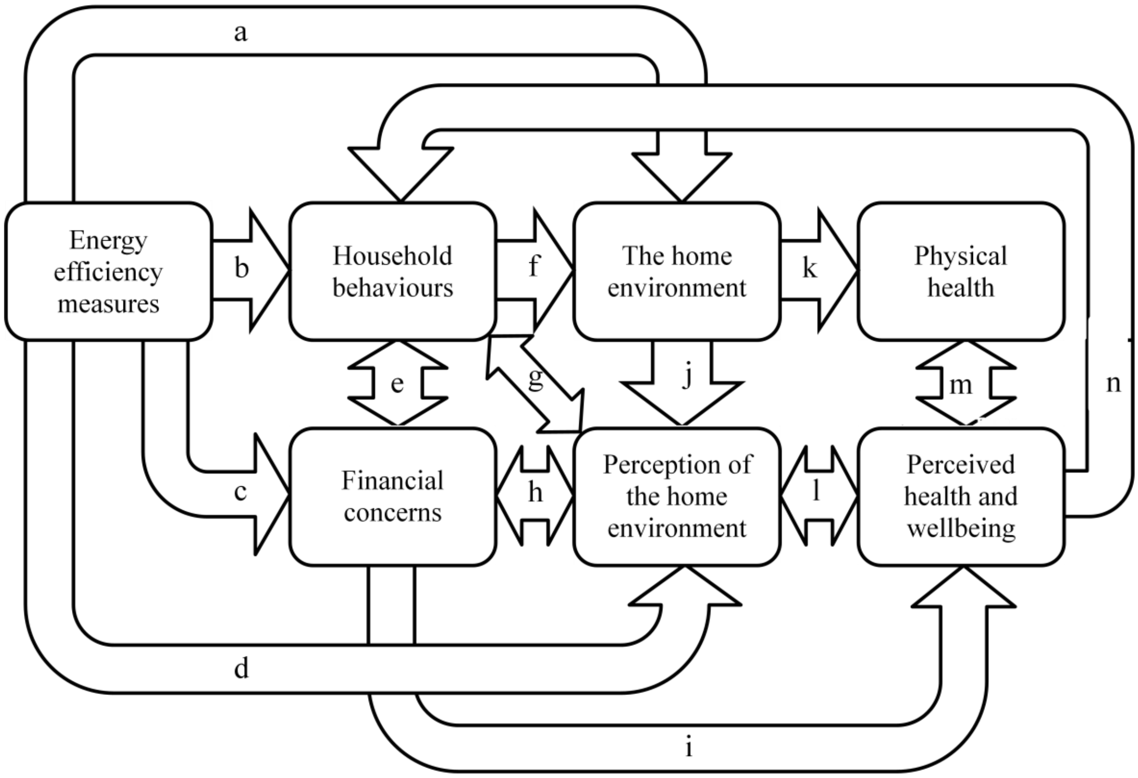

Figure 3: Illustrative model of the potential routes between energy efficiency and health including behavioural, financial and perceptual factors

No mechanism was envisaged for energy efficiency measures to have a *direct* effect on health, independent from any changes to the home environment, household finances or one of the other factors illustrated above. This link was therefore omitted from the illustrative model, although the relationship between energy efficiency measures and perceived health was tested (see the following chapter). In addition to their designed and incidental impacts on the home environment (a) (Frey, Destaillats, Cohn, Ahrentzen, & Fraser, 2014; Shrubsole et al., 2014), energy efficiency measures were considered to have potential direct impacts on residents' perceptions of this environment (d) and their financial concerns regarding energy bills (c) (Gilbertson, Stevens, Stiell, & Thorogood, 2006). The installation of energy efficiency measures has also been found to affect household behaviours related to energy use and the indoor environment (Long, Young, Webber, Gouldson, & Harwatt, 2014b). As the need for warmth or to save money could also prompt investment in energy efficiency measures, financial concerns and the home environment could be linked back to energy efficiency. The current research however was primarily concerned with the effect that energy efficiency measures have on health when present, not the reasons for their uptake, so links into energy efficiency measures were not included in the model.

Changes to the home environment, if noticeable, influence perceptions of the home environment by definition (j), and have been found to have various direct effects on health (k, Martin, Platt, & Hunt, 1987; Thomson, Thomas, Sellstrom, & Petticrew, 2013). Some behavioural impacts are self-evident; household behaviours may directly affect the home environment, both actual (f) and perceived (g), and financial concerns (e). For instance, turning the heating up may create a noticeably warmer environment while increasing energy bills. Such balances that can be struck between saving money and keeping homes warm suggest that financial concerns and perceptions of their home environment are potentially co-dependent (h, Howden-Chapman et al., 2009). A resident's financial concerns and perception of their home environment therefore has potential impacts on household behaviours (e & g) to control this balance of energy use and warmth, and on perceived health and wellbeing with the struggle or failure to provide a warm environment causing anxiety and harming quality of life (i & l, Gilbertson, Grimsley, Green, & Warm Front Study, 2012). The relationship between actual and perceived health and wellbeing (m) has also been shown previously to be cyclical − stress has substantial impacts on physical and mental health (Thoits, 2010) and can encourage unhealthy coping behaviours (Krueger & Chang, 2008), while any *noticeable* health complaint will affect a person's perception of their health state (e.g.,Dusselier, Dunn, Wang, Shelley, & Whalen, 2005). Finally, a resident's perception of their health and wellbeing can affect household behaviours (n), for instance in turning heating up to follow medical advice for people with existing health conditions (PHE, 2014).

In order to investigate whether energy efficiency measures have a positive impact on the health of residents, two associated studies were conducted. While the second study (discussed in the following chapter) surveyed a larger sample of residents by questionnaire to ascertain their perceptions of their home environment and health status, the first study (discussed here) focused on the environmental conditions and energy performance in nine case study homes. Long-term monitoring of this smaller sample allowed detailed investigation of the direct impacts of energy efficiency measures in order to provide insight on the potential causes for changes in health. In particular, both objective and self-report measures were used to assess the indoor environment in each home to help differentiate between physical and psychological effects.

Method

The present research − both the set of case studies discussed here and the wider questionnaire-based survey discussed in the following chapter − was conducted in a residential area bordering Scunthorpe town centre. Over a hundred homes in this area had been fitted with external wall insulation (EWI) roughly 12 to 18 months previously as part of a North Lincolnshire Council retrofit programme designed to improve the thermal efficiency of 'hard-to-treat' homes unable to accommodate standard energy efficiency measures. The homes eligible for the programme were unsuitable for cavity wall insulation due to their wall construction; either solid brick or with 'thumbnail' cavities too narrow to insulate. Around three quarters of these homes were social housing and benefited from further measures including solar panels or aesthetic / other improvements (e.g., replacing guttering), while the remaining private homes qualified only for the EWI due to the limited financial resources available to the local authority.

Location

The centre of Scunthorpe is made up of areas of high deprivation alongside areas of relative affluence (DCLG, 2011). In terms of economic activity it is broadly similar to the rest of England with slightly higher-than-average employment levels balanced by lower levels of self-employment (see Table 1). Average income levels in central Scunthorpe though are lower than the local region and unemployment levels are higher, with a greater proportion of Job Seekers Allowance claimants. This is disguised to some degree by the relatively low number of retirees in the area. The survey was conducted almost exclusively in areas within the 10% most deprived in the country.

Table 1: Census employment data and model-based income estimates (ONS 2011) comparing the local survey area (Scunthorpe, Town ward) to the region (Yorkshire and the Humber) and nation (England)

	Local	Regional	National
Full-time employed	47%	42%	43%
Full-time self-employed	5%	8%	9%
Unemployed	5%	4%	3%
Job seekers	39%	30%	26%
Retired	22%	26%	25%
Aged 25-49	52%	50%	51%
Weekly household income	£410	£520	Not given

Recruitment and installation

I approached residents in the area by going door-to-door to discuss the research, distribute the questionnaire (see Chapter 3) and identify potential case study participants. I then visited the nine selected households that had agreed to take part in December 2013 to install and activate the monitoring equipment. Temperature, relative humidity and carbon dioxide levels were recorded continuously at participating households at 15 minute intervals for a minimum of a three month period. The monitor outputs also included records of the dew point, the temperature below which moisture in the air would start to condense on surfaces in the home. Specifications of the monitors and more detailed descriptions of the installation and data collection process are provided in Table 31 in the appendix.

Two monitors were set up in each case study household: one in the room that the main participant stated they spent most of their waking hours when at home (in each case a downstairs reception room henceforth referred to as the living room), and one in the bedroom where the main participant slept. As far as was practical the monitors were positioned to measure a representative sample of the air that would be breathed by people in the room, but out of the way to avoid disturbance. The outdoor temperature was also recorded at hourly intervals throughout the monitoring period in four of the case study gardens. I returned to download the data from the both the indoor and outdoor monitors every 6 to 8 weeks.

In addition to the environmental monitoring I asked participants to complete an initial questionnaire (see Figure 37 in the appendix) which had previously been piloted in Greater Manchester (discussed in detail in the following chapter). The participants also completed shortened versions of the survey (Figure 38) when prompted on random days roughly every two weeks throughout the monitoring period. These 2 page 'diary surveys' asked for further details regarding health, household problems and behaviours related to energy or air quality, as well as any changes to themselves or their homes since the original survey. I also recorded gas and electricity meter readings at each visit where possible in order to calculate the energy used between visits. Finally, I took thermal images of the exterior of each home. Again, further details can be found in Table 31 in the appendix.

Five of the nine case study households selected had received external wall insulation (EWI)[2] a year to eighteen months prior to the start of the monitoring as part of the local authority retrofit programme for homes with either solid walls or thumbnail cavities unfit for standard cavity wall insulation. Table 2 summarises some of the key characteristics of the case study households, including the energy efficiency measures present at each, and further details about each of the homes are provided in the following pages.

[2] 60mm Phenolic insulation boards, mechanically fixed, with 1.5mm Silicone 'K' finish

Table 2: Summary of case study homes - participant and property characteristics (in descending order of the number of types of energy efficiency measure present)

	Occupants			Main participant		Types of energy efficiency measure present					
	No of residents	Years at address	Own or rent	Age	Working status	Loft insulation	Wall insulation	Solar panels	Double glazing	Draught proofing	'A-rated' boiler
A	2	13	Rent (Council)	45 to 54	Sick or disabled	✓	✓	✓	✓	✓	✓
B	7	2	Rent (Council)	55 to 64	Looking after home	✓	✓	✓	✓	✓	
C	4	8	Own with mortgage	25 to 34	Full-time work	✓	✓		✓	✓	✓
D	2	28	Own outright	65 to 74	Retired	✓	✓		✓		✓
E	5	2	Rent (Council)	35 to 44	Looking after home		✓	✓	✓		
F	2	1	Rent (Private)	18 to 24	Full-time work	✓			✓		✓
G	4	13	Own with mortgage	45 to 54	Full-time work	✓			✓	✓	
H	1	20	Own with mortgage	65 to 74	Retired	✓			✓		
I	3	3	Rent (Private)	25 to 34	Full-time education	✓					

Eight types of energy efficiency measure were surveyed. Central heating was present in all case study homes and home energy monitors were present in none, so both are omitted above.

Case study participants

Home A

West-facing, 3 bedroom, semi-detached house with 2 occupants

Figure 4: Front view and orientation of Home A

The participants

The main participant lived with his partner and was not working due permanent sickness and disability. He had been renting the house from the local authority for thirteen years when the monitoring started. He was not satisfied with the overall standard of housing or the air freshness indoors and only slightly satisfied with the temperature and humidity. However, he rarely had problems paying bills and felt that moisture-related problems had improved a little during the previous year, reporting no current problems other than slight draughts. He had made numerous visits to the GP and hospital regarding respiratory, heart and circulatory problems and suffered from various other conditions: psychological issues including dementia, joint pain, persistent flu symptoms, allergies and accidents in the home. This left him with some problems with mobility, self-care and performing usual activities, and moderate levels of pain and anxiety. His health and mental wellbeing had both worsened considerably over the previous year, describing bad energy levels (vitality) and fair mood and relationships, and a rating of 35 out of 100 for health.

Property characteristics

Construction was solid brick wall. External wall insulation (EWI) was installed as part of council retrofit programme the year prior to monitoring along with loft insulation and solar photovoltaic panels. The local authority had also previously installed central heating and, within the previous five years, double glazing (uPVC windows and doors), draught proofing and an efficient boiler. An Energy Performance Certificate (EPC)(DCLG, 2015) from September 2012, after the EWI had been installed, assessed the energy efficiency of the property as band D (SAP rating 62). However, as the assessment was carried out before the installation of solar panels and assumed no loft insulation, an updated assessment of band C would be expected (as per the data on recommended measures provided on the EPC).

Table 3: Energy efficiency measures present in Home A

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✓ Solar panels	✓ A-rated boiler
✓ Wall	✓ Draught proofing	✗ Energy monitor	✓ Central heating

While gas central heating was present, gas usage averaged just 0.3 kWh per day during the winter monitoring period. For comparison, gas consumption per household is assumed to average 41 kWh per day when assessing gas prices (DECC, 2015), even before the greater demand for heating during winter months is considered. Electric room heaters were also present although the usage was not available and electricity was supplemented by a 1.5 kW array of solar panels (Electricity consumption is assumed to average 10 kWh per household per day (DECC, 2015)). The participant reported that living areas and bedrooms were heated often (and only) in winter, and that an extractor fan was sometimes used when cooking and windows were sometimes opened for ventilation.

Monitors were placed in the living/dining room at the front of the house and the bedroom at the back upstairs. The measurements taken in Home A were all close to the average of the nine case study homes except in the bedroom where the mean temperature was the lowest of the participating households and the mean relative humidity the highest − much higher than the living room humidity levels.

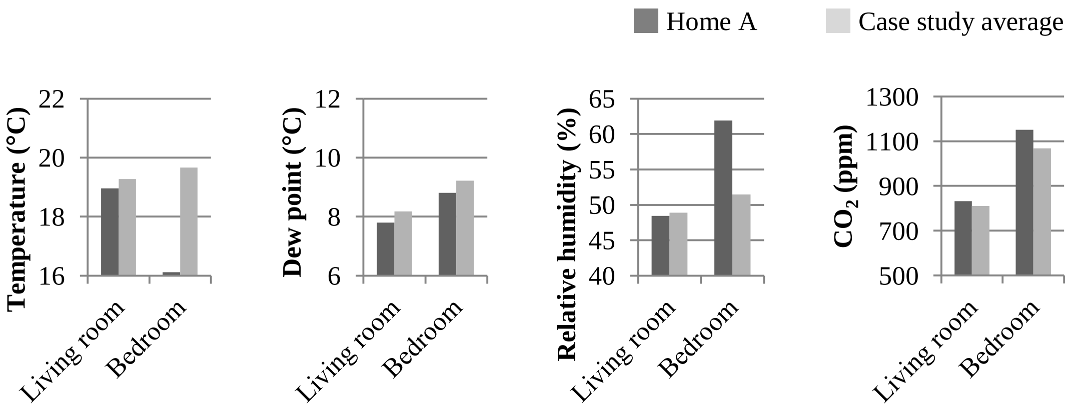

Figure 5: Average indoor environmental readings - Home A compared to the average of the 9 case studies, December 2013 - March 2014

Home B

South-facing, 3 bedroom, 1950s semi-detached house with 7 occupants

Figure 6: Front view and orientation of Home B

The participants

The main participant was a househusband of working age living with his wife and five children, and had been renting the home from the local authority for over two years when the monitoring started. He was very satisfied with the indoor environment and the overall standard of housing, reporting no problems with condensation, damp, mould, draughts or paying bills, feeling that all of these except the indoor environment had improved a lot during the previous year. He had seen a GP regarding psychological conditions and persistent flu symptoms during that year and visited a hospital twice, rating his health as 50 out of 100 and reporting moderate anxiety or depression, fair mood and fair energy levels (vitality). However, he felt that his health had improved a little over the last year and described his relationships with others as good.

Property characteristics

Construction was brick cavity wall. However, since the cavities were too narrow to insulate, EWI was installed as part of council retrofit programme the year prior to monitoring along with solar photovoltaic panels and increasing loft insulation to 200mm. Double glazing (uPVC windows and doors), draught proofing and central heating were present when they moved in. An EPC (DCLG, 2015) in May 2012 assessed the energy efficiency of the property as band D (SAP rating 62), but predicted an increase to band C or B for the EWI and other retrofits since carried out.

Table 4: Energy efficiency measures present in Home B

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✓ Solar panels	✗ A-rated boiler
✓ Wall	✓ Draught proofing	✗ Energy monitor	✓ Central heating

The participant indicated that the main fuel used for heating in the home was electricity in the form of electric room heaters. A total of 11.0kWh of grid electricity was used per day on average during the winter period, supplemented with electricity generated by the 1.75kW array of solar panels. The participant reported that living areas and bedrooms were heated sometimes in winter but not in summer. The participant also reported that sometimes bathroom extractor fans were used, windows were opened for ventilation, and clothes were hung to dry indoors.

Monitors were placed in the living room at the front of the home and in the bedroom at the front upstairs. Compared to the other case studies, Home B recorded high temperatures, average living room CO_2 and low relative humidity, dew points and bedroom CO_2. Humidity was higher on average in the bedroom than the living room.

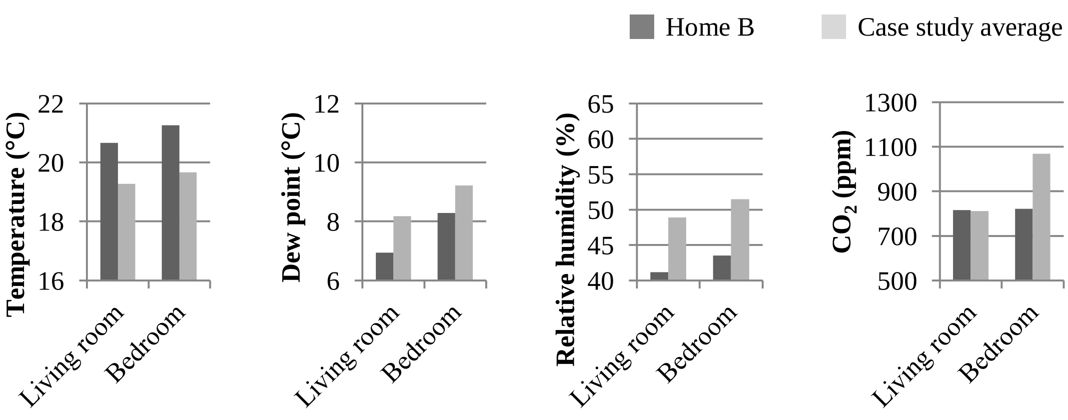

Figure 7: Average indoor environmental readings - Home B compared to the average of the 9 case studies, December 2013 - March 2014

Home C

East-facing, 3 bedroom, 1940s end-terraced house with 4 occupants

Figure 8: Front view and orientation of Home C

The participants

The main participant was a young mother working full time in accountancy and living with her partner and two children. She owned the house (with a mortgage) and had lived there for around eight years when the monitoring started. While she reported slight problems with condensation, damp and mould, she was extremely satisfied with the indoor environment and the overall standard of housing, feeling that both improved a little during the previous year. She did not suffer from any particular health conditions or use health services, rating her own health at 100 out of 100 and her mood, energy levels (vitality) and relationships as very good, all unchanged from the previous year.

Property characteristics

Construction was solid brick wall. External wall insulation was installed as part of council retrofit programme the year prior to monitoring along with 200mm loft insulation. Double glazing (uPVC windows and doors), draught proofing and central heating were present when they moved in. An Energy Performance Certificate (DCLG, 2015) from July 2012, after the council improvements had been completed, assessed the energy efficiency of the property as band C (SAP rating 73).

Table 5: Energy efficiency measures present in Home C

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✗ Solar panels	✓ A-rated boiler
✓ Wall	✓ Draught proofing	✗ Energy monitor	✓ Central heating

Both gas and electricity were used to heat the home, using respective totals of 49.1kWh and 8.0kWh per day on average during the winter period. The participant reported that living areas and bedrooms were heated occasionally in summer and almost always in winter − more often recently due to a new baby. The participant also reported that bathroom extractor fans were often used, kitchen fans were almost always used when cooking, and windows were sometimes opened for ventilation.

Monitors were placed in the living room at the back of the house and the upstairs bedroom also at the back. Compared to the other case study homes monitored, Home C recorded high temperatures, dew points and CO_2 levels, with relative humidity slightly below average. Relative humidity was higher on average in the bedroom than the living room.

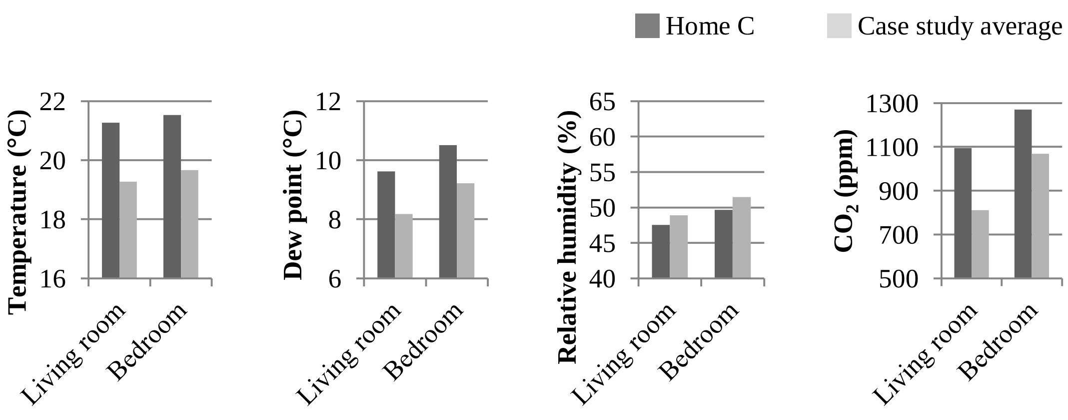

Figure 9: Average indoor environmental readings - Home C compared to the average of the 9 case studies, December 2013 - March 2014

Home D

East-facing, 3 bedroom, 1930s terraced house with 2 occupants

Figure 10: Front view and orientation of Home D

The participants

The main participant was a former part-time health worker who had lived with her husband in their home for 28 years when the monitoring started. The couple were retired and owned their home outright. She was very satisfied with the indoor environment and extremely with the overall standard of housing, feeling that both improved a little during the previous year. However, she did report slight problems with condensation and her husband reported slight problems with damp. She visited a GP and the hospital on a few occasions regarding circulatory issues and felt that her health had worsened a little during the previous year. Despite this she rated her health at 90 out of 100 and her mood and relationships as good, with fair energy levels (vitality). Her husband reported a broadly similar but unchanging health state − a score of 85, due to some joint pain − although he felt his mood and wellbeing had improved a little during the previous year.

Property characteristics

Construction was brick cavity wall. However, since the cavities were too narrow to insulate, external wall insulation was installed as part of council retrofit programme the year prior to monitoring. A new central heating system and boiler were installed at around the same time by the residents, who had also installed loft insulation and double glazing (uPVC windows and doors) over five years beforehand. No Energy Performance Certificate (DCLG, 2015) was available for this property.

Table 6: Energy efficiency measures present in Home D

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✗ Solar panels	✓ A-rated boiler
✓ Wall	✗ Draught proofing	✗ Energy monitor	✓ Central heating

The home was heated with gas central heating, using a total of 41.7kWh per day on average during the winter period. The participant reported that living areas and bedrooms were heated often (and only) in winter. The participant also reported that kitchen and bathroom extractor fans were almost always used, that windows were almost always opened for ventilation, and that clothes were often hung to dry indoors.

Monitors were placed in the living room at the back of the house and the upstairs bedroom also at the back. Compared to the other case study homes monitored, Home D recorded above average values for all the indoor measurements except bedroom relative humidity, which was slightly below average. Relative humidity was higher on average in the living room than the bedroom, while the daytime average dew point was lower in the bedroom than the living room.

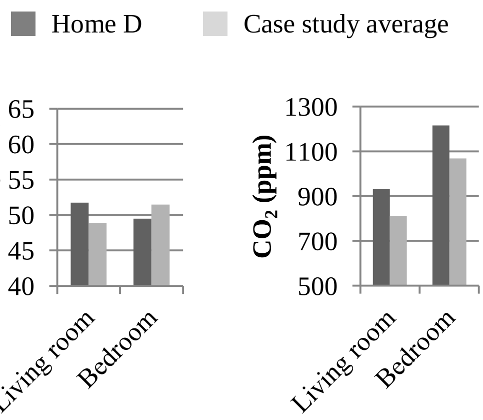

Figure 11: Average indoor environmental readings - Home D compared to the average of the 9 case studies, December 2013 - March 2014

Home E

North-facing, 4 bedroom, 1930s semi-detached house with 5 occupants

Figure 12: Front view and orientation of Home E

The participant

The participant was a single mother of working age, living with four children. She looked after the home which she had been renting from the local authority for nearly two years when the monitoring started. She was somewhat satisfied with the indoor environment and the overall standard of housing, feeling that the latter improved a little during the previous year. However, she did report slight problems with condensation, damp and mould, and sometimes had problems paying bills. She did not suffer from any particular health conditions or use health services other than a single GP visit, rating her own health at 70 out of 100 and her mood and relationships as good. The only health issues mentioned were moderate anxiety or depression and fair energy levels (vitality).

Property characteristics

Construction was solid brick wall. External wall insulation was installed as part of council retrofit programme the year prior to monitoring, along with uPVC double-glazed windows and doors, and solar photovoltaic panels. An EPC (DCLG, 2015) from

September 2012 assessed the energy efficiency of the property as band D (SAP rating 59) but predicted an updated assessment of band B for the retrofits since carried out.

Table 7: Energy efficiency measures present in Home E

Insulation	Sealing measures	New technology	Heating
✗ Loft	✓ Double glazing	✓ Solar panels	✗ A-rated boiler
✓ Wall	✗ Draught proofing	✗ Energy monitor	✓ Central heating

The participant indicated that the main fuel used for heating in the home was electricity in the form of electric room heaters. A total of 15.7kWh of electricity per day on average during the winter period, supplemented with electricity generated by the 1.75kW array of solar panels. The participant reported that living areas and bedrooms were heated sometimes in summer and almost always in winter, while kitchen and bathroom extractor fans were often used, windows often opened for ventilation and clothes sometimes hung to dry indoors.

Monitors were placed in the living room at the back of the house and the bedroom at the front upstairs. Compared to the other case study homes monitored, Home E recorded temperatures slightly below the case study average but high CO_2 levels, relative humidity and dew points. At weekends both relative humidity and CO_2 decreased in the living room and increased in the bedroom.

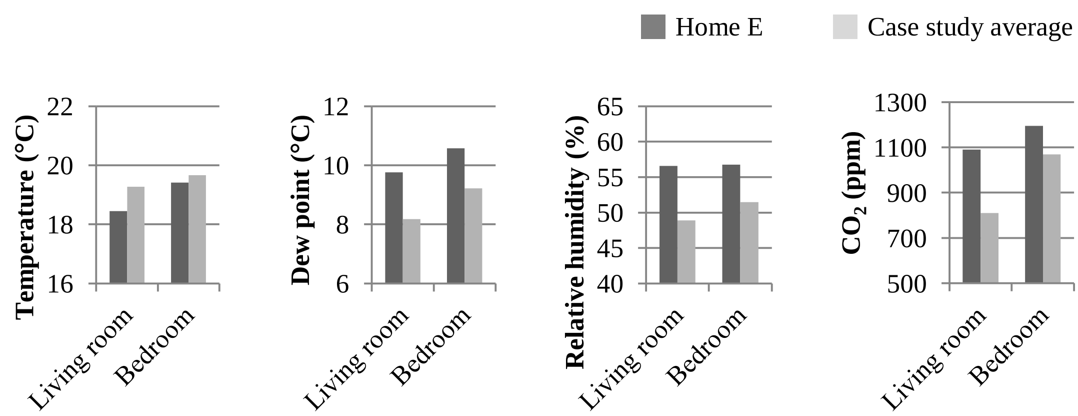

Figure 13: Average indoor environmental readings - Home E compared to the average of the 9 case studies, December 2013 - March 2014

Home F

South-facing, 3 bedroom, 1930s semi-detached house with 2 occupants

Figure 14: Front view and orientation of Home F

The participant

The participant was a young full-time postal worker living with his partner. They had been renting the home from a private landlord for less than a year when the monitoring started. No problems were reported other than slight draughts. The participant was somewhat satisfied with the indoor environment and the overall standard of housing, and very satisfied with the air freshness, all having improved a little during the previous year. He suffered from respiratory problems and allergies resulting in a few GP and hospital visits but rated his health as 77 out of 100, unchanged from the previous year. His mental wellbeing had worsened a little though and he described his mood and energy levels (vitality) as bad and his relationships as fair.

Property characteristics

Construction was solid brick wall. The landlord had provided extra loft insulation, new gas central heating and an A-rated boiler in the two years prior to the monitoring, and double glazing over five years before monitoring began. An Energy Performance Certificate (DCLG, 2015) from March 2009 assessed the energy efficiency of the property as band E (SAP rating 41) but predicted an updated assessment of band D for the retrofits carried out in the four years following the EPC.

Table 8: Energy efficiency measures present in Home F

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✗ Solar panels	✓ A-rated boiler
✗ Wall	✗ Draught proofing	✗ Energy monitor	✓ Central heating

The home was heated by gas central heating, using a total of 76.4kWh per day on average during the winter period. The participant reported that living areas and bedrooms were heated often (and only) in winter. The participant also reported that an extractor fan was almost always used when cooking and windows almost always opened for ventilation, while clothes were sometimes hung to dry indoors.

One monitor was placed against the side wall in roughly the centre of the living/dining room, which ran from the front to the back of the house. A second monitor, which measured temperature and humidity only due to availability, was placed in the bedroom at the back upstairs. Compared to the other case study homes monitored, Home F recorded high relative humidity levels but low temperatures and low living room dew points and CO_2. In the bedroom the dew point was roughly average while CO_2 monitoring was not available. Relative humidity was higher on average in the bedroom than the living room

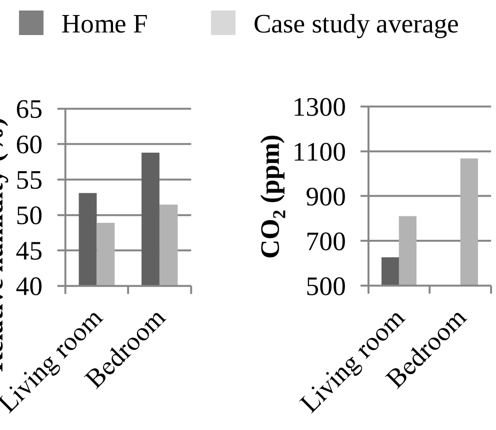

Figure 15: Average indoor environmental readings - Home F compared to the average of the 9 case studies, December 2013 - March 2014

Home G

South-facing, 3 bedroom, 1930s semi-detached house with 4 occupants

Figure 16: Front view and orientation of Home G

The participants

The main participant was a full-time lecturer living with his partner and two children in a 1930s three bedroom semi-detached house. They own the home with a mortgage and had lived there for around thirteen years when monitoring started. He was very satisfied with the indoor environment and the overall standard of housing, but only somewhat satisfied with the humidity, citing moderate problems with condensation and mould and slight draughts. He felt though that the housing, indoor environment and problems with moisture had all improved a little during the previous year. He did not suffer from any particular health conditions or use health services other than a single GP visit, rating his own health at 95 out of 100 and his mood and relationships as very good, with good energy levels (vitality). Both his health and his mental wellbeing had improved a little during the previous year.

Property characteristics

The home was brick wall construction with narrow cavities. Gas central heating was present when the participant moved in. The participant then paid to install double glazing, over five years before monitoring began, and draught proofing two to five years prior to the monitoring. More recently the council had also provided pitched roof loft insulation as the home was ineligible for funding for either standard loft insulation or external wall insulation. No Energy Performance Certificate (DCLG, 2015) was available for this property.

Table 9: Energy efficiency measures present in Home G

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✗ Solar panels	✗ A-rated boiler
✗ Wall	✓ Draught proofing	✗ Energy monitor	✓ Central heating

The participant primarily used gas to heat the home, using a total of 78.1kWh per day on average during the winter period. The participant reported that living areas and bedrooms were heated occasionally in summer and often in winter, while an extractor fan was almost always used when cooking, windows often opened for ventilation and clothes often hung to dry indoors.

Monitors were placed in the living room at the front of the house and the bedroom at the back upstairs. Compared to the other case study homes monitored, Home G recorded high relative humidity levels, dew points and bedroom CO_2 with average bedroom temperatures and low living room temperatures and CO_2. Relative humidity was higher on average in the living room than the bedroom during the day but higher in the bedroom at night.

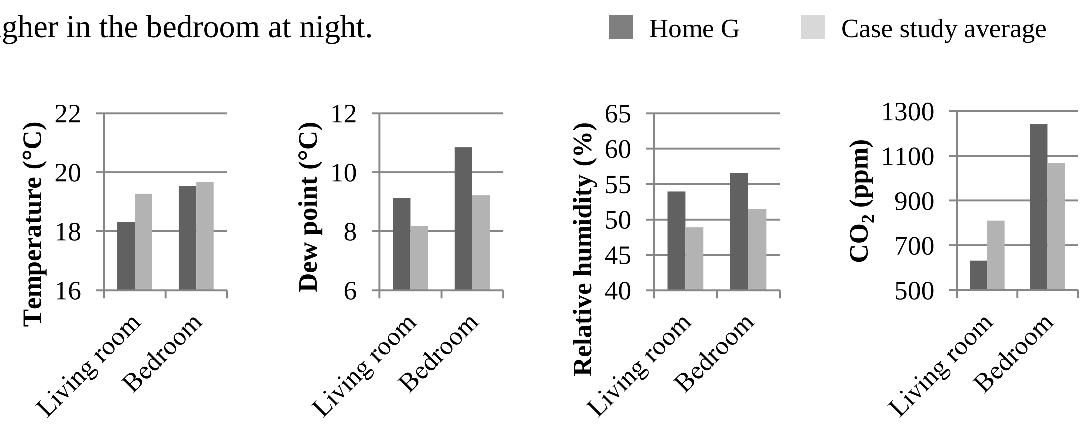

Figure 17: Average indoor environmental readings - Home G compared to the average of the 9 case studies, December 2013 - March 2014

Home H

East-facing, 3 bedroom, 1920s semi-detached house with 1 occupant

Figure 18: Front view and orientation of Home H

The participant

The participant was a retired lady living alone. She owned the home and had lived there for over 20 years. She was very satisfied with the indoor environment and the overall standard of housing, reporting no problems with condensation, damp, mould, or draughts and only occasional problems paying bills, none of which had changed during the previous year. She saw a GP regarding circulatory issues and also suffered from allergies, respiratory problems and joint pain which caused some problems walking and performing activities, and moderate discomfort. She reported low energy levels (vitality) and rated her own health as 50 out of 100, unchanged from the previous year, although she felt her mood had improved a little, rating it as good and her relationships as very good.

Property characteristics

The home was brick wall construction with open cavities. Loft insulation (150mm) was provided by the council and the participant paid to install double glazing and gas central heating, all over five years prior to the monitoring. A thin layer of external render had been applied to the brickwork some years previously and was not mentioned by the participant. An Energy Performance Certificate (DCLG, 2015) from October 2013, two months before monitoring commenced, assessed the energy efficiency of the property as band D (SAP rating 55, the lower limit of band D).

Table 10: Energy efficiency measures present in Home H

Insulation	Sealing measures	New technology	Heating
✓ Loft	✓ Double glazing	✗ Solar panels	✗ A-rated boiler
✗ Wall	✗ Draught proofing	✗ Energy monitor	✓ Central heating

The home was heated by gas central heating, using a total of 103.2kWh per day on average during the winter period. The participant reported that living areas and bedrooms were heated almost always in winter (and seldom in summer), while an extractor fan was often used in the kitchen and occasionally in the bathroom. Windows were opened sometimes for ventilation.

Monitors were placed in the living room at the front of the house and the bedroom at the front upstairs. Compared to the other case study homes monitored, Home H recorded high temperatures but particularly low CO_2 levels, relative humidity and dew points. Relative humidity was higher on average in the bedroom than the living room.

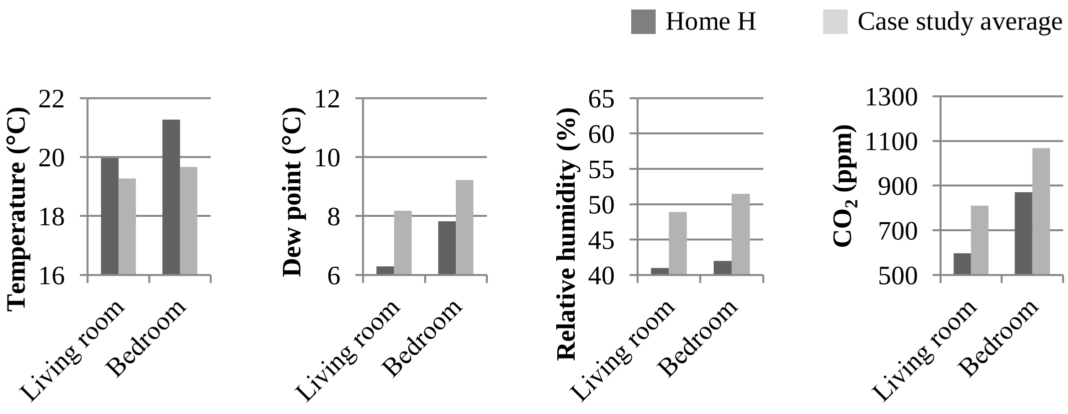

Figure 19: Average indoor environmental readings - Home H compared to the average of the 9 case studies, December 2013 - March 2014

Home I

East-facing, 3 bedroom, 1930s semi-detached house with 3 occupants

Figure 20: Front view and orientation of Home I

The participant

The participant was a single mother living with two young children and in full-time higher education. She had been renting the house from a private landlord for around three years when the monitoring started. She was only slightly satisfied with the indoor environment and the overall standard of housing, feeling that both had worsened a little during the previous year along with problems paying bills and that problems with damp and mould had worsened a lot. She had seen a GP for psychological or emotional conditions and suffered from joint pain, allergies and flu symptoms, reporting moderate pain and anxiety. She rated her mood as fair and her energy levels (vitality) and relationships as bad. Despite this she rated her own health at 70 out of 100 and felt that her health and mental wellbeing had improved a little.

Property characteristics

Construction was solid brick wall. Central heating was present when the participant moved in and a grant had been obtained to install 300mm loft insulation within the two years prior to the monitoring. A thin layer of external render had been applied to the brickwork some years previously, not mentioned by the participant, and the property was single glazed throughout. An Energy Performance Certificate (DCLG, 2015) from November 2013, shortly before monitoring commenced, assessed the energy efficiency of the property as band D (SAP rating 60).

Table 11: Energy efficiency measures present in Home I

Insulation	Sealing measures	New technology	Heating
✓ Loft	✗ Double glazing	✗ Solar panels	✗ A-rated boiler
✗ Wall	✗ Draught proofing	✗ Energy monitor	✓ Central heating

Energy usage data was not available for this property. The participant reported that living areas and bedrooms were heated occasionally in summer and almost always in winter, using the gas central heating. The participant also reported that clothes were sometimes hung to dry indoors and windows almost always opened for ventilation, more often in recent months due to problems with steam and condensation.

Monitors were placed in the living room at the back of the house and the upstairs bedroom also at the back. Compared to the other case study homes monitored, Home I recorded average temperatures but low CO_2 levels, relative humidity and dew points. Relative humidity was higher on average in the living room than the bedroom, while the daytime average dew point was lower in the bedroom than the living room.

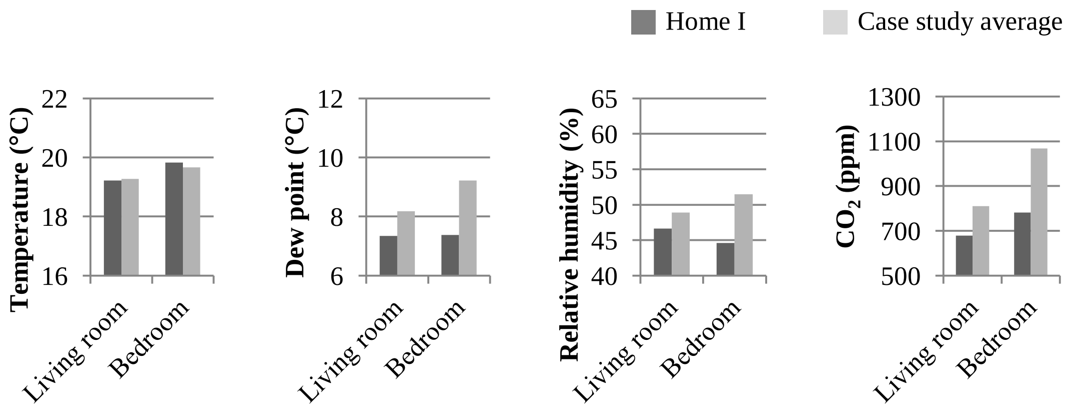

Figure 21: Average indoor environmental readings - Home I compared to the average of the 9 case studies, December 2013 - March 2014

Table 12: Average indoor environmental readings for the case study homes across the December − March monitoring period

Case study	Temperature,[a] T (°C)		Relative humidity,[b] RH (%)		Carbon dioxide,[c] CO_2 (ppm)		Dew point, DP (°C)		Temp − dew point, T-DP (°C)		Proportion of time T-DP < 10°C (%)	
	Living	Bed	Living	Bed	Living	Bed	Living	Bed	Living	Bed	Living	Bed
A	19.0	16.1	48.4	61.9	832	1151	7.8	8.8	11.2	7.3	15	100
B	20.7	21.3	41.2	43.5	815	822	6.9	8.3	13.7	13.0	0	2
C	21.3	21.5	47.5	49.6	1095	1270	9.6	10.5	11.7	11.0	13	27
D	20.2	20.7	51.8	49.5	931	1215	10.0	9.6	10.3	11.0	39	29
E	18.5	19.4	56.6	56.8	1090	1195	9.8	10.6	8.7	8.8	86	84
F	16.4	17.4	53.1	58.8	626	−	6.8	9.1	9.6	8.3	65	95
G	18.3	19.5	54.0	56.6	632	1240	9.1	10.9	9.2	8.7	77	91
H	20.0	21.3	41.0	42.0	597	871	6.3	7.8	13.7	13.4	0	0
I	19.2	19.8	46.6	44.6	680	782	7.3	7.4	11.9	12.4	22	3
Average	19.3	19.7	48.9	51.5	811	1068	8.2	9.2	11.1	10.4	35	48

Recommended conditions:

[a] A minimum temperature of 18°C in living areas, unless under 65, healthy, and active (NHS, 2015)

[b] Relative humidity of 40-70% for thermal comfort (HSE, 2015). Above this may result in mould growth, below might cause health effects.

[c] CO_2 below 2,500ppm to avoid adverse health effects, though the risk Sick Building Syndrome symptoms may increase at lower concentrations (Seppanen, Fisk, & Mendell, 1999)

[d] Dew point is the temperature below which condensation forms, so the smaller the difference between temperature and dew point (T-DP) and the more time that the temperature and dew point are close together (T-DP < 10°C), the greater the risk of moisture-related problems.

Table 12 above summarises the environmental conditions in each of the case study homes in terms of the average temperature, relative humidity and carbon dioxide levels recorded in the living rooms and bedrooms during the winter monitoring period. Two further sets of figures are provided as an indication of the risk of damp problems in each home. The temperature minus dew point (T-DP) indicates how much the temperature would have to drop for moisture to condense from the air so the smaller the figure, the closer the home is to potentially damp-forming conditions. The T-DP < 10°C figure gives the proportion of time that the temperature was within 10°C of the dew point during the monitoring, giving an indication of the extent or regularity that such damp-forming conditions may have been present.

Analysis

To compare the characteristics and monitoring outcomes of the nine case studies a simple means of viewing the large amounts of data collected was needed. A process suggested by Eisenhardt (1989) was used, assigning case studies to one of two categories for each variable, for instance; Yes or No, Higher or Lower, Better or Worse. Particular relationships could therefore be investigated further by identifying any similarities within selected groups, such as those with a particular energy efficiency measure, and any differences between two groups, such as those with the measure and those without. A summary of the key variables of interest is shown in Table 13.

The variables were split into categories at the median where possible for simplicity and consistency, and to avoid any bias as theoretical arguments could be made for different categorisations for many of the variables. For instance, fuel poverty impacting most severely on the ill and vulnerable (Liddell & Morris, 2010) could justify

Table 13: Summary of the key differentiators between case studies

Case study	**Household**	Energy efficiency measures [a]	Wall insulation [b]	'A-rated' boiler	Temperature (°C) [c]	Dew point (°C) [d]	**Participant**	Age group [e]	Daytime occupancy [b]	Mood and happiness [g]	Health [h]	**Perceptions**	Household problems [i]	Satisfaction with the home [j]	Financial worries [k]
A		More	Yes	Yes	Lower	Lower		45−54	At Home	Worse	Worse		More	Lower	More
B		More	Yes	No	Higher	Lower		55−64	At Home	Worse	Worse		Fewer	Higher	More
C		More	Yes	Yes	Higher	Higher		25−34	At Work	Better	Better		Fewer	Higher	Fewer
D		More	Yes	Yes	Higher	Higher		65−74	At Home	Better	Better		Fewer	Higher	Fewer
E		Fewer	Yes	No	Lower	Higher		35−44	At Home	Better	Worse		More	Lower	More
F		Fewer	No	Yes	Lower	Lower		18−24	At Work	Worse	Better		More	Lower	More
G		Fewer	No	No	Lower	Higher		45−54	At Work	Better	Better		More	Higher	Fewer
H		Fewer	No	No	Higher	Lower		65−74	At Home	Better	Worse		Fewer	Higher	Fewer
I		Fewer	No	No	Lower	Lower		25−34	At Work	Worse	Worse		More	Lower	More

[a] More = 5 or more of the 8 types of energy efficiency measure surveyed are present.
[b] Households without external wall insulation had no other form of wall insulation.
[c] Higher = above median temperatures = 19.2°C for living room and 19.8°C for bedroom on average.
[d] Higher = above median dew points = 7.8°C for living room and 9.1°C for bedroom on average.
[e] Median age group = 45 to 54.
[f] At Home = Residents are retired, permanently sick / disabled or looking after the home. At Work = Residents are in full time work or education.
[g] Better = mood reported as Good or very good, Worse = Fair or Bad.
[h] Better / Worse health = EQ-5D Utility score of 1 / below 1 respectively. (Also = EQ-VAS self-ratings of health above / below 75 out of 100).
[i] Household problems recorded in the diary survey = Condensation, damp, mould and draughts. More / Fewer = More / less than half of the four problems reported are above the median.
[j] Satisfaction with housing, temperature, humidity and air freshness recorded in dairy survey. Higher / Lower = All four aspects are above / below the median.
[k] More / Fewer = Indicated that they had worried recently about finances in at least 50% / at most 10% of the diary surveys.

comparing people in very poor health to those in average or better health whereas the relatively small health improvements expected (Thomson et al., 2013) could justify comparing those in very good health to those in average or worse health. The median approach also provided more comparable group sizes therefore limiting the influence of a single unusual household. As nine households were being compared, the median household for each variable was assigned to either the upper or lower group according to which it was nearest to in value so that the categories reflected how the data was distributed as closely as possible. The exceptions to this median split were where the data fell into two natural but uneven categories, such as the presence of a particular energy efficiency measure (only one household did not have double glazing) or the frequency of certain behaviours (three households never cooked on a gas hob while the remaining six all usually did).

As this was a retrospective study on a small sample of households the goal was not to produce statistically significant evidence of causes and effects but to develop a better understanding of the potential routes between household energy efficiency and health. Key variables were selected to test theoretical associations based on the findings of previous research but also in light of practical considerations, preferring variables that split the case study households into distinct groups of comparable size. Once grouped by the selected key variable, the full list of variables was checked for any notable trends in order to investigate the broader context in which effects might be occurring. For instance, participants reported how often they undertook a range of actions or behaviours such as heating or opening windows in different rooms and at different times. While patterns in some individual variables would be expected to result by chance, recurring patterns in related behaviours (for instance heating different rooms at different times) provided insight into how the homes were being used and how this could be influencing the impacts of the energy efficiency measures.

The physical impacts of energy efficiency measures on the home environment

This study aimed to shed light on the potential routes between energy efficiency and health by investigating the range of impacts arising from energy efficiency measures. Before looking at the effects on the residents themselves, the home environments of residents were analysed using results from the case study monitoring. These records of temperature, humidity and carbon dioxide levels could then be compared to residents' perceptions of their environments.

The key measure of used to represent the energy efficiency of the case study homes was the overall number of energy efficiency measure types present in each home from the following list: loft insulation, wall insulation (cavity, external and internal), solar photovoltaic panels, double glazing, draught proofing, home energy monitors, efficient 'A-rated' boilers, and central heating. It was recognised though that this simple count method did not take into account the varying impacts of different energy efficiency measures − the likelihood that a central heating system, for instance, is likely to affect the thermal performance more than a home energy monitor. A number of more sophisticated measures were therefore considered but ultimately dismissed:

- Theoretical and practical reasons prevented the use of SAP ratings from the Energy Performance Certificates, EPCs, (DCLG, 2015) for each home. As the aim of the study was to investigate various associations that could form potential routes between energy efficiency and health, the first measure had to relate to the first step of the route − i.e., the installation or presence of an intervention −

and not assume an automatic improvement in energy efficiency[3]. Additionally, EPCs were either not available or out of date for some of the properties. Estimating values for the missing data would have required levels of expertise and, more importantly, access to the properties that were not within the scope of this project.

- Similarly, weighting the energy efficiency measure results according to their expected impacts would have relied on assumed increases to SAP ratings, the values of which depend on the building characteristics, not just the energy efficiency measure in isolation. This approach would also have been based on the assumption that the key impact of energy efficiency measures is physical (on either the home environment or finances), potentially marginalising any effects on residents' perceptions or behaviour.
- An alternative approach considered was to class energy efficiency measures according to their prevalence across the survey population, for instance classifying central heating as 'essential' because it was present in almost all the respondent's homes, while home energy monitors were very rare and therefore classified a 'luxury'. Homes would then be categorised by whether or not they had the most 'essential' measures in place. However, it was decided that too many factors unrelated to importance (e.g., cost) could affect their prevalence for this to be a valid measure of household energy efficiency.

Given these barriers, the simple count (out of 8) of energy efficiency measure types present was used to denote energy efficiency. In order to recognise the differences between energy efficiency measures and their impacts, further analysis was carried out

[3] The SAP rating is a detailed but theoretical assessment of energy performance given the building characteristics and components, not an empirical measure of energy efficiency.

looking separately at improvements to the 'shell' of the home (e.g., insulation and sealing measures) and the 'core' (e.g., heating). Measures such as central heating, loft insulation and double glazing might be expected to yield significant results, either for individual homes by providing a significant boost in energy performance or collectively by providing small but cost-effective improvements that lead to cumulative savings (in CO_2 for instance) when installed in a large number of homes. Their prevalence though among the case study participants and in the wider survey population made assessment on their impacts difficult. Consequently, for the purposes of the case study research, external wall insulation (EWI) and efficient boilers were chosen to represent energy efficiency measures improvements to the shell and the core of the home respectively. The differences between the indoor environments of homes with and without efficient boilers, however, were similar (though less pronounced) than those of the homes with more or fewer energy efficiency measures overall, so are not discussed separately here. As the presence of EWI closely coincided with a higher number of energy efficiency measure types in total, the two were combined and analysed together as described below.

Four of the case study homes had more than half of the eight energy efficiency measure types listed, all of which had been fitted with EWI as part of the council retrofit programme (see Table 13). Energy performance data was available for three of these homes, each of which was estimated as band C or above where the national average is band D (DCLG, 2015). These four homes were therefore labelled as the More Measures group, the number of measures acting a proxy for the energy efficiency of the building for the purposes of the analysis.

Of the homes with fewer than half of the listed energy efficiency measures, only Home E had received EWI from the council[4]. This distinguished home E from the remaining four homes (F-I) as the EWI has a clear effect on its energy efficiency: the EPC assessment of Home E prior to the retrofit programme estimated and increase in 14 SAP points from the installation of EWI alone. The effect of EWI was also demonstrated by thermal images taken of the homes shown in Figure 22. Homes A-E (with EWI) all appear yellow/orange in colour indicating a surface temperature around 0-3°C, compared to the hotter red colour of Homes F-I (without EWI) which indicates surface temperatures around 4-7°C. This shows that the homes with EWI suffer from less overall heat loss through the walls despite the indoor temperatures tending to be similar[5] and is supported by the energy performance data. SAP ratings could be estimated for three of the four homes, placing each in band D. The four homes with no EWI and at most half of the listed energy efficiency measures (Homes F-I) were therefore labelled as the Fewer Measures group for the analysis.

[4] Homes F and G had both had a thin layer of render applied to the external brick surfaces for aesthetic reasons some years before.

[5] At the time each photograph was taken living rooms were roughly 1°C warmer and bedrooms 1°C colder on average in EWI homes than in non-EWI homes.

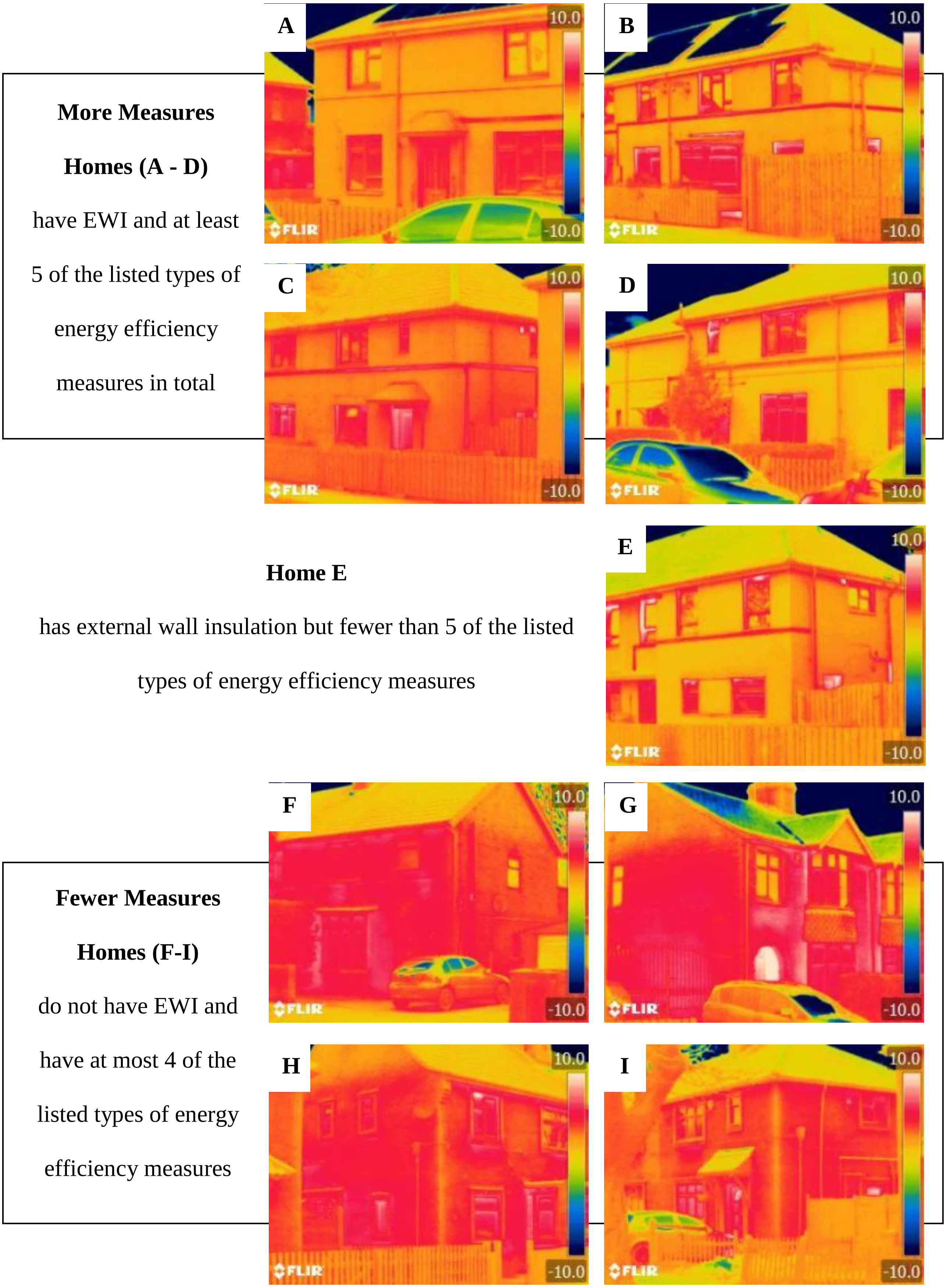

Figure 22: Thermal images of the case study households, taken between 9pm and 10pm on 21st February 2014, where red and yellow colourings respectively indicate surface temperatures of around +5°C and 0°C

The key purpose of energy efficiency for residents − making a warm home environment more affordable − was evident in the case studies. Three of the homes with More Measures, compared to just one of those with Fewer Measures, were kept at higher temperatures with a difference of 1.8°C in average living room temperature between the two groups (see Figure 23). This is despite the More Measures group tendency to use heating less: only one of the four reported near-constant heating of living areas during winter compared to two of the Fewer Measures group. These reports were supported by the gas usage data. Of the homes where usage data was available, the Fewer Measures homes each used more gas energy than the More Measures homes.

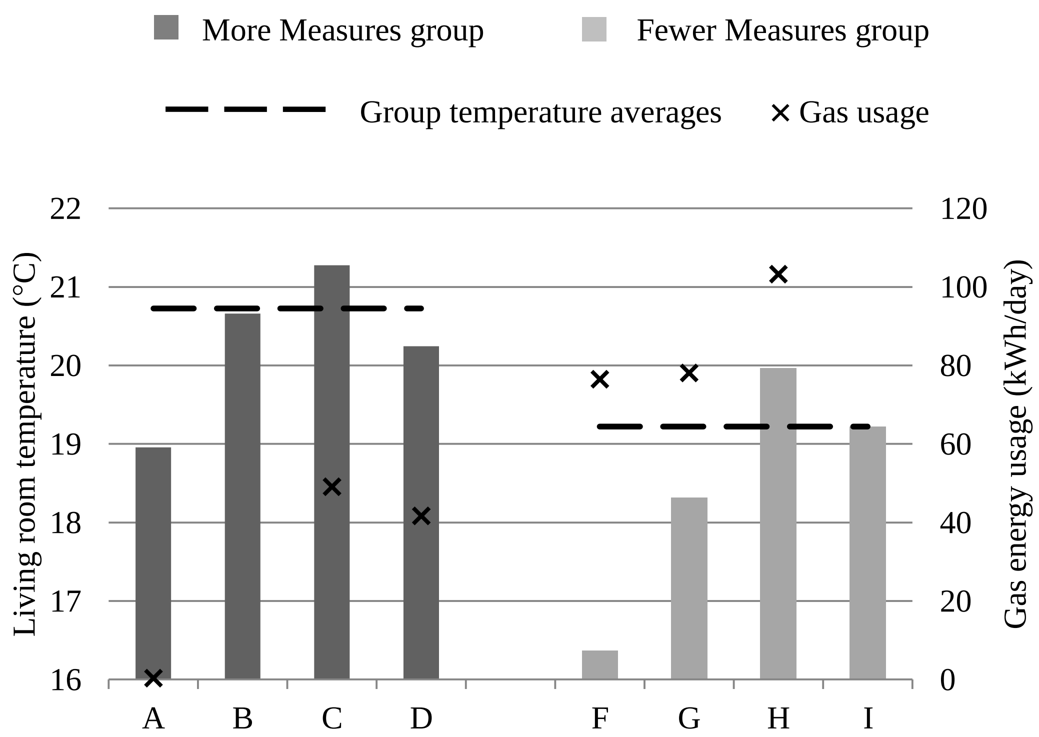

Figure 23: Average living room temperatures for the winter measurement period: the More Measures homes (A-D) averaged 20.3°C and the Fewer Measures homes (F-I) averaged 18.5°C. Crosses denote the average daily gas energy usage for the period where available [6]

[6] Electricity usage is not included as gas central heating was present in each home. While electric heating sources were used in some instances, their usage could not be distinguished from lighting and appliances. Some homes were also supplemented by unknown quantities of electricity from solar panels.

If improved thermal efficiency has led not just to warmer home environments but also to reduced energy use as the above responses suggest, the resulting benefits will not be limited to improved comfort and health for residents. To quantify any financial and environmental benefits generated the heat losses through the walls of case study homes with and without EWI was estimated using the equation:

$$Q_{heat\ loss} = UA\Delta T$$

Where U is the heat transfer coefficient of the walls in W/m^{2}K, A is the wall surface area in m^2 and ΔT is the average difference between the indoor and outdoor temperatures in K (= °C). As the council programme retrofitted EWI to houses with solid brick walls and those with 'thumbnail' cavities too small for cavity wall insulation, data provided by CIBSE (Chapman, 2012) and the EWI manufacturer was used to estimate U values for both construction types as follows:

- Without EWI: $U_{solid\ brick\ wall}$ = 2.11 W/m^{2}K, $U_{open\ cavity\ wall}$ = 1.37 W/m^{2}K.
- With EWI: $U_{solid\ brick\ wall}$ = 0.29 W/m^{2}K, $U_{open\ cavity\ wall}$ = 0.27 W/m^{2}K.

A value of 84m^2 was used for the surface area of the external walls excluding doors and windows. This was estimated from the case study homes which were mainly semi-detached and similar in size though not identical. Temperature differences (ΔT) were initially calculated over the winter monitoring period from the combined averages of the living room and bedroom monitor data and the from the outdoor monitoring data. As the average indoor temperatures were found to be relatively consistent[7] regardless of the outdoor temperature, these averages were also used in conjunction with current and projected weather data to estimate annual losses. The nearest available locations were

[7] Standard deviations of 1.0°C for the More Measures group and 1.1°C for the Fewer Measures group during the winter monitoring period. Also, two homes (one with EWI and one without) continued monitoring until August 2014 and the average indoor temperature for the whole period was less than 1°C higher than the winter average for each home.

used; annual design weather data at Leeds (CIBSE, 2015) and estimated future temperatures based on climate change projections for Hull in 2080 (Eames, Kershaw, & Coley, 2011). The results are shown in Table 14.

Table 14: Estimated energy, carbon and cost savings from installing EWI on a typical case study home, based on current measured and projected future outdoor temperature data [a]

Wall construction	Average indoor temp after EWI installed	Energy saving (kWh)	CO_2e [b] (kg)	Cost saving
Savings over the 15 week winter monitoring period [c] based on measured temperatures				
Solid brick	If kept the same at 19.4°C [d]	5059	924	£249
Open cavity		3059	559	£151
Solid brick	If increased to 20.3°C [e]	5005	914	£246
Open cavity		3009	549	£148
Yearly savings based on current expected temperatures [f]				
Solid brick	If kept the same at 19.4°C [d]	15724	2871	£774
Open cavity		9509	1736	£468
Solid brick	If increased to 20.3°C [e]	15533	2836	£764
Open cavity		9330	1704	£459
Yearly savings based on temperatures projected for 2080 [g]				
Solid brick	If kept the same at 19.4°C [d]	2105	384	*£104* [h]
Open cavity		1273	232	*£63* [h]
Solid brick	If increased to 20.3°C [e]	2051	375	*£101* [h]
Open cavity		1223	223	*£60* [h]

Notes: [a] Based on data from www.gov.uk, accessed 9/7/2015, and U Values from CIBSE (Chapman, 2012).
[b] Carbon dioxide equivalent = carbon dioxide plus a supplement representing other greenhouse gases emitted.
[c] 18th December 2013 to 31st March 2014
[d] Following installation the average indoor temperature is assumed to remain at 19.4 ℃, the mean living/bedroom temperature for the case study homes without EWI (F-I) during the winter monitoring period.
[e] Following installation the average indoor temperature is assumed to increase to 20.3 ℃, the mean living/bedroom temperature for the case study homes with EWI (A-D) during the winter monitoring period.
[f] Based on design year data for Leeds, 2002 - 11 (CIBSE, 2015). Average outdoor T winter = 0.4 ℃, annual = 7.6 ℃.
[g] Based on Prometheus data for Hull 2080 (Eames, Kershaw, & Coley, 2011), using 50% (most likely) projections and assuming high levels of emissions. Average outdoor T winter = 8.0 ℃, annual = 13.8 ℃.
[h] Based on current UK average gas prices, not projected prices for 2080.

During the winter that monitoring took place, the solid wall Fewer Measures homes lost an estimated 5,800 kWh each on average through their walls alone while those with open cavities (uninsulated other than by the air in the cavity) lost 3,800 kWh each. This is in stark contrast to the More Measures homes that each lost an estimated 850 kWh through externally insulated solid walls (or 800 kWh through cavity walls) on average. The difference in heat loss equates to savings of £150 to £250 using current UK gas prices (DECC, 2015) and 550 to 900kg of carbon dioxide emissions avoided per house, even if the temperature of the Fewer Measures homes was increased after installation of the EWI to match the average temperature of the More Measures homes. Those choosing to forgo warmth improvements would see little financial benefit as maintaining the same temperature would save around £3 from reduced heat losses through the walls for the whole winter period[8].

While it might be expected that the above figures would constitute the bulk of available annual savings given that monitoring was carried out over the coldest part of the year, the winter in question was particularly mild averaging 6.0°C over the monitoring period. Design temperatures based on data collected in Leeds from 2001 to 2011 (CIBSE, 2015) suggest an expected average of 0.4°C for the same period, which would result in savings of up to £350. Using the annual CIBSE design figures and the same average indoor temperatures, over the course of a year the energy saved by EWI would be over 9,300 kWh in homes with cavity walls and 15,500 kWh for solid walls. The latter figure would mean annual savings of over £750 − more than the total annual gas bill for the average household at the time[9]. This would also save

[8] Maintaining lower indoor temperatures would also reduce heat losses through door, windows and the roof, leading to further financial savings. If double glazing and loft insulation perform in a similar manner to the EWI however, the savings lost by increasing the temperature would be a fraction of the savings generated by installing these measures.
[9] Estimated as £729 by DECC (2015), assuming annual consumption of 15,000 kWh.

2,800kg of CO_2, nearly as much as is emitted by running two cars in the UK over the same period[10]. Even allowing for more substantial warmth improvements the financial and environmental benefits are significant. After increasing the temperature from the lowest monitored (Home F averaged 17.1°C in the living room) to the More Measures home average (20.3°C), installing EWI would still save a solid wall home £590 and 2,200kg of CO_2 or a cavity wall home nearly £350 and 1,300kg of CO_2 per year.

Over the coming decades climate change is expected to increased outdoor temperatures thereby reducing any heat losses. However, even projected high emission rates result in major changes. For instance, if winter temperatures averaged 13.8°C in 2080 as estimated by the Prometheus project (Eames, Kershaw, & Coley, 2011), installing EWI would reduce annual energy demand of the average case study home by 1,200 to 2,000 kWh. While this is a fraction (less than a seventh) of what might be saved currently, statutory climate change targets mean that only a fraction of current emissions will be allowed − 20% by 2050 (DECC, 2013). Also, the £60 to £100 savings given in Table 14 are unrealistic as they assume that gas prices will remain constant for the next 60 years when the average UK gas bill has more than doubled in just the past decade, taking inflation into account (ref gov). Gas prices doubling every 15 years would be enough to completely outweigh any savings from the projected hotter climate.

Ventilation and moisture-related problems

Concerns that sealing homes to improve thermal efficiency might result in damp home environments with consequent health impacts (Milner et al., 2015) were not substantiated for these case study participants. The homes with More Measures all

[10] Based on latest UK government figures the average emission rate for newly registered cars is 123.1g/km (DfT, 2015a) and the average mileage is 7500m (DfT, 2015b), which gives the total CO_2 emissions as 1486kg per car per year.

recorded higher levels of CO_2 in the living room, all averaging between 800-1100ppm compared to 680ppm at most in the Fewer Measures homes. This, along with the comparative lack of draughts reported in More Measures homes (see Figure 24), suggests lower rates of ventilation and infiltration. Reduced infiltration may have been caused by the wall insulation or simultaneous draught proofing improvements (Home E has EWI and the second highest level of living room CO_2), while behaviour was found to reduce ventilation as only one of the households with More Measures, compared to three of those with Fewer, stated that they often or almost always opened windows in the home. The other potential cause of higher CO_2 − greater occupancy − was only partially supported by the diary survey results as although the More Measures homes housed more occupants on average (3.8) than the Fewer Measures homes (2.5), participants in the More Measures group did not spend any more time in the home on average. However, despite the reduced ventilation in all four homes with More Measures, none recorded CO_2 levels that would be considered to indicate poor air quality or expected to impair health (Seppanen, Fisk, & Mendell, 1999) while three reported fewer household problems and greater satisfaction.

As three of the More Measures homes also recorded lower relative humidity levels, the group approached moisture-forming conditions less frequently, living room temperature dropping to within 10°C of the dew point 17% of the time in More Measures homes compared to 41% in Fewer Measures homes. None of this points to increased moisture or risk of damp-related illness due to energy efficiency measures in these case study homes. Compared to the case study average, Home E has high humidity levels (though below the levels needed for mould growth) and frequent moisture conditions. However, including these figures makes the risk of damp in the

EWI group more similar to the Non-EWI group, not significantly worse, while making the risk of damp even higher for the Fewer Measures group.

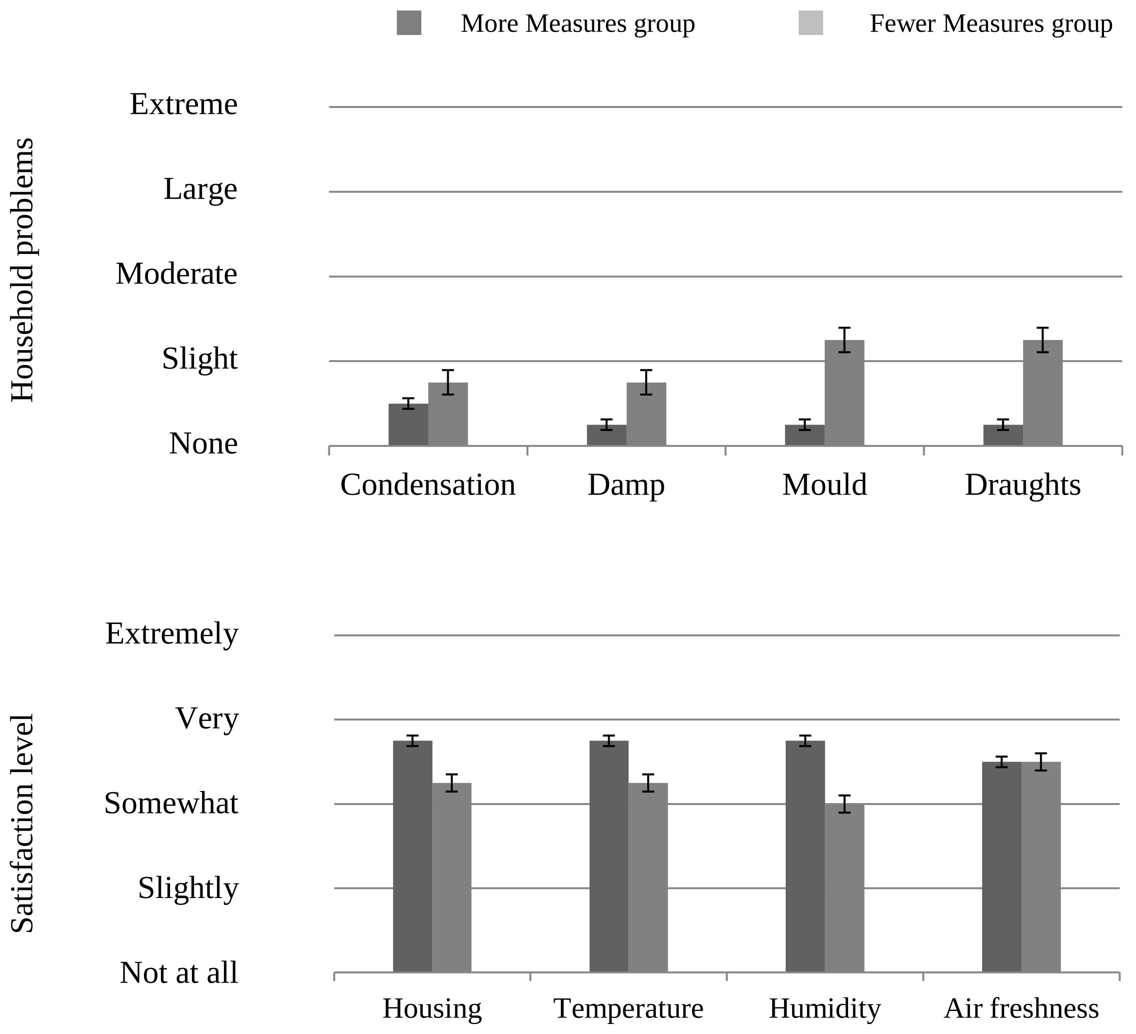

Figure 24: Average levels of household problems and satisfaction with the home environment reported by the case study participants

Although the CO_2 levels measured were moderate at worst and below the level needed to have any direct negative impact on health, other harmful effects from failing to counter reduced infiltration have not been entirely ruled out. While even the highest average CO_2 levels recorded would not be expected to affect participants beyond some increased drowsiness (Seppanen et al., 1999), this may be due to unavoidable infiltration in these older homes that is less likely to exist in newly built properties. As homes become more airtight there is a greater likelihood that their residents could suffer from the build up of concentrations of harmful pollutants from indoor sources such as cleaning products (Carslaw & Wolkoff, 2006).

Other concerns regarding overheating caused by insulation and sealing effects (Bone, 2010) were not the primary focus of this study. Four participants though agreed to leave monitoring in place into the summer. The two of these homes with More Measures saw greater temperature increases between the winter monitoring period and June/July, increasing by an extra 0.8°C in the living rooms and 2.4°C in the bedrooms on average compared to the two Fewer Measures homes. However, the highest indoor temperature recorded in any of the homes during the summer period was still below 27°C. These limited findings suggest little current concern regarding health, though the extra increase in bedroom temperatures could cause comfort to suffer during hot summers and present a growing health problem should climate change as predicted over the coming decades (Eames, Kershaw, & Coley, 2011).

Impacts of the indoor environment on residents

Having determined that energy efficiency measures are likely to affect the home environment and may affect residents to some extent, the next step was to compare the case study homes to determine how physical changes to the indoor environment might affect a resident's perceptions and behaviours.

Temperature and dew point (DP, the temperature below which condensation starts to occur) were used to assess the indoor environment because energy efficiency measures are expected to combat cold- and damp-related illness (Thomson et al., 2013). The results were consistent between rooms, i.e. the four homes with the warmest living rooms also had the warmest bedrooms so were labelled the Warmer group, with five homes in the Colder group. The same was true for dew point. Although the Warmer and Higher DP groups did not match, the four homes in the

Higher DP group had the highest average dew points in both the living room and bedroom. Reduced infiltration can have conflicting effects on the damp formation through increased temperatures but also increased humidity levels. Therefore, to provide further indication of which homes were therefore more likely to be at risk of damp, the average difference between the temperature and dew point was subsequently analysed.

Temperature and dew point both appeared to affect residents' perceptions. Three of the four Warmer homes and three of the four Higher DP homes, two of which were in both groups, reported greater satisfaction with the home environment, compared to just one of the five homes in the Colder and Lower DP groups. Three homes in each of the Warmer and Higher DP groups also reported fewer financial problems. Household problems such as damp and draughts were found to be linked to temperature but not dew point. The four Warmer homes reported the fewest household problems while the five Colder homes reported the most problems.

Table 15: Comparison of household perceptions in case study homes, grouped by temperature and dew point (where ✓ = More satisfied / fewer problems and ✗ = Less satisfied / more problems)

	Higher DP				Lower DP			
	Home	Household problems	Satisfaction with the home	Financial worries	Home	Household problems	Satisfaction with the home	Financial worries
Warmer	C	✓	✓	✓	B	✓	✗	✗
	D	✓	✓	✓	H	✓	✓	✓
Colder	E	✗	✗	✗	A	✗	✗	✗
	G	✗	✓	✓	F	✗	✗	✗
					I	✗	✗	✗

Comparing homes by both temperature and dew point together though demonstrated a clear distinction in the nine case studies. As shown in Table 15, both homes that were in the Warmer *and* Higher DP groups unanimously reported greater satisfaction with the home and fewer household or financial problems than the three homes that were in both the Colder *and* Lower DP groups.

The fewer household problems and greater satisfaction reported by participants in Warmer homes (Figure 25) show that residents' perceptions are more clearly affected by indoor temperatures than by the presence of more energy efficiency measures (the relationship shown earlier in Figure 24). Given that temperature is directly experienced by residents, this greater effect on perceptions is not unexpected and supports the relationship between actual and perceived environments set out in the earlier model (see Figure 3). The first steps of a potential route to health improvement therefore starts to emerge as energy efficiency measures are linked with higher temperatures (Figure 23), and higher temperatures with more positive perceptions of the home environment.

Links between the indoor environment and the behaviour of residents tended to be self-explanatory; two of the Colder homes reported wearing outdoor clothes such as hats or gloves indoors to keep warm compared to none of the Warmer homes. The living areas in Warmer homes were less likely to be heated though with just one of the four reporting heating these rooms in every diary response compared to three of the five Colder homes. All of the Warmer homes but just one of the Colder homes reported ever using a bathroom extractor fan. Putting this information together may provide an explanation of how Warmer homes are able to use heating less: a more stable environment can be maintained through a more insulated envelope and the use of extractor fans for ventilation, rather than opening windows, as was suggested with More Measures homes earlier.

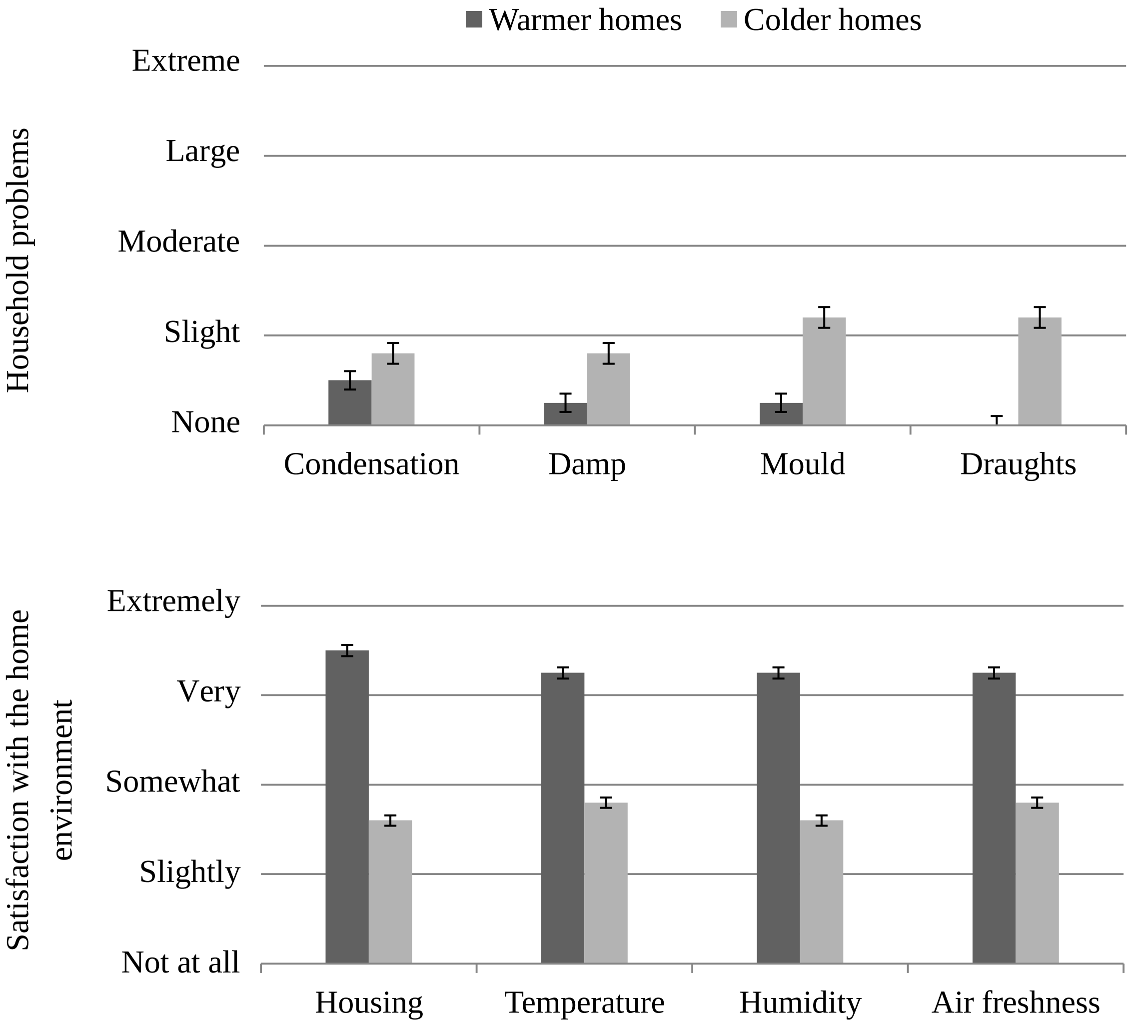

Figure 25: Average levels of household problems and satisfaction reported by participants grouped by indoor temperature (where Warmer homes averaged above 19.2°C in the living room and 19.8°C in the bedroom)

The effects of moisture in the homes were investigated by looking at relative humidity levels and the difference between the temperature and dew point (i.e. how much the indoor temperature were need to drop for condensation to start forming). Grouping for these were identical: the living rooms with the highest humidity levels spent the most time within 10°C of the dew point temperature and the same was true for the bedrooms. Over 50% relative humidity was classed as high[11] for both the living rooms and the bedrooms as the median value for each was similar, although the bedrooms in the higher group tended to record a higher relative humidity on average (59%) than the living rooms with higher humidity (54%). Residents' perceptions appear closely linked to bedroom moisture levels with all four higher bedroom humidity homes reporting more household problems and three of the four reporting more problems paying bills and less satisfaction with the home environment. The causes and effects of living room moisture levels are less clear however. All four homes with more humid living rooms reported hanging clothes to dry indoors (which can increase moisture levels), using kitchen extractor fans more (which can reduce moisture levels) and opening windows more (which can reduce moisture but also reduce temperature making condensation more likely).

Conclusion

Analysing the characteristics of the case study participants, properties and indoor environments identified three key findings:

- The presence of energy efficiency measures is linked to higher indoor temperatures,
- Higher indoor temperatures are linked to more positive perceptions of the home environment, and
- Energy efficiency measures (EWI specifically) can generate substantial savings in energy use, carbon dioxide emissions and, most importantly for many residents, cost.

[11] Due to the median split. 50% relative humidity would not normally be considered high, although the outdoor air will have been drier than average due to the time of year.

Any of these outcomes, in isolation or combination, may potentially benefit residents through physical or psychological mechanisms that improve health and wellbeing, or through the removal of stressors such as discomfort or financial anxiety. While the case study participants also rated their health states, the sample is too small to identify any significant links between energy efficiency measures and health. Instead, to determine whether any of the above outcomes are factors in reported health status a wider survey of residents was conducted in the same area using the same initial questionnaire. The following chapter discusses the results of this questionnaire-based survey in conjunction with the case study findings to shed light on the relationship between energy efficiency and health.

Using household surveys to assess the health of residents following the installation of household energy efficiency measures

The relationship between housing (household energy efficiency in particular) and health has been shown to be complex in existing literature. For example, Figure 3 earlier illustrated the wide range of factors and numerous, often conflicting, associations that complicate attempts to predict the health impacts of energy efficiency schemes. The case study research presented in the previous chapter, however, identified a number of positive and, perhaps, intuitive effects − namely that energy efficiency measures (such as external wall insulation) were linked with a) warmer homes, b) residents more satisfied with their home environment, and c) opportunities for financial savings. As each of these outcomes could potentially affect the health and wellbeing of the residents, the illustrative model in Figure 3 was refined to suggest a simpler process as shown in Figure 26 below.

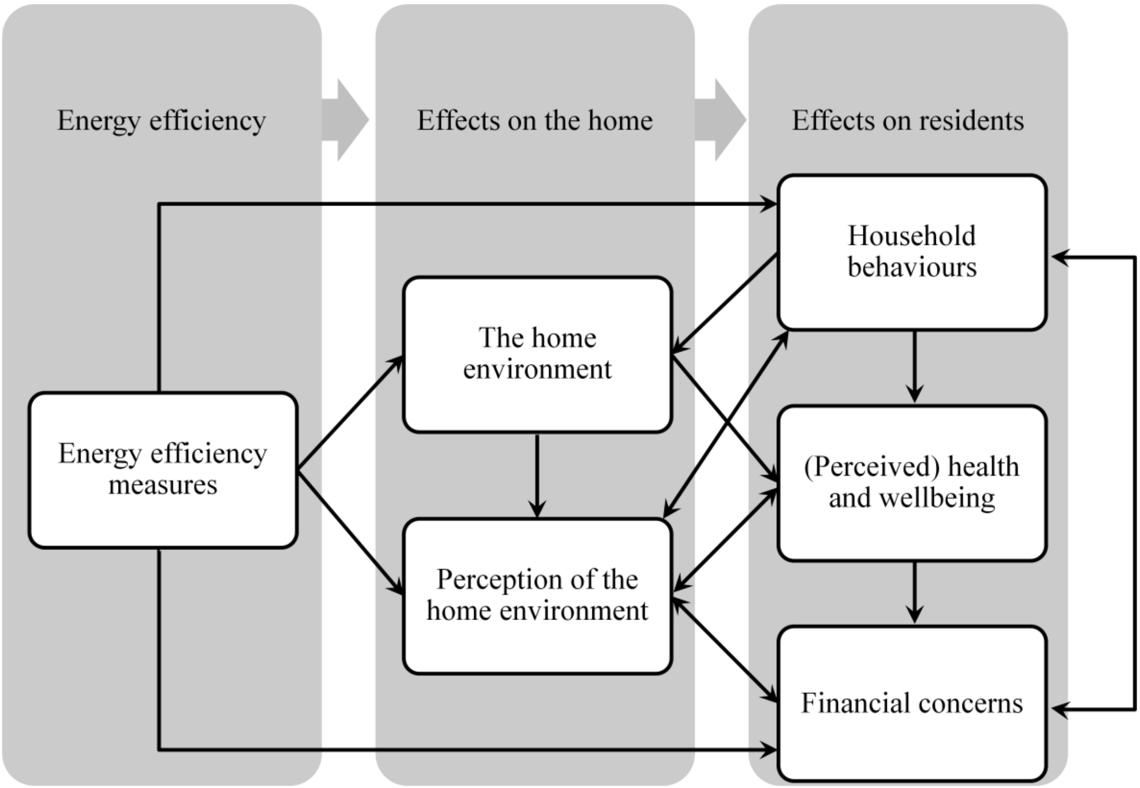

Figure 26: Revised model of the potential routes between energy efficiency and health

While the range of factors and associations included is unchanged, they are organised into two stages that follow the installation of energy efficiency measures: the direct impacts on the home environment (physical, perceptual, financial) and the possible consequential effects on the residents. As such, the suggested process mirrors the simplistic, expected process originally set out in Figure 2. The next step therefore was to test whether impacts from household energy efficiency measures on the home environment translate into health changes for the residents.

In addition to identifying and quantifying the size of any effect of energy efficiency measures on the health of the residents, the research sought to provide insight into the potential routes to health changes. This study was therefore designed to capture the above range of factors and thereby assess their influence on the health outcomes of residents. A questionnaire-based study was developed to concurrently investigate the health, behaviour, and home environments of residents in receipt of energy efficiency interventions. To differentiate between actual and perceived impacts, self-reported factual data[12] was used alongside more subjective measures in the questionnaire where possible while a minimum study period of one year was chosen to capture long-term health impacts. Prior to being distributed to residents in Scunthorpe, North Lincolnshire, including the case study participants from Chapter 2, the questionnaire was piloted in Greater Manchester.

[12] In contrast to the objective environmental measurements described in the previous chapter, this study used factual but self-reported survey questions (e.g., the number of hospital visits made) to provide an element of objectivity alongside entirely subjective measures such as rating health on a five-point Likert scale.

Pilot study

Pilot study materials

Initially a survey was developed for completion by householders due to receive free insulation as part of the Association of Greater Manchester Authorities "Get Me Toasty" campaign (AGMA, 2014). The staff administering the campaign, from Manchester City Council and the Greater Manchester Energy Advice Service, provided some advice regarding the questionnaire content and format. The aim was to measure each of the factors described in Figure 3 before and after the intervention in a concise manner; brevity was considered essential for achieving an adequate response, based on the local authority staff's previous experience of similar research.

The development process resulted in an 8-page questionnaire (see Figure 36 in the appendices) with questions regarding:

- **The presence of existing energy efficiency measures.** The permanent and physical measures identified during the literature review were: loft insulation, wall insulation (cavity, external and internal), solar thermal energy, other renewable energy, double glazing, draught proofing, home energy monitors, efficient boilers and central heating. Respondents were also asked when these measures were installed *(free format)* and how they were funded *('I / We paid', 'Received a grant', 'Landlord or Council',* or *'Other').*
- **The frequency of household behaviours related to the indoor environment.** A short list was compiled of actions or behaviour patterns commonly undertaken by residents that might have direct impacts on the temperature and presence of moisture or pollutants indoors. Questions on household behaviours therefore included the frequency of heating lived-in areas (in winter and summer), ventilation (using windows and kitchen / bathroom extractor fans) and hanging

clothes to dry indoors[13]. For each the respondent was offered a 5 point Likert-scale: *'Never', 'Seldom', 'Sometimes', 'Often',* or *'Almost always'.*

- **Financial concerns**, assessed by the reported frequency of problems with energy bill payments using the same 5 point scale of responses as the household behaviours question *('Never'* to *'Almost always').* General anxiety was also included in the measurement of health and wellbeing (see below). Direct income-related questions that might be deemed intrusive were avoided to maximise the response rate.
- **Perceptions of the home environment**, specifically the elements most likely to be affected by energy efficiency interventions. Respondents were asked to rate:
  - their levels of satisfaction with the standard of the home, the indoor temperature, humidity levels and air freshness on a 5 point Likert-scale; *'Not at all', 'Slightly', 'Somewhat', 'Very',* or *'Extremely'.*
  - the presence of household problems related to temperature and ventilation − specifically condensation, damp, mould and draughts − as an indication of the actual home environment. However, the severity of such problems could not be assessed objectively without a professional audit of each home (to determine, for instance, the risks of widespread mild damp compared to occasional or localised severe damp). Respondents were therefore asked for subjective ratings of the severity of these household problems on a 5 point Likert-scale; *'Not at all', 'Slight', 'Moderate', 'Large',* or *'Extreme'.*

[13] More complex relationships with unclear impacts on the indoor environment could not be included concisely and were therefore omitted. For instance, volatile organic compounds and other pollutants generated during decorating or cleaning have been linked to respiratory illness (Norbäck, Björnsson, Janson, Widström, & Boman, 1995) but their existence depends on the particular products and methods used which could not be adequately captured without significantly lengthening the questionnaire.

- **Perceived health and wellbeing**, rated by respondents on a 5 point Likert-scale; *'Very bad', Bad', 'Fair', 'Good',* or *'Very good'.* More objective health questions included:
  - a count of health service visits over the previous year, specifically the number of visits to doctors, walk-in centres, and hospitals, plus the total number of nights spent in hospital,
  - whether the respondent suffered from any of a checklist of cold- and damp-related illnesses drawn from previous research (e.g., Marmot, 2011); '*Joint pain, arthritis'; 'Respiratory problems, breathing, wheeze'; 'Psychological / emotional conditions'; 'Heart problems, angina'; 'Circulatory problems, high blood pressure'; 'Persistent flu symptoms, headaches'; 'Allergies, hay fever'; 'Falls or accidents in the home'; 'Other(s)'.* The responses offered were *'No, I do not suffer from this', 'Yes but I have not seen a doctor',* or *'Yes and I have seen a doctor'.*
  - whether day-to-day activities were limited because of a long-term health problem or disability. Three options were given: *'Yes, limited a lot', 'Yes, limited a little',* and *'No'*, matching the UK census (ONS, 2011), and
  - The key measure used for health assessment: the EQ-5D™ health instrument (© 1990 EuroQol Group).

Used extensively in the NHS (e.g., Devlin, Parkin, & Browne, 2010) and the National Institute for Health and Clinical Excellence (NICE) (e.g., Mulhern et al., 2014), the EQ-5D is in two parts, the first of which comprises five dimensions: *mobility, self-care, performing usual activities, pain* and *anxiety*. Each dimension given a score of 1, 2 or 3, representing *'no problems'*, *'some problems'* or *'extreme problems'* respectively, from which an overall Health Utility Score can be calculated.

The second part asks respondents to rate their current health state out of 100 using a thermometer-style scale (the Visual Analogue Scale EQ-VAS).

In order to account for the personal circumstances identified in previous research as potentially having an effect on energy efficiency or health, respondents were also asked to provide information about the characteristics of both the building (e.g., the type of house − terraced, detached etc − and when it was built) and its occupants (e.g., the number of adults and children, whether any were smokers, the presence of pets, household tenure and the respondent's age, gender and working situation). Finally, two questions were added to the questionnaire. The first, *'Will you be installing insulation through the 'Toasty' scheme?'* was included to assess whether or not to return to the respondent for further data collection at a later date. The second, *'What effect, if any, do you think the scheme will or would have on your life?'* was included to allow investigation into whether health outcomes are affected by resident's expectations of the impacts from energy efficiency measures.

Pilot study recruitment

Manchester City Council (MCC) agreed to help pilot the questionnaire through their “Get Me Toasty” programme (AGMA, 2014), which, in partnership with the Energy Saving Trust (EST), provided free loft and cavity wall insulation to residents in their district and throughout Greater Manchester. Residents who had seen the promotions for free insulation were invited to call the Greater Manchester Energy Advice Service (GMEAS) and, where agreed, installation was generally completed within a short turnaround of 2-3 weeks. The GMEAS call centre staff who took the initial calls were asked to mention the current research to the residents and forward the contact details of any who might be willing to participate. Potential participants were then contacted independently to explain the research in further detail and, if proceeding, to arrange a home visit to complete the questionnaire face-to-face. After requests from a few of the participants, an online version of the questionnaire was provided as an alternative to completing a paper questionnaire in person.

Time pressures on the GMEAS staff meant that only 25 referrals were received, far fewer than expected. Of these, 13 chose to participate (a completion rate of 52%) and one household provided two responses. However, an unknown number of scheme participants were also directed to the online questionnaire by some GMEAS staff independently prompting a further 8 responses, so that a total of 22 questionnaires were completed.

Pilot study results and implications for the main study

The survey responses were analysed to check for any differences between the two modes of collection that might indicate possible misunderstandings in the self-completed questionnaires and, therefore, a need for further explanation or clarification. Responses from both the face-to-face (n = 8) and online (n = 14) versions of the questionnaire were consistent. Although the small sample size restricted the power to identify statistically significant effects, the method of survey completion was found to account for less than 1% of the variance in health ratings and

Box 1 - Example of fieldwork problems during pilot

One resident mistook a text regarding a survey appointment for one by the surveyor assessing the property. This caused suspicion because the surveyor had already visited and, despite the misunderstanding being resolved, the resident refused to proceed. Subsequently, the fact that the survey formed part of a programme of PhD research was emphasised in all communications and the word “questionnaire” was used instead of “survey” to avoid confusion.

n 10% of the variance of health service use[14], indicating that the researcher completing the questionnaire did not affect the responses.

Participants were able to understand and complete the questionnaire without assistance and only minor refinements to the wording were needed to emphasise that the survey could be completed anonymously if desired. Due to the scarcity of renewable energy technology present in respondents' homes, the list of energy efficiency measures was also refined to combine solar photovoltaic panels, solar thermal energy with all other renewable energy as a single item. The main changes following the pilot though were to the process of contacting residents and carrying out the survey itself. As potential recipients were spread throughout the Greater Manchester area, visiting each resident around their schedules was highly inefficient, particularly as some appointments were missed despite the resident being sent a text reminder. An alternative approach to data collection was therefore required, especially given the lack of referrals received. While expanding the pilot into a larger scale study was originally envisaged, greater numbers of referrals could not be guaranteed and in any case, the EST funding for the Get Me Toasty campaign soon came to an end. After some continuation through MCC alone, the programme ceased and research opportunities were sought elsewhere.

[14] The method of survey completion had no significant effect on health and wellbeing Likert scale rating (F (1, 19) = 0.10; p = .76; partial $\eta^2 < .01$), on the EQ-VAS health rating (F (1, 19) = 0.08; p = .78; partial $\eta^2 < .01$), or on the number of visits to a GP in the previous year (F (1, 19) = 2.00; p = .17; partial $\eta^2 = .10$).

Main study - Method

North Lincolnshire Council agreed to allow research on a retrofit energy efficiency programme implemented in Scunthorpe by themselves and the local social housing provider. Details of the location and the retrofit programme were provided in the previous chapter. To avoid the problems that had previously hindered progress (see Box 2 below) it was agreed that the research would be conducted independently by the University of Sheffield with the local authority merely providing advice and support where needed. This meant that residents due for energy efficiency improvements could not be contacted easily (the local authority initially sent questionnaires on the university's behalf to a number of homes earmarked for insulation improvements but received little response from residents). Consequently the proposed repeated measures design (i.e., measuring relevant variables 'before and after' delivery of the intervention) was changed to a retrospective design in which the

Box 2 - Problems recruiting for the main study

Following the pilot study, various attempts were made, in partnership with both MCC and other local authorities, to recruit a larger sample of participants in receipt of, or about to receive, an energy efficiency intervention. Unfortunately, while many of the various council staff involved were enthusiastic about the research, they encountered barriers that prevented them from participating. Such barriers included lengthy delays to installation schedules, funding being postponed or cancelled, a lack of management support (for instance due to unspecified concerns over data protection), or the failure to find a method of data collection that was both feasible and met the requirements of the research and the local authority.

presence of energy efficiency interventions was linked to health outcomes following those interventions. The questionnaire was updated accordingly; the final version is provided in full, with the response options, in the appendices (see Figure 37). Any non-relevant text or questions were removed such as those relating to the respondent's intentions to proceed with, and their expectations for, the scheme. For ease of analysis, the question '*How long ago was [each energy efficiency measure] installed?'* was changed from a free format response to a choice of three options; '*0-2 years', '2-5 years', or 'Over 5 years'*.

To avoid the need for multiple analyses of how respondents' perceptions of their home environment fit into the range of associations set out in Figure 3 (e.g., whether these perceptions influence the respondent's health or are influenced by the presence of energy efficiency measures), simplification of the responses regarding perceptions was required. While condensing the nine perception-related survey questions into a single measure of perceptions was considered, this would have aggregated subjective measures of satisfaction with more objective measures of the presence of household problems. Instead, maximum internal reliability was achieved through the use of separate scales that matched the categorisation used in the questionnaire, hence the following three measures of perception were used:

a) A **Household Problems scale** ($\alpha = 0.89$), combining the 4 questions on the presence of condensation, damp, mould and draughts,

b) A Household **Dissatisfaction scale** ($\alpha = 0.94$), combining the 4 questions on satisfaction with the housing, temperature, humidity and air freshness, and reversing the direction to match Household Problems scale (higher = worse), and

c) The original individual question regarding frequency of problems paying bills, assessed on a 5 point Likert-scale from *'Never'* to *'Almost always'*.

The household behaviour questions were treated individually as they were designed to measure distinct behaviours related to energy use and the indoor environment. To test this approach, groups of behaviours that could arguably be related (for instance hanging clothes to dry indoors, opening windows and having heating on could all indicate laundry activities) were checked and no combination that warranted an aggregation was found (maximum $\alpha = 0.55$).

The responses regarding health highlighted some redundancy in the questionnaire. The health rating out of 100 (EQ-VAS) provided by each respondent correlated closely with both the health and wellbeing Likert-scale self-rating ($r_s = 0.90$, $p < .01$) and the census long-term illness and disability question ($r_s = 0.64$, $p < .01$). Consequently the EQ-VAS rating was considered sufficient to measure self-rated health, so the Likert-scale and census health questions were deemed superfluous to requirements and removed from the survey[15]. These changes allowed questions to be added regarding changes to the home and to the resident's health over the previous year, along with question rating aspects of wellbeing − specifically, mood, energy and the quality of relationships. The questionnaire was also adapted to include more investigation of impacts on wellbeing, an area of interest raised by the local authority and a knowledge gap noted during the initial literature review. Respondents were asked to rate aspects of their wellbeing previously shown to be affected by the home environment:

[15] The number of times respondents indicated that they had visited their GP in the previous 12 months also correlated significantly with the EQ-VAS health rating ($r_s = -0.59$, $p < .01$). This was kept however as a more objective measure of health than self-rating.

- **mood and happiness**, as an indication of their comfort and overall wellbeing (Bashir, Gilbertson, & Wilson, 2013),
- **energy levels (vitality)**, as the home environment may influence lifestyle and activity (e.g., Packer, Stewart-Brown, & Fowle, 1994) and,
- the **quality of relationships with others**, as cold home environments can lead to family disruption and social exclusion (Richardson & Eick, 2006).

The questionnaire based survey was conducted door to door, targeting streets in the designated area (see the previous chapter for details) where at least one home had been improved as part of the programme. These could be identified by sight as the external wall insulation (EWI), a key feature of the programme, was distinctive and uniform. Over five hundred households were visited up to three times during the second half of 2013, varying between different times of day and at evenings and weekends in order to maximise the chances of finding residents at home. The purpose of the research was explained to residents, although to avoid biasing responses the outcome being investigated was described simply as 'the effect of energy efficiency interventions on residents', rather than mentioning health specifically. Those that were willing to take part were given a questionnaire, a freepost envelope to return it and an information sheet that included contact details along with frequently asked questions developed during the pilot stage. In total, 117 completed questionnaires were received − a response rate of around 23%.

Survey responses

The following pages summarise the 117 responses to the questionnaire:

- Table 16 shows the gender, age, and working situation of respondents along with self-ratings of wellbeing (certain aspects), changes in health and wellbeing, and the presence of specific medical problems.

- Table 17 shows the results of the EQ-5D health instrument (including the EQ-VAS health rating out of 100) and self-reported health service use.
- Table 18 shows the building type and tenure, the presence of smokers or pets in the home, the frequency of energy/air quality-related behaviours, and perceptions of the home environment in terms of problems identified, current satisfaction and changes over the previous year.
- Table 19 shows the presence of household energy efficiency measures in the home including how long ago they were installed and how they were funded.

Table 16: Survey responses - Respondent demographics, wellbeing and medical conditions

(% in brackets)

What is your gender?	Total	
Male	40	*(34)*
Female	76	*(66)*

How old are you?	Total	
Under 18	1	*(1)*
18 to 24	8	*(7)*
25 to 34	17	*(15)*
35 to 44	16	*(14)*
45 to 54	28	*(24)*
55 to 64	15	*(13)*
65 to 74	27	*(23)*
75 to 84	3	*(3)*
85 or over	2	*(2)*

Which of these best describes what you are doing at present?	Total	
Full-time paid work (30 hours or more each week)	22	*(19)*
Part-time paid work (under 30 hours each week)	16	*(14)*
Full-time education at school, college or university	4	*(3)*
Unemployed	16	*(14)*
Permanently sick or disabled	5	*(4)*
Fully retired from work	35	*(30)*
Looking after the home	14	*(12)*
Doing something else	3	*(3)*

How would you describe your ...	Very bad		Bad		Fair		Good		Very good	
Mood and happiness?	0	*(0)*	8	*(7)*	35	*(30)*	53	*(46)*	19	*(17)*
Energy levels?	1	*(1)*	17	*(15)*	47	*(41)*	39	*(34)*	10	*(9)*
Relationship with others?	1	*(1)*	4	*(3)*	16	*(14)*	68	*(59)*	26	*(23)*

Over the last year, has your...	Worsened a lot?		Worsened a little?		Not changed?		Improved a little?		Improved a lot?	
Health	11	*(9)*	27	*(23)*	61	*(53)*	12	*(10)*	5	*(4)*
Mood and wellbeing	7	*(6)*	21	*(18)*	69	*(60)*	16	*(14)*	2	*(2)*

Do you suffer from any of the following problems, and, if so, have you seen a doctor or health professional about it in the last 12 months?	No, I do not suffer from this		Yes but I have NOT seen a doctor		Yes and I HAVE seen a doctor	
Joint pain, arthritis	56	*(53)*	20	*(19)*	29	*(28)*
Respiratory problems, breathing, wheeze	67	*(71)*	6	*(6)*	22	*(23)*
Psychological / emotional conditions	79	*(81)*	5	*(5)*	14	*(14)*
Heart problems, angina	79	*(80)*	1	*(1)*	19	*(19)*
Circulatory problems, high blood pressure	63	*(59)*	5	*(5)*	38	*(36)*
Persistent flu symptoms, headaches	80	*(82)*	8	*(8)*	9	*(9)*
Allergies, hay fever	73	*(74)*	11	*(11)*	15	*(15)*
Falls or accidents in the home	88	*(90)*	3	*(3)*	7	*(7)*
Other(s)	26	*(63)*	4	*(10)*	11	*(27)*

Table 17: Survey responses - EQ-5D Health instrument and health service use

EQ-5D *(© 1990 EuroQol Group EQ-5D™)*

Mobility	Total	%
I have no problems in walking about	79	*(68)*
I have some problems in walking about	38	*(32)*
I am confined to bed	0	*(0)*

Self-care	Total	%
I have no problems with self-care	107	*(92)*
I have some problems washing or dressing myself	8	*(7)*
I am unable to wash or dress myself	1	*(1)*

Usual Activities (e.g. work, study, housework, family or leisure)	Total	%
I have no problems with performing my usual activities	87	*(74)*
I have some problems with performing my usual activities	27	*(23)*
I am unable to perform my usual activities	3	*(3)*

Pain / Discomfort	Total	%
I have no pain or discomfort	58	*(50)*
I have moderate pain or discomfort	51	*(44)*
I have extreme pain or discomfort	7	*(6)*

Anxiety / Depression	Total	%
I am not anxious or depressed	81	*(70)*
I am moderately anxious or depressed	29	*(25)*
I am extremely anxious or depressed	6	*(5)*

	Mean	SD
EQ-5D health utility score	0.77	0.28

	Mean	SD
EQ-VAS health rating (out of 100)	67.58	26.34

Health service use	Mean	SD
In the previous 12 months:		
Number of visits to a GP	3.88	6.14
Number of visits to a walk-in centre	0.17	1.15
Number of visits to a hospital	1.25	2.94
Number of nights spent in a hospital	0.76	5.65

Table 18: Survey responses - Household characteristics

(% in brackets)

What type of house do you live in?	Total	
Detached house	8	*(7)*
Semi-detached house	58	*(51)*
Flat	0	*(0)*
Terraced house	31	*(27)*
End-terraced house	17	*(15)*

In your home..

Does anyone regularly smoke?	Total	
Yes	32	*(28)*
No	84	*(72)*

Are there any pets?	Total	
Yes	56	*(48)*
No	60	*(52)*

Do you own or rent your home?	Total	
Own outright	32	*(28)*
Own with a mortgage or loan	17	*(15)*
Shared ownership	1	*(1)*
Rent	63	*(55)*
Live here rent free	1	*(1)*
Other	1	*(1)*

If renting, who is your landlord?	Total	
Housing association	20	*(31)*
Council (local authority)	20	*(31)*
Private landlord or letting agency	24	*(37)*
Employer of a household member	0	*(0)*
Relative or friend	1	*(2)*
Other	0	*(0)*

Household behaviours	Never		Seldom		Sometimes		Often		Almost always	
Problems paying bills	62	*(55)*	13	*(12)*	25	*(22)*	6	*(5)*	5	*(4)*
Opened windows	8	*(7)*	5	*(4)*	31	*(28)*	41	*(37)*	26	*(23)*
Used kitchen extractor fan	38	*(35)*	4	*(4)*	16	*(15)*	20	*(18)*	32	*(29)*
Used bathroom extractor fan	49	*(45)*	4	*(4)*	11	*(10)*	15	*(14)*	31	*(28)*
Hang clothes to dry indoors	28	*(25)*	11	*(10)*	43	*(38)*	23	*(21)*	7	*(6)*
Heat living areas in winter	8	*(7)*	4	*(4)*	12	*(11)*	22	*(20)*	65	*(59)*
Heat living areas in summer	67	*(60)*	28	*(25)*	13	*(12)*	1	*(1)*	2	*(2)*

Household problems	None		Slight		Moderate		Large		Extreme	
Condensation	41	*(39)*	33	*(32)*	19	*(18)*	5	*(5)*	3	*(3)*
Damp	36	*(33)*	32	*(30)*	18	*(17)*	15	*(14)*	6	*(6)*
Mould	49	*(47)*	22	*(21)*	15	*(14)*	12	*(12)*	5	*(5)*
Draughts	49	*(46)*	26	*(24)*	11	*(10)*	15	*(14)*	4	*(4)*

Satisfaction	Not at all		Slightly		Somewhat		Very		Extremely	
Standard of housing	14	*(13)*	11	*(10)*	27	*(24)*	50	*(45)*	9	*(8)*
Indoor temperature	12	*(11)*	14	*(13)*	25	*(23)*	49	*(45)*	10	*(9)*
Humidity indoors	13	*(12)*	13	*(12)*	34	*(32)*	38	*(36)*	9	*(8)*
Freshness of air indoors	11	*(10)*	13	*(12)*	33	*(30)*	41	*(38)*	11	*(10)*

Changes in the last year	Worsened a lot		Worsened a little		Not changed		Improved a little		Improved a lot	
Standard of housing	3	*(3)*	21	*(19)*	45	*(40)*	27	*(24)*	17	*(15)*
Indoor environment	3	*(3)*	9	*(8)*	57	*(51)*	32	*(29)*	11	*(10)*
Household problems	7	*(6)*	16	*(15)*	56	*(52)*	19	*(18)*	10	*(9)*
Problems paying bills	5	*(4)*	23	*(21)*	67	*(60)*	7	*(6)*	10	*(9)*

Table 19: Survey responses - Energy efficiency measures including when they were installed and by who (i.e., how they were paid for)

(% in brackets)

Which of these measures do you currently have in your home?	Yes		No		Not sure	
Loft insulation	95	*(84)*	10	*(9)*	8	*(7)*
Cavity wall insulation	23	*(23)*	57	*(57)*	20	*(20)*
External wall insulation	54	*(51)*	40	*(38)*	12	*(11)*
Internal wall insulation	7	*(7)*	70	*(73)*	19	*(20)*
Renewable energy	37	*(37)*	59	*(59)*	4	*(4)*
Double or triple glazing	102	*(92)*	8	*(7)*	1	*(1)*
Home energy monitor	6	*(6)*	85	*(84)*	10	*(10)*
Draught proofing	23	*(23)*	60	*(61)*	15	*(15)*
Efficient ‘a-rated’ (condensing) boiler	63	*(62)*	28	*(28)*	10	*(10)*
Central heating	105	*(95)*	5	*(5)*	0	*(0)*

For the measures you have in your home only, how long ago was it installed?	0-2 years		2-5 years		Over 5 years	
Loft insulation	30	*(33)*	32	*(35)*	30	*(33)*
Cavity wall insulation	10	*(43)*	10	*(43)*	3	*(13)*
External wall insulation	44	*(81)*	7	*(13)*	3	*(6)*
Internal wall insulation	6	*(55)*	3	*(27)*	2	*(18)*
Renewable energy	33	*(83)*	4	*(10)*	3	*(8)*
Double or triple glazing	10	*(11)*	21	*(23)*	62	*(67)*
Home energy monitor	2	*(50)*	2	*(50)*	0	*(0)*
Draught proofing	5	*(17)*	9	*(30)*	16	*(53)*
Efficient ‘a-rated’ (condensing) boiler	19	*(32)*	24	*(41)*	16	*(27)*
Central heating	14	*(14)*	12	*(12)*	72	*(73)*

And who paid?	I/ We paid		Received a grant		Landlord / council		Other	
Loft insulation	17	*(18)*	14	*(15)*	46	*(50)*	15	*(16)*
Cavity wall insulation	6	*(24)*	0	*(0)*	18	*(72)*	1	*(4)*
External wall insulation	4	*(7)*	2	*(4)*	45	*(82)*	4	*(7)*
Internal wall insulation	1	*(8)*	1	*(8)*	10	*(83)*	0	*(0)*
Renewable energy	5	*(13)*	0	*(0)*	34	*(87)*	0	*(0)*
Double or triple glazing	38	*(41)*	1	*(1)*	47	*(51)*	6	*(7)*
Home energy monitor	1	*(20)*	0	*(0)*	3	*(60)*	1	*(20)*
Draught proofing	9	*(30)*	1	*(3)*	19	*(63)*	1	*(3)*
Efficient ‘a-rated’ (condensing) boiler	16	*(25)*	10	*(16)*	33	*(52)*	4	*(6)*
Central heating	28	*(30)*	7	*(7)*	51	*(54)*	8	*(9)*

Characteristics of the survey respondents

A full summary of the 117 responses is provided on the previous pages (Table 16 to Table 19). Two thirds of respondents were female and, as can be seen in Figure 27, only a fifth (n = 22) were in full-time employment (a group who make up nearly half of the local population). This may reflect that, despite efforts to reach working people at evenings and weekends, those out of work were more reachable or perhaps more willing to spare time to respond.

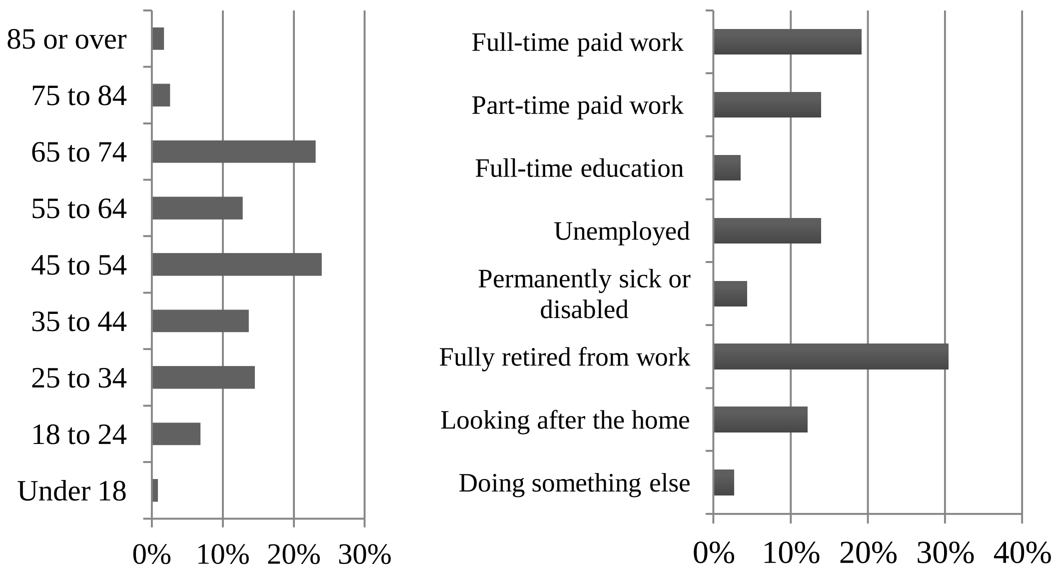

Figure 27: Survey responses - Distribution of respondents by a) age group and b) living / work situation category

The high number of older people, particularly retirees, that responded may to some extent explain the high prevalence of certain medical conditions reported in this survey (see Figure 28) compared to the local population. Arthritis or joint pain was reported by 47% of respondents but only in 16% of responses to the GP Patient Survey (NHS, 2014) in the North Lincolnshire CCG area. Respondents to the present survey also reported far more cases of high blood pressure (41% compared to 21% locally), respiratory problems (29% compared to 11%) and heart problems (20% compared to 7%). However, some conditions less associated with age were also more common in the survey respondents − 19% reporting psychological conditions compared to 4% locally for example. Differences in the terminology used for the two surveys may have had some effect on the results. For example, the GP Patient Survey specifically investigated long-term conditions while the current survey made no such distinction in order to capture all relevant health information, including conditions or symptoms that may have recently arisen following the installation of energy efficiency measures.

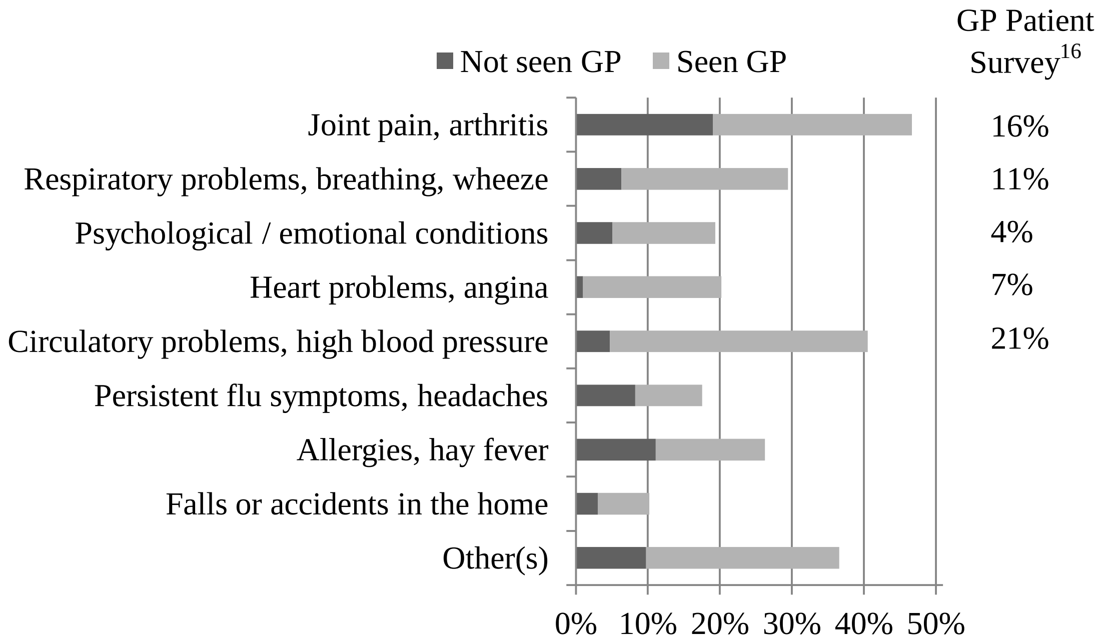

Figure 28: Survey responses - % of respondents reporting certain medical conditions potentially related to indoor temperature or air quality, compared to the GP Patient Survey results for North Lincolnshire CCG where equivalent health data was available[16]

Overall though, the health of the survey respondents was similar to that of the local population. The EQ-5D health instrument used to assess health levels in this research also forms part of the GP Patient Survey (NHS, 2014). Using current UK value sets (Oemar & Oppe, 2013) the instrument produces an average health utility score of 0.77 (*SD* = 0.28) for survey respondents and 0.86 for the North Lincolnshire CCG population[17], where 1 reflects the best health imaginable. The GP Patient Survey

[16] Respective GP Patient Survey health outcomes: *'Arthritis or long-term joint problem', 'Asthma or long-term chest problem', 'Long-term mental health problem', 'Angina or long-term heart problem', 'High blood pressure'.*

[17] Standard deviation not available.

uses a format of the EQ-5D that offers a choice between 5 responses per health dimension rather than 3, which has been shown to produce utility scores greater by a similar magnitude (Oppe, Devlin, van Hout, Krabbe, & de Charro, 2014). The descriptive statistics for the EQ-5D questionnaire are in Table 20 on the following page, showing little difference between the survey and local populations (denoted by the effect size). An effect ten times the largest calculated for any of the five dimensions (d = 0.03) would still be considered small (Cohen, 1992). These similarities are also reflected in the self-ratings of health provided by respondents to the survey and to the 2011 Census in the local ward, as shown in Figure 29. While fewer survey respondents reported the very highest ratings and more reported lower ratings, this resulted in only a small difference (d = 0.25) between the average ratings from respondents to the survey (M = 67.58, SD = 26.34) and the census (M = 73.32, SD = 18.38).

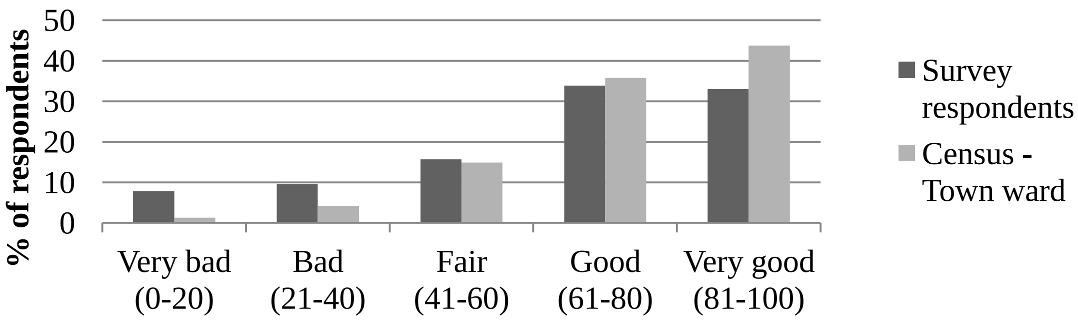

Figure 29: Self-rated health showing similar distributions for survey respondents (EQ-VAS score by quintile) and the local population (Census ward responses on Likert scale from Very good to Very bad)

Table 20: Comparison of the health of survey respondents and the North Lincolnshire population (NHS, 2014) using the EQ-5D health instrument [a], with effect sizes of 0.3 or less denoting small differences between the mean health scores for each of the five dimensions and 0 denoting no difference

Mobility	Survey	N. Lincs.[b]
I have no problems in walking about	68%	74%
I have some problems in walking about	32%	25%
I am confined to bed	0%	1%
Effect size [c]		< 0.01
Self-care		
I have no problems with self-care	92%	90%
I have some problems washing or dressing myself	7%	9%
I am unable to wash or dress myself	1%	1%
Effect size [c]		< 0.01
Usual Activities (e.g. work, study, housework, family or leisure)		
I have no problems with performing my usual activities	74%	71%
I have some problems with performing my usual activities	23%	27%
I am unable to perform my usual activities	3%	2%
Effect size [c]		0.03
Pain / Discomfort		
I have no pain or discomfort	50%	48%
I have moderate pain or discomfort	44%	50%
I have extreme pain or discomfort	6%	1%
Effect size [c]		< 0.01
Anxiety / Depression		
I am not anxious or depressed	70%	68%
I am moderately anxious or depressed	25%	31%
I am extremely anxious or depressed	5%	1%
Effect size [c]		< 0.01

Notes:
[a] (© 1990 EuroQol Group EQ-5D™)
[b] The GP Patient Survey uses a 5 point scale for each of the dimensions rather than 3 as used in this research. The intermediate figure shown for each is therefore a combined total of the 3 intermediate values from the GP Patient Survey. For example, the GP Patient Survey indicated that 74% of the 'Town' ward population had no problems walking and 1% were unable to walk as shown. The 11% with slight problems, 8% with moderate problems and 5% with severe problems were combined into a group of 25% with SOME problems as shown.
[c] Cohen's d calculated for the difference between mean health utility scores, using the root mean square standard deviation.

Survey respondents tended to rate their wellbeing favourably on the same five-point Likert scale as used for health (see Figure 30), averaging between fair and good for their mood (*M* = 3.72, *SD* = 0.82), energy levels or vitality (*M* = 3.35, *SD* = 0.87), and relationships with others (*M* = 3.99, *SD* = 0.77).

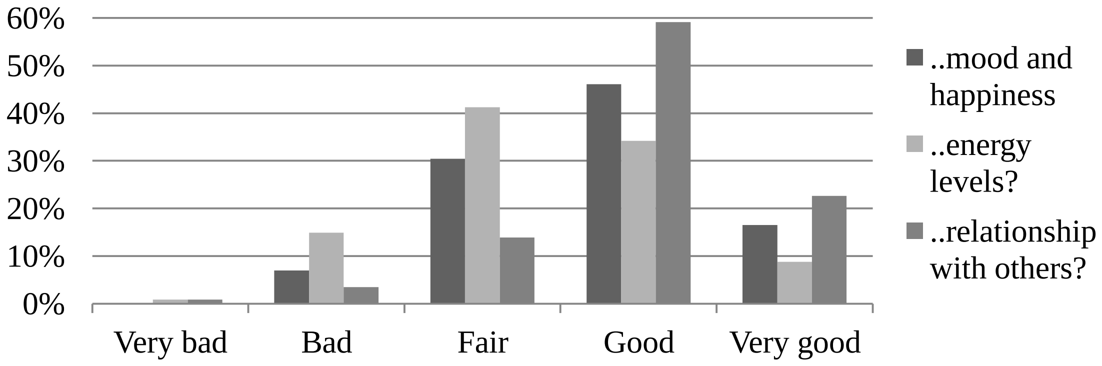

Figure 30: Survey responses - self-rated aspects of wellbeing (% of respondents)

Assessing self-reported changes during the previous year (on a five point Likert scale where 3 indicated no change − see Figure 31), both health (*M* = 2.77, *SD* = 0.92) and wellbeing (*M* = 2.87, *SD* = 0.79) were more likely to have worsened. Over half of the respondents though reported no change in health or wellbeing.

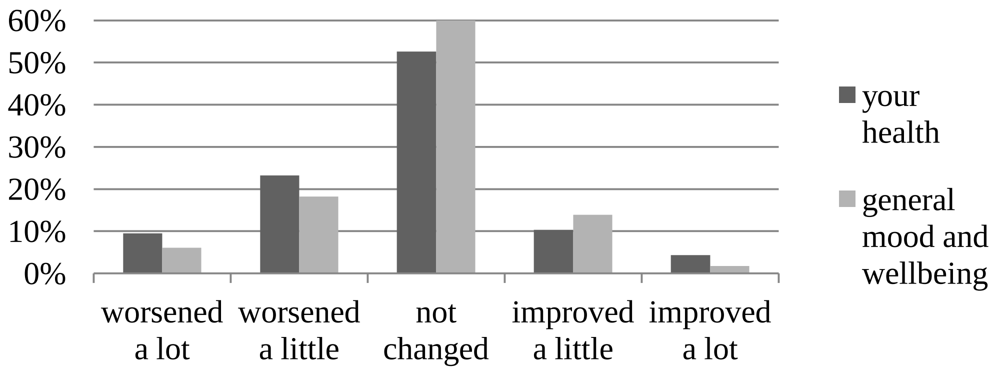

Figure 31: Survey responses - Changes in health and wellbeing during the previous year (% of respondents)

Characteristics of the households

Only 43% of the respondents owned their home (with or without a mortgage), in keeping with the local area (50%, z = 1.46, *p* = .07) if not the rest of the country (63%, z = 4.61, p < .01). A greater proportion of social renters than average responded with 35% of respondents renting from either the council or a housing association compared to 21% in the local ward (z = 3.45, p <.01). This is understandable as the survey was targeted at streets containing some recently improved social / council homes and the nature of the research encouraged more participation from those who had received improvements. This oversampling is also desirable given that people who are on low incomes or otherwise vulnerable experience disproportionate impacts from fuel poverty and a greater need to reduce energy use (Anderson, White, & Finney, 2012) but tend to be hard to reach (Mackenzie et al., 2012).

The questionnaire measured the presence or absence of ten energy efficiency measures, as shown in Figure 32. Of these, central heating (in 95% of homes), double- or triple-glazing (92%) and loft insulation (84%) were the most ubiquitous among the survey respondents while home energy monitors (6%) and internal wall insulation (7%) were the rarest. EWI was relatively prevalent at 51% due to the recent major council retrofit programme, although the research targeted homes both within and without the programme.

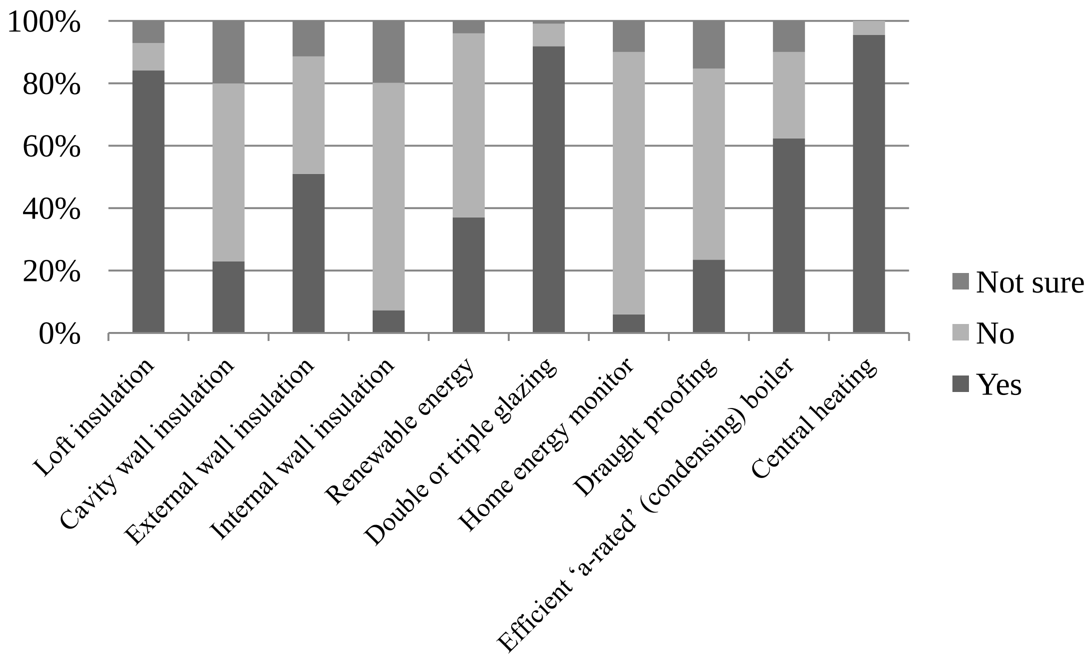

Figure 32: Survey responses - prevalence of energy efficiency measures (% of respondent households)

As shown in Table 21, respondents tended to report either slight or no household problems while most described themselves as at least somewhat satisfied with each of the home environment aspects measured. Many respondents had seen no change regarding their perceptions of the home over the previous year. Where changes in the standard of housing, the indoor environment or the presence of moisture-related problems were reported, improvements were more common than declines. The exception was experiences of financial issues, where more respondents had seen problems paying bills worsen than improve.

Table 21: Survey responses - household problems, satisfaction levels, recent changes to the home and frequency of behaviours, rated on a 5-point Likert scale

Household problems *(1 = none, 5 = extreme)*	Mean	SD
Condensation	1.97	1.03
Damp	2.28	1.23
Mould	2.05	1.24
Draughts	2.04	1.22
Satisfaction *(1 = none, 5 = extreme)*		
Standard of housing	3.26	1.15
Indoor temperature	3.28	1.14
Humidity indoors	3.16	1.13
Freshness of air indoors	3.26	1.12
Changes over the previous year *(1 = worsened a lot, 3 = no change, 5 = improved a lot)*		
Standard of your housing	3.30	1.03
Indoor environment	3.35	0.87
Problems with damp, mould and condensation	3.08	0.98
Problems paying bills	2.95	0.90
Behaviours and experiences *(1 = never, 5 = almost always)*		
Problems paying energy bills	1.91	1.19
Open a window for ventilation	3.65	1.11
Use an extractor fan when cooking	3.04	1.67
Use an extractor fan in the bathroom	2.77	1.75
Hang clothes to dry indoors	2.73	1.22
Heat living areas and bedroom(s) in winter	4.19	1.21
Heat the same rooms in summer	1.59	0.87

Table 21 also details how often certain behaviours that can affect the indoor environment (as well health and finances in some cases) occur. Unsurprisingly using heating was common in winter and rare in summer, while 60% often opened windows for ventilation. The use of extractor fans in the kitchen and bathroom was polarised, with the largest proportion of respondents never using them and the next largest proportion almost always using them. Responses varied regarding laundry, 35% seldom or never hung clothes to dry indoors, 38% did so sometimes and 27% often or almost always hung clothes to dry indoors.

Analysis of the survey responses

The relationship between energy efficiency interventions and health

After considering alternatives to represent the overall energy efficiency of a home (see Chapter 2), the number of energy efficiency measures present from the surveyed list of 8 (counting the presence of one or more types of wall insulation together) was used. The results are shown in Table 22 below.

Table 22: Number of types of household energy efficiency measure present in survey respondents' homes

Number of measures	0	1	2	3	4	5	6	7	8
Proportion of homes	2%	2%	12%	15%	26%	20%	18%	6%	0%

Correlations between this count of energy efficiency measures and health (both the EQ-VAS rating and the health utility score calculated from the EQ-5D responses) and the wellbeing measures (self-ratings of mood, energy and relationships) were then computed. A Spearman rank order coefficient was used due to the large proportion of very healthy responses skewing the health data, as expected for general populations. As can be seen in Table 23, the results of these calculations were all found to be close to zero, indicating little or no correlation. Consequently, none of the relationships between the number of energy efficiency measures and the ratings of health or wellbeing provided by residents was found to be significant.

Further analysis was conducted on changes in health over the previous year in comparison to when energy efficiency measures were installed (within 2 years, 5 years or ever). As the health change data approximated a normal distribution curve (see Figure 31 earlier), a Pearson product-moment correlation coefficient was used. No significant correlations were found between energy efficiency and health for any of the time periods (see Table 23), though small but significant correlations were found between greater numbers of energy efficiency measures and reports of *worsening* mental wellbeing when looking solely at measures installed in the previous 2 years (r = -0.20, p = .04) [18].

Table 23: Correlations between the number of energy efficiency measures present (of the 8 listed types) and the health and wellbeing of respondents

Number of energy efficiency measures	Correlation coefficient	*p*
Health utility score	-0.08 [a]	.44
Self-rated health	0.02 [a]	.84
Self-rated mood and happiness	-0.02 [a]	.82
Self-rated energy levels (vitality)	-0.05 [a]	.64
Self-rated relationships with others	0.02 [a]	.83
Changes in health during the previous year	-0.09 [b]	.34
Changes in wellbeing during the previous year	-0.09 [b]	.32
Number of energy efficiency measures installed in the previous 5 years		
Changes in health during the previous year	-0.14 [b]	.15
Changes in wellbeing during the previous year	-0.18 [b]	.06
Number of energy efficiency measures installed in the previous 2 years		
Changes in health during the previous year	-0.15 [b]	.11
Changes in wellbeing during the previous year	-0.20 [b]	.04 *

*Notes: [a] Spearman's rho. [b] Pearson correlation. * $p < .05$, ** $p < .01$ *** $p < .001$.*

[18] Seventy-three (62%) of respondents had installed at least one energy efficiency measure within the previous two years.

Given the lack of correlation found between energy efficiency and health, further investigation into associations that might potentially form routes between the two was warranted. This was conducted by addressing the illustrative model shown earlier (Figure 3) from two perspectives: the range of effects resulting from energy efficiency measures and the range of variables affecting the health of residents.

The effects of energy efficiency interventions on residents' perceptions and behaviours

The relationship between energy efficiency and perceptions of the home was analysed by calculating the correlations between the number of measures present and the scales developed from the perception responses: household problems (condensation, damp, mould and draughts) and satisfaction (with the housing, temperature, humidity and air freshness indoors). Spearman's rank order coefficient was used as perception responses were skewed towards few reported problems and high levels of satisfaction. No significant relationships were detected between the number of energy efficiency measures present and reported household problems (r_s = -0.12, p = .21), dissatisfaction (r_s = -0.13, p = .17) or the frequency of problems paying bills (r_s = -0.07, p = .44).

A scale was also developed combining questions regarding changes to the housing, to the indoor environment and to any moisture-related problems over the previous year, forming a reliable scale reflecting “Changes to perceptions of the home” (α = 0.85). This scale was then used to assess whether the installation of energy efficiency measures led to noticeable changes in the home by calculating Pearson correlation coefficients as the change data was normally distributed. As shown in Table 24, improvements in perceptions of the home were found to be significantly associated with a higher number of energy efficiency measures present regardless of when they were installed. A higher number of measures installed in the previous 2 years also correlated closely with reductions in reported bills problems.

Table 24: Correlations between the number of energy efficiency measures installed in a given time period and changes to perceptions of the home and financial problems

Changes to perceptions of the home during the previous year	Pearson r	*p*	
No. of energy efficiency measures installed in the previous 2 years	0.45	<.01	***
No. of energy efficiency measures installed in the previous 5 years	0.37	<.01	***
No. of energy efficiency measures installed ever	0.40	<.01	***
Changes in problems paying bills during the previous year			
No. of energy efficiency measures installed in the previous 2 years	0.24	.01	*
No. of energy efficiency measures installed in the previous 5 years	0.14	.13	
No. of energy efficiency measures installed ever	0.15	.12	

*Notes: * p < .05, ** p < .01 *** p < .001.*

The final analysis of potential effects from energy efficiency measures was to check for any correlation with the behaviour of residents. The results are shown in Table 25. Of the six surveyed behaviours that might affect the indoor environment, only the use of bathroom extractor fans was correlated with the number of energy efficiency measures, with more energy efficiency measures significantly linked to more fan use ($r_s = 0.30$, $p < .01$) . The behaviours were also analysed to identify any impacts they may have had on or from residents' perceptions of the home. Only one clear and significant correlation was found, again related to extractor fans but in this case linking to their use while cooking to higher levels of satisfaction in the home ($r_s = -0.29$, $p < .01$).

Table 25: Correlations between behaviours related to the indoor environment and both the number of energy efficiency measures present and perceptions of the home environment, using Spearman's rank order coefficient

Number of energy efficiency measures present	r_s	*p*
Opening windows	-0.02	.83
Using kitchen extractor fans	0.17	.08
Using bathroom extractor fans	0.30	<.01
Hanging clothes to dry indoors	-0.01	.92
Heat living areas in winter	0.05	.58
Heat living areas in summer	-0.11	.27
Reported household problems		
Opening windows	0.04	.66
Using kitchen extractor fans	-0.04	.71
Using bathroom extractor fans	0.13	.18
Hanging clothes to dry indoors	0.14	.16
Heat living areas in winter	0.14	.14
Heat living areas in summer	0.16	.10
Reported dissatisfaction levels		
Opening windows	0.03	.74
Using kitchen extractor fans	-0.29	<.01
Using bathroom extractor fans	0.04	.72
Hanging clothes to dry indoors	0.10	.30
Heat living areas in winter	-0.04	.72
Heat living areas in summer	0.17	.09
Reported problems paying bills		
Opening windows	0.15	.13
Using kitchen extractor fans	-0.10	.30
Using bathroom extractor fans	<-0.01	.97
Hanging clothes to dry indoors	-0.07	.49
Heat living areas in winter	0.01	.92
Heat living areas in summer	0.12	.23

Notes: * $p < .05$, ** $p < .01$ *** $p < .001$.

Factors affecting the health of residents

The health of respondents proved consistent across the different subjective and, to an extent, objective measures used in the survey. The subjective EQ-VAS rating provided by the respondent and the utility score calculated from their responses to the EQ-5D instrument correlated significantly ($r_s = 0.67$, $p < .01$). Significant correlations were also identified between the EQ-VAS ratings and the measures used to assess both wellbeing and health service use[19]. The EQ-VAS rating was found to correlate with self-rated mood and happiness ($r_s = 0.56$, $p < .01$), energy levels or vitality ($r_s = 0.58$, $p < .01$), and relationships with others ($r_s = 0.24$, $p = .01$), and to inversely correlate with the number of visits to a GP ($r_s = -0.33$, $p < .01$), the number of visits to hospital ($r_s = -0.32$, $p < .01$), and the number of nights spent in hospital ($r_s = 0.24$, $p = .01$) during the 12 months prior to the survey.

To further investigate the potential routes between energy efficiency and health suggested by the earlier model (Figure 3), the correlation between respondents' perceptions of their home environment (measured using reports of household problems, dissatisfaction and problems paying bills) and the EQ-VAS health outcome (rating out of 100) was computed. Significant correlations were found between greater dissatisfaction and poorer health ratings ($r_s = -0.27$, $p < .01$) and more problems paying bills and poorer health ratings ($r_s = -0.21$, $p = .03$). The results are shown in Table 26 along with correlations between the EQ-VAS health ratings and behaviours related to the indoor environment. The only behaviour found to correlate significantly with health was hanging clothes to dry indoors ($r_s = 0.23$, $p = .02$), an activity that might be expected to harm health by encouraging damp but was instead linked here with higher EQ-VAS ratings. Looking specifically at changes over the previous year,

[19] Except for the reported use of walk-in centres, which was rare.

reductions in problems paying bills correlated significantly with health improvements while improvements to the home environment and problems paying bills both correlated significantly with improvements in mental wellbeing (see Table 26 below).

Table 26: Correlations between health ratings (and changes in health and wellbeing) and perceptions, behaviours and changes related to the home environment

EQ-VAS health rating	Correlation coefficient	*p*
Reported household problems	-0.17 [a]	.08
Reported dissatisfaction levels	-0.27 [a]	< .01
Reported problems paying bills	-0.21 [a]	.03
Opening windows	0.05 [a]	.61
Using kitchen extractor fans	0.14 [a]	.14
Using bathroom extractor fans	0.02 [a]	.84
Hanging clothes to dry indoors	0.23 [a]	.02
Heat living areas in winter	0.14 [a]	.14
Heat living areas in summer	0.02 [a]	.83
Changes in health during the previous year		
Changes to perceptions of the home during the previous year	0.17 [b]	.07
Changes in problems paying bills during the previous year	0.26 [b]	< .01
Changes in mood and wellbeing during the previous year		
Changes to perceptions of the home during the previous year	0.22 [b]	.02
Changes in problems paying bills during the previous year	0.22 [b]	.02

*Notes: [a] Spearman's rho. [b] Pearson correlation.. * p < .05, ** p < .01 *** p < .001.*

Discussion

The purpose of this research was to explore the mechanisms by which household energy efficiency measures might affect the health of residents. To this end, this survey study aimed to determine whether the improvements to home environments, both actual and perceived, evident in the case study households in Chapter 2 translate to health and wellbeing benefits for the wider population. Recognising that this overall relationship is complex, a questionnaire was designed to capture a comprehensive list of factors that might form relevant associations, while remaining concise enough to encourage a high response.

The area selected for distribution allowed the comparison of homes that had received extensive energy efficiency improvements 12 to 24 months prior to the survey with a comparable number that had received very little. The intention was to ensure that enough time had passed to minimise any short term psychological effects − whether positive (as found by Egan et al., 2013) or negative due to disruption or unwanted change − but not so much time that the more permanent effects resulting from the energy efficiency improvements would be disguised and diluted by other effects occurring naturally over time (e.g., from life events or changes in personal circumstances or lifestyles that affect health and wellbeing, or from people moving home after installation and thereby reducing the 'intervention' sample). The relatively high levels of deprivation in the area also made it likely that some respondents would be particularly vulnerable to fuel poverty and therefore most likely to benefit from energy efficiency improvements (Liddell & Morris, 2010). However, greater financial pressures lead to more complexity as other outgoings (on food, rent / mortgage or lifestyle for instance) may take priority over maintaining a warm home environment, influencing the overall impact on health and wellbeing (Beatty, Blow, & Crossley, 2014).

Analysis of the survey responses found no direct relationship between the presence of energy efficiency measures and the health state reported by residents. Energy efficiency measures were found to affect wellbeing though, with respondents who had installed more energy efficiency measures in the previous 2 years more likely to report that their general mood and wellbeing had *worsened* during the previous year. This was unexpected as various evaluations of energy efficiency schemes have shown positive mental health effects (Liddell & Guiney, 2015). There are various possible explanations for these worsening moods though: disruption (if the installation involves any negative experiences), imposition (if the measures were foisted on residents by housing providers), disappointment (if high expectations for improvements in health, warmth or finances are not met), or targeting people in poor health (whose mood might be expected to decline if health does not improve).

If wellbeing is impaired even temporarily following the installation of a household energy efficiency measure, this may help to explain why empirical studies tend to find smaller overall health effects than are suggested by epidemiological and anecdotal evidence (Marmot, 2011). Where health is self-reported soon after installation, temporarily lowered feelings of wellbeing might lower health ratings (either subconsciously by the respondent or intentionally where measures such as mood and vitality are included in assessing overall health). Clearly there is value in identifying temporary changes in mood and vitality in order to help maintain or enhance the wellbeing of energy efficiency measure recipients. However, monitoring for longer periods might provide a more complete assessment of the permanent changes in health that can have lasting effects on quality of life. Such assessments would then be key to policymakers who might otherwise base decisions primarily on existing empirical evidence, unaware that effects may have been underestimated.

More detailed investigation of potential routes between energy efficiency and health uncovered some important findings, particularly regarding associations between the (perceived) home environment and the health of residents. Poorer health was reported by respondents that felt less satisfaction with their home environment while those that had seen recent improvements in the home environment also reported recent improvements in wellbeing. What was perhaps more surprising was the close relationship identified between finances and health. Respondents who reported fewer problems paying energy bills tended to report better health while those whose bills problems had reduced during the previous year were more likely to have seen improvements in both wellbeing and health. While each of these findings is encouraging and fits with existing evidence (Howden-Chapman, 2015), it is the last finding that perhaps sheds most light on the potential route between energy efficiency and health. If improvements in health are the result of reductions in problems paying bills, not improvements in the home environment (and if the freedom from moisture-related household problems is not linked with better health), the main mechanisms for improving health appear to be the removal of finance-related stress, one of the stressors identified by Liddell & Guiney (2015), or possibly through increasing the ability to afford healthier lifestyles such as healthy eating, sports activities or funding health products and services (Gilbertson et al., 2012).

Study limitations

Conducting this study has shed some light on why much of the existing evidence regarding energy efficiency and health has been limited in the ways described above. Monitoring periods beyond a year were found to be very rare in existing scheme evaluations but because of delays and changes to local authority plans, this research was not able to address this gap. Carrying out the research independently provided greater control over schedules but effectively blocked this possibility of collecting sufficient 'before' data. While retrospective studies could be targeted at schemes more than a year old, a wide range of factors (residents moving out, changing lifestyles or ageing for instance) can confuse or disguise effects over time. Further, similar scale studies were planned to supplement the data and create a larger sample, therefore increasing the possibilities for analysis. Plans were also made to conduct a further survey before and after a large programme of EWI installations took place in order to dramatically increase the power to detect smaller health changes but, as with the other planned studies, the programme became subject to extensive delays and more than a year later is only just starting to proceed. Ultimately the decision was made that instead of continuing to pursue opportunities to increase the survey sample size, time and resources were better directed at investigating the research question from alternative perspectives (see Chapter 4 for a meta-analysis of the existing evidence base and Chapter 5 for a set of interviews with energy, housing and health professionals).

The limited sample size of the survey prohibited the use of certain types of statistical analyses such as regression, hence simple correlations were investigated. These analyses and the ability to generalise the findings were further compromised by a number of factors. The self-reported "EQ-VAS" was an entirely subjective measure of health status (and one used more commonly for patients with specific health conditions, not the general population). Without matched groups or baseline data it was not possible to determine how much of the variation in scores could be attributed to different interpretations of the scoring scale. It should be noted though that the EQ-

VAS scores correlated closely with health responses on a Likert scale during the pilot, suggesting consistent interpretations of the EQ-VAS scale. Also, despite efforts to distribute the survey on different days and at different times in order to catch as many residents as possible, the face-to-face approach naturally tended to select residents at home during the day. This would explain the greater proportion of retirees and the unemployed than expected, and possibly the gender bias in the responses, further limiting the ability to generalise the results to the wider population.

The assessment of the energy efficiency of the homes raised a number of issues. Intention To Treat issues were avoided by the retrospective approach, the actual presence of energy efficiency measures being recorded rather than the prior intention install or not. However, the study instead relied on the residents' knowledge of the energy efficiency measures installed in their homes and their memory of when and how this took place. This potentially unreliable data was then used to form a simple energy efficiency score for each home based on the count of types of measure present. More sophisticated measures were discounted as weighting the measures according to their expected effects could potentially introduce assumptions or further unreliability into the analysis (see earlier), while assessing the actual energy performance of the homes would have reduced the sample size due to the availability of this information. These methods may have resulted in more power to identify relationships than treating all energy efficiency measures as equivalents. With the approach used it was unlikely that an overall relationship between household energy efficiency measures and health would be identified, particularly as many of the survey respondents would not be classed as vulnerable to fuel poverty and that the retrofit scheme made significant but not dramatic improvements to the energy performance of the homes in question (see Figure 23 in Chapter 2 for the indoor environmental conditions of the case study homes).

While the limited sample size and retrospective nature of the survey limited its statistical power, the key strength of this study was as an extension of the case study research, allowing energy efficiency, the indoor environment, health, wellbeing, behaviour, and perceptions to be investigated concurrently. The survey results were therefore analysed alongside those of the case studies and the comparison is discussed in the following section.

Key outcomes

A number of benefits can be taken from this study that could help to shape future research, despite the various setbacks that delayed and disrupted the data collection. A significant link was found between newly installed energy efficiency interventions and both improved home environments and fewer problems paying bills, supporting the findings if the case study research. Following on from this, the slightly higher health scores reported in homes with warmer living rooms show possible signs of a physical health impact arising from energy efficiency measures. The stronger relationship between perceptions and health, however, suggests that psychological benefits are present and, in this study, dominant. Little evidence was found linking energy-related behaviours to health but this does not preclude the possibility that the impacts from energy efficiency measures or environmental changes are diminished or otherwise influenced by behaviour. Similarly the possibility exists that the full extent of health impacts has not been captured by the self-report questionnaires.

Despite the positive effects of energy efficiency measures on the home, the present research found that newer interventions were linked with worsening wellbeing and (possibly) health, with both the positive and negative links being weaker for measures installed longer ago. This appears to indicate that energy efficiency improvements cause negative impacts that dissipate over time. If this is the case, these impacts may be psychological due to failure to meet expectations, imposition or disruption (Gilbertson, Stevens, Stiell, & Thorogood, 2006), temporary physical effects from pollutants in the intervention materials or from necessary redecorating (Carslaw & Wolkoff, 2006), or more permanent effects such as those caused by reduced ventilation (Milner et al., 2015) that become diluted over time by other factors that affect health.

The survey and monitoring studies conducted in North Lincolnshire identified a set of associations that raise the possibility of a logical, intuitive process taking place in many homes from the installation of energy efficiency to improvements in the health of the residents. The studies also demonstrated the difficulty in accurately describing and quantifying the relationship and the obstacles that can arise when conducting such research. This prompted a return to the existing literature on energy efficiency and health in order to determine whether an assessment of the overall health impacts of household energy efficiency measures could be made.

The Impact of Household Energy Efficiency Measures on Health: A Meta-Analysis

The two empirical studies described in the previous chapters collected substantial amounts of information − continuous environmental recordings over an entire winter season and an array of both factual and perceptual data reported by residents. Analysis of these results in tandem uncovered a series of associations indicating a potential route between the installation of household energy efficiency measures and health improvements for residents, via perceived or actual changes to the home environment and finances. However, the size of the samples and the retrospective nature of the studies (with no baseline data prior to installation) limited their ability to identify a clear, direct relationship between energy efficiency and health. In order to conduct a more statistically powerful investigation of this relationship, the extant literature was reviewed again in more detail.

The present research systematically reviews studies investigating the impact of household energy efficiency measures on the physical health and mental wellbeing of building occupants. Meta-analysis is used to estimate the size of the relationship between measures (e.g., the installation of double-glazing) and outcomes (e.g., respiratory health) across a range of studies by computing a sample-weighted average effect size – the standardised mean difference in outcomes between an experimental and a control group (Schwarzer, 1987). The approach adopted has a number of strengths. Broad inclusion criteria were applied to recognise the diversity of household energy efficiency measures that are available and used internationally. This served to generate a large, unbiased sample for the effect size calculation, maximising confidence in the result. The large sample size and the diversity of the studies included also enabled effect sizes to be determined for subgroups within this sample (e.g., studies targeting vulnerable participants, those with objective versus self-report measures of health outcomes) in order to identify the factors that influence the relationship between energy efficiency measures and health and wellbeing. The result is an empirical comparison of the impact of different samples, interventions and study designs on the apparent health impacts of energy efficiency measures.

Material and methods

Data collection

Bibliographic databases including Web of Science, BIOSIS Citation Index, MEDLINE, PsychINFO and Google Scholar were searched in December 2011 for any of the keywords (energy, efficiency, "energy efficiency") AND (domestic, residen* hous*, home*) AND (soci*, health, wellbeing, "well-being", mental, anxiety, depression, stress, happiness, distress). Quantitative studies that examined the relationship between household energy efficiency measures and the health of the households' occupants were selected. In order to identify the maximum number of relevant studies, no restrictions were placed on the study date, location, or design. Studies that did not measure health directly but used existing literature to estimate the likely health impact of an intervention from an intermediate outcome, such as temperature or air quality (e.g., Dharmage et al., 1999) were excluded. Reference and, where possible, citation lists were searched for each accepted study, as well as for a number of the rejected studies and selected reviews.

The review included studies investigating the effects of one or more household energy efficiency measures that could be widely retrofitted, including various insulation types (e.g., loft, cavity, internal, and external solid wall insulation), installing or upgrading central heating, draught proofing, double glazing, and other sealing measures. To ensure the broader transferability of our findings, the focus was limited to permanent, conventional housing. Studies relating solely to ultra-low-cost housing interventions, such as adding cardboard insulation or replacing corrugated iron walls and roofs with better materials (Mathews et al., 1995) were therefore excluded. All measures of general health, mental health, wellbeing, and specific illnesses were included whether physically tested, self-reported, observed, or obtained from a third party (e.g., from general practitioner (GP) records).

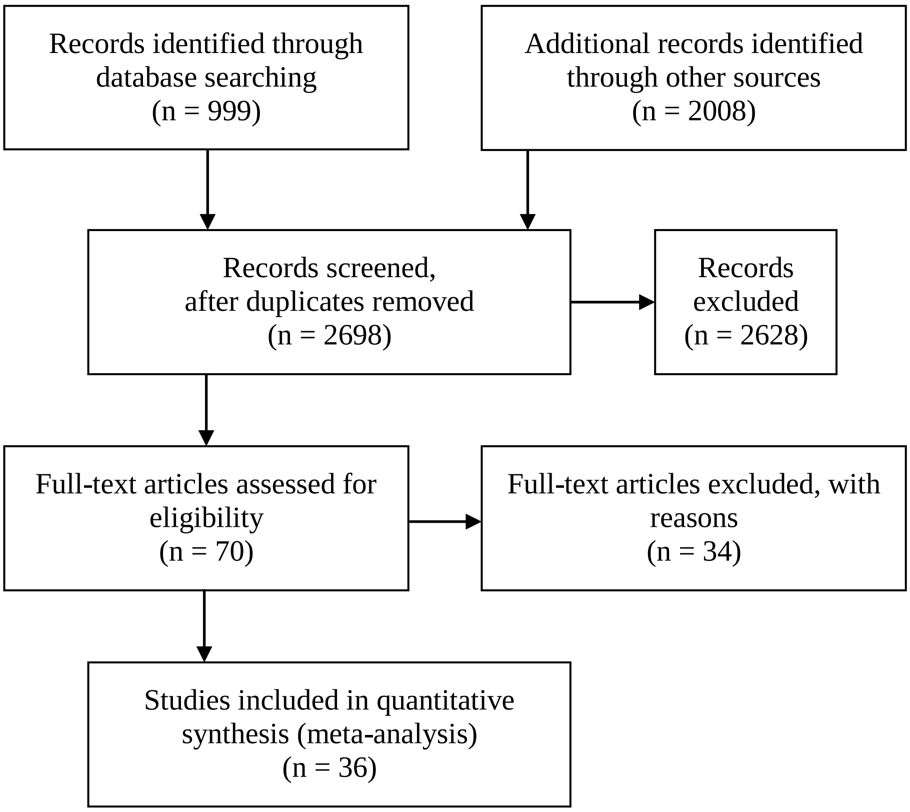

Figure 33: PRISMA flow diagram (based on Liberati et al., 2009) of the study selection process, where n = number of studies

Exclusions

Figure 33 shows the flow of papers through the review. After screening and removing duplicates, seventy papers warranted further examination. Where two papers reported effects for the same sample, the more direct measure of the health impact of the energy efficiency measure was selected. For example, a study by Jedrychowski et al.

(1998) investigating the impact of home heating on health was selected over their two papers focusing on the same sample (1998, 2005) that featured heating as a possible moderator of the impact of outdoor pollution. On the basis of this exclusion criterion, ten articles (14%) were rejected.

The authors of fifteen studies were emailed to request data in order to enable the calculation of effect sizes, nine of which replied. Six of these studies subsequently proved suitable for inclusion in the final analysis. Therefore, lack of reported data meant that effect sizes could not be extracted from nine studies (13%), with sample size *n* not always specified for each group of interest (e.g., Zock et al., 2002), controls not included or reported (e.g., Schenker et al., 1982) and insufficient data provided, either on the measures employed (e.g., Kasznia-Kocot et al., 2010) or the outcome statistics (e.g., Osman et al., 2010).

Five studies (7%) were excluded as they investigated the impact of factors relating to energy efficiency (such as the fuel used for heating) on health, but did not report the systems or technologies present (e.g., Baker et al., 2006). Seven studies (10%) were excluded for not reporting enough information to be able to attribute effects to energy efficiency measures. For instance, Woodfine et al. (2011) studied the health impact of a programme that included central heating upgrades but also made improvements to ventilation. The effects of the two interventions were not separated when analysing the results. Three papers (4%), comprising two repeated measures studies (e.g., Somerville et al., 2000) and one study generating relative risks (Hunter et al., 2003), were rejected as the data provided was insufficient to allow the results to be converted into effect sizes compatible with the effect sizes derived from other designs[20].

[20] Insufficient data was available, for instance, to convert the effect sizes derived in these particular repeated measures studies from the change-score metric into the correct raw-score metric to make them compatible with the other effect sizes calculated.

Extracting effect sizes

In order to determine the difference in health between participants who received an energy efficiency measure and participants who did not, effect size *d* (Hedges and Olkin, 1985) was calculated for each study using the formula:

$$d = \frac{x_1 - x_2}{(sd_1 + sd_2)/2}$$

where *x* = mean of each group and *sd* = standard deviation of each group. Positive effect sizes indicate that the energy efficiency measure improved health relative to the comparison condition, while negative effect sizes indicate that the energy efficiency measure led to poorer health relative to the comparison condition. Values of *d* = 0.20, 0.50 and 0.80 indicate small, medium and large effects respectively, according to Cohen (1992).

Throughout the data extraction process, unadjusted effect sizes (i.e., before accounting for other factors) were used where possible to ensure consistency between the studies. In studies that reported more than one health outcome (e.g., Howden-Chapman et al., 2007) the most direct measure of overall health was selected, preferring physical tests or self-report health questionnaires, over more indirect indicators (e.g., health service use or work or school absences). Where sample sizes differed greatly within a study, measures with the largest samples were chosen in order to maximise the power to identify relationships. For example, from Yarnell and Stleger (1977) the 550 responses regarding the presence of symptoms were selected over the lung function tests carried out on a small sample of these children. If no single health measure was clearly preferable in these terms, or where multiple interventions were assessed, the effect sizes within the study (across measures and interventions) were computed prior to inclusion in the main data set. Where studies did not report the sample sizes for the experimental and control groups separately, it was assumed that each group comprised half of the total sample. Where participants were matched, chi square was used to determine the average difference between the experimental and control (or before and after) groups. Studies reporting effects in terms of odds ratios (i.e., the odds of a health outcome occurring following an intervention over the odds of this occurring without the intervention) were included by following the method described by Chinn (2000) .

Table 27: Studies included in the meta-analysis

Study	Intervention	Health measure	*n* experimental	*n* control	*d*
Austin and Russell (1997)	Heating, insulation	Self-reported	768[a]	769	0.02
Barton et al. (2007)	Heating, insulation[b]	Self-reported	193	254	-0.02 **
Braubach et al. (2008)	Insulation, heating, glazing	Self-reported	209	148	0.17
Broder et al. (1991)	Insulation	Self-reported	699	605	-0.24 **
Butland et al. (1997)	Heating	Self-reported	566	383	0.23 ***
Demissie et al. (1998)	Heating	Lung function tests	307	545	0.09
Emond et al. (1997)	Heating	Parent-held record	231	71	0.12
Engvall et al. (2003)	Heating, sealing measures	Self-reported	1620[a]	1621	-0.03
Heyman et al. (2005)	Heating, insulation	Self-reported inc. SF-36[c]	166[a]	167	0.20 *
Homoe et al. (1999)	Insulation	Medical examination	194	261	0.06
Hopton and Hunt (1996)	Heating	Reported by parent	55	77	0.03
Hosein et al. (1989)	Heating	Self-reported	1015	159	0.02
Howden-Chapman et al. (2007)	Insulation, sealing measures	Self-reported inc. SF-36[c]	967	954	0.20 ***
Howden-Chapman et al. (2008)	Heating	Reported by parent	173	173	0.43 ***
Infante-Rivard (1993)	Heating, insulation	Reported by parent	457	457	-0.18
Iversen et al. (1986)	Glazing	Self-reported	106	535	0.60
Jarvis et al. (1996)	Heating	Blood & lung tests, ECRH Survey[d]	496[a]	497	0.00
Jedrychowski et al. (1998)	Heating	Reported by parent	557[a]	558	0.24
Jones et al. (1999)	Heating	Reported by parent	100	100	0.00
Jordan et al. (2008)	Heating	Self-reported	157	639	0.22
Leen et al. (1994)	Heating, glazing	Reported by parent	115	96	0.04
Lloyd et al. (2008)	Package of measures[e]	Blood pressure tests	27	9	1.41 ***

Miyake et al. (2007)	Heating	Reported by parent inc. OMCHS[f]	214	575	0.11
Mommers et al. (2005)	Sealing measures, glazing	Reported by parent inc. ISAAC[g]	580	601	0.09
Norman et al. (1986)	Insulation	Reported by parent	29	58	0.13
Roulet et al. (2006)	Building energy efficiency[h]	Self-reported	42	42	-0.18
Sammaljarvi (1991)	Heating	Reported by parent	850[a]	850	0.00
Schafer et al.(1999)	Heating	Self-reported & blood/urine/skin tests	484	1831	0.09 *
Shortt and Rugkåsa (2007)	Heating, insulation	Self-reported	46	54	0.04
Tavernier et al. (2006)	Heating, insulation, glazing	Self-reported	90	90	0.00
Vandentorren et al. (2006)	Insulation	Medical records	272	228	0.45 ***
Viegi et al. (1991)	Heating	Self-reported	1181[a]	1181	0.05
Walker et al. (2009)	Heating	Self-reported inc. SF-36[c]	670[a]	670	-0.16
Windle et al. (2006)	Heating, insulation	Self-reported inc. EQ-VAS[i]	205[a]	206	-0.43
Yarnell and St Leger (1977)	Heating	Self-reported	298	252	-0.10
Zacharasiewicz et al. (2000)	Heating	Self-reported inc. ISAAC[g]	3551	330	0.21

Notes: n = sample size, d = effect size, p = significance, denoted by *$p < .05$. **$p < .01$. ***$p < .001$.

[a] Where n was not given separately for experimental and control groups, the total n was halved.
[b] plus other improvements including ventilation, rewiring and re-roofing.
[c] Short Form 36 Health Survey.
[d] European Community Respiratory Health Survey.
[e] including heating, insulation, sealing measures, glazing.
[f] Osaka Maternal & Child Health Study.
[g] The International Study of Asthma and Allergies in Childhood.
[h] "low-energy" vs. "high-energy" buildings.
[i] EuroQol Visual Analogue Scale.

Coding Sample, Intervention, and Design Features

Table 27 shows the effect sizes obtained from the thirty-six studies included in the meta-analysis, along with the type of intervention and measure of health employed. Samples ranged from a few dozen participants in specific areas (e.g., Norman et al., 1986), to thousands of respondents in wider cross-sectional surveys (e.g., Zacharasiewicz et al., 2000). Most studies focused on populations in Europe (number of studies, k = 27, 75%), including fifteen in the UK (42% of all studies), seven in central or eastern Europe (19%) and three in Scandinavia (8%). The remainder comprised six studies in North America (17%), two in New Zealand (6%), and one in Japan (3%). Fourteen studies (39%) investigated the health impact of a package of two or more types of intervention; seventeen studies (47%) looked solely at central heating, four studies (11%) at insulation and one study (3%) at glazing measures.

The effect sizes from the primary studies were then combined using Meta 5.3 software (Schwarzer, 1987), weighting each effect by its sample size (n). Given the wide range of study characteristics, a random effects model was used (Cooper, 1986) and the initial meta-analysis was followed by an analysis of the factors that might moderate effect sizes. These moderators included:

(1) The type of installed measures, including heating upgrades, wall or loft insulation, draught-proofing / sealing around doors or windows, glazing improvements and packages of these measures.

(2) The age, health, and income level of residents, noting where interventions targeted 'vulnerable' groups (e.g., children, the elderly, and those with low incomes or medical conditions).

(3) Where the interventions took place (e.g., in deprived urban or rural communities, or across a wider, more diverse area) and how they were implemented (e.g., were the interventions imposed or voluntary?).

(4) When interventions were carried out, particularly in relation to changes in legislation expected to affect residential energy efficiency. For instance, the Kyoto Protocol (UN, 1998) was finalised in 1998, prompting global efforts on energy efficiency, and came into force in 2005 when the EU began implementing stricter housing standards.

(5) The type of assessment measures used. For example, whether subjective measures (e.g. self-report surveys) or objective measures (e.g. physical tests such as blood pressure measurements and lung function tests) of health were used.

(6) The health aspect investigated, such as whether specific conditions (e.g., asthma) or overall health and wellbeing were assessed.

(7) The sampling procedure employed. For instance, whether studies used case/control designs, where participants receiving an intervention are compared to a non-intervention or non-condition group, or cross-sectional designs, where the prevalence of energy efficiency measures and certain health conditions are identified within a cross-section of a population (e.g., those who have central heating).

(8) Whether or not an intention-to-treat approach was used, where the study group analysed is based on the numbers initially selected to receive the intervention including those who later withdrew, rather than just those who received the intervention and provided outcome measures.

Results

Overall effect of energy efficiency measures on health

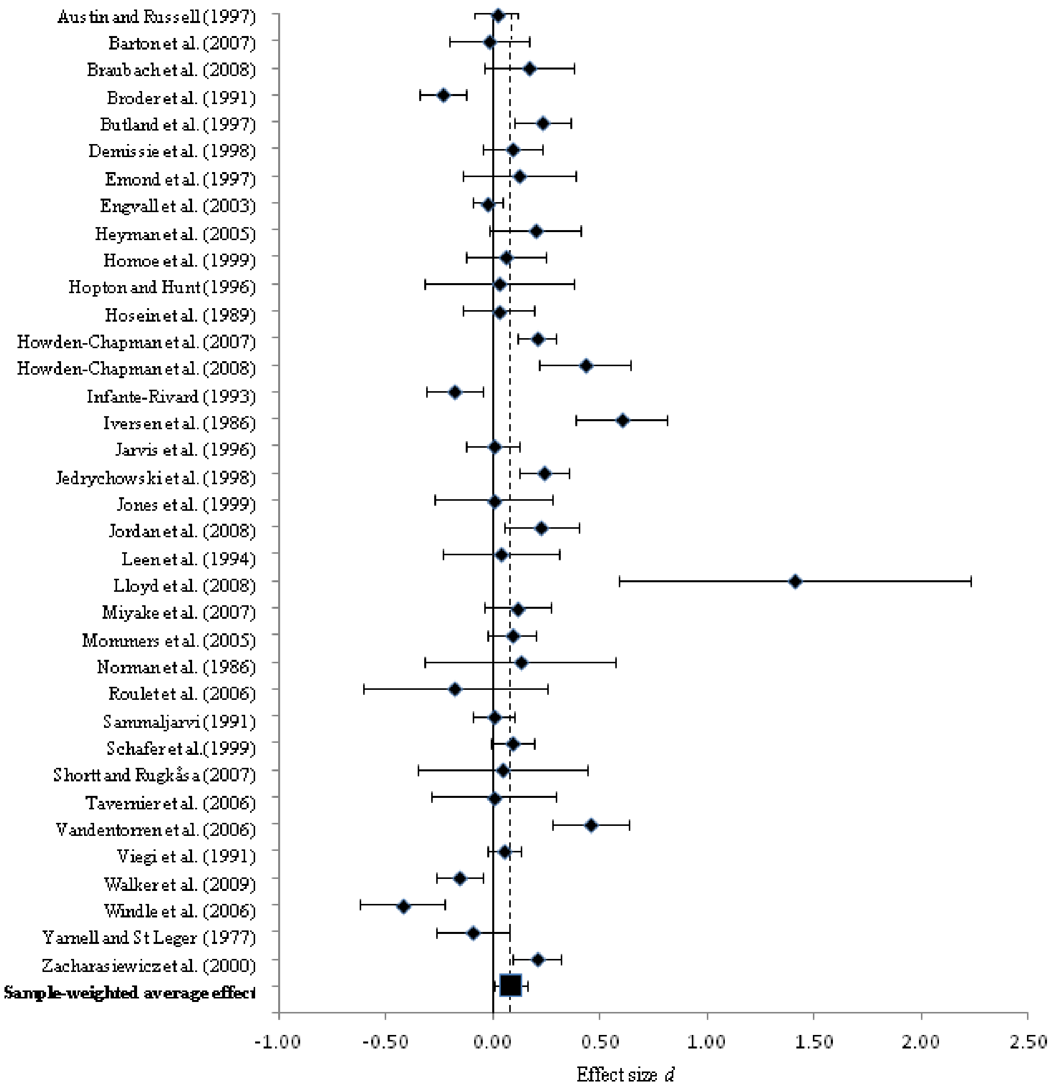

Figure 34: Forest plot showing the sample-weighted average effect of *d*+ = 0.08 (dashed line) and the range of effect sizes extracted from the individual studies. The error bars indicate the 95% confidence intervals for each effect

As shown in Figure 34, effect sizes from the primary studies ranged from *d* = −0.43 (a small-to-medium effect linking energy efficiency measures with poorer health) to *d* = +1.41 (a very large effect linking these measures with health benefits). At more than three times the size of any other effect included, the very large effect found by Lloyd et al. (2008) is a clear outlier. However, removing this value only reduces the sample weighted average effect size by 0.01 and in fact increases the statistical significance of this overall result. Where studies did not report the size of non-significant effects, these values were assumed to be zero for the calculations. This conservative approach was taken in order to ensure that the overall effect size was not overestimated.

Moderators of the relationship between energy efficiency measures and health

Effect sizes were heterogeneous, $Q(1) = 199.72$, $p < .001$, prompting a search for moderators of the effect of measures on health. The findings are shown in Table 28. Results are presented showing the sample-weighted effect size (d_+), alongside the significance (p) the homogeneity statistic (Q) and the number of studies (k). Studies that investigated the health impact of packages of measures found significantly smaller positive health effects ($d_+ = 0.04$) than studies where individual measures were implemented ($d_+ = 0.11$), $Q(1) = 8.17$, $p < .01$. No differences were found between the health effects of installing insulation only ($d_+ = 0.09$) and central heating only ($d_+ = 0.09$), $Q(1) = 0.00$, *ns* (not significant). The health benefit from installing central heating only was found to be significant ($p < .01$).

Table 28: Moderators of the Impact of Household Energy Efficiency Measures on Householder Health

Variable	*Q*	*k*	*n*	*d+*	*95% CI*
Energy efficiency measures					
Intervention type	0.00				
Central heating only		17	19,796	0.09**	0.03-0.15
Insulation only		4	2,346	0.09	-0.18-0.36
Scale of intervention	8.17**				
Single measure		22	22,783	0.11**	0.03-0.19
Multiple measures		14	10,953	0.04	-0.16-0.25
Participants and setting					
Type of participant	2.12				
Vulnerable groups[a]		29	24,754	0.09*	-0.01-0.20
Not vulnerable groups		7	8,982	0.06	-0.15-0.26
Income level of participants	4.60*				
Low income		8	3,699	0.15	-0.18-0.48
Not low income		28	30,037	0.08*	-0.02-0.12
Health of participants	2.74				
Poor health[b]		8	3,247	0.13*	-0.02-0.29
Not poor health		28	30,489	0.07	-0.04-0.18
Age of participants	0.36				
Children (< 18 years)		20	18,870	0.08***	0.03-0.13
Adults (≥ 18 years)		8	8,355	0.10	-0.10-0.30
Voluntary or imposed	1.56				
Voluntary interventions		4	3,739	0.12	-0.12-0.36
Other interventions		32	29,997	0.08	-0.02-0.18
Location	32.37***				
Urban-based interventions		18	11,407	0.15*	0.00-0.31
Other interventions		18	22,329	0.02	-0.06-0.11
Study methods					
Health aspect measured	9.43**				
General health		13	12,286	0.04	-0.10-0.17
Specific conditions		23	21,450	0.11*	-0.01-0.23
Specific condition measured	47.80***				
Respiratory health conditions		16	16,982	0.07**	0.02-0.12
Non-respiratory conditions		4	3,595	0.33	-0.30-0.95
Health measure	See notes[c]				
Self-report only		19	21,608	0.05	-0.05-0.14
Medical tests included		5	4,651	0.24	-0.27-0.75
Third party information only		12	7,477	0.12**	0.03-0.21

	Q	k	n	d+	CI
Health measure: *Self-report only*	3.10				
Existing instruments		5	7,886	0.01	-0.24-0.26
Purpose-built questions only		15	13,854	0.06	-0.04-0.15
Health measure: *Medical tests included*	33.07***				
Medical tests only		3	1,343	0.43	-0.41-1.27
Medical tests and self-report		2	3,308	0.05	-0.04-0.14
Study design	12.91***				
Cross section		16	21,544	0.05	-0.03-0.12
Case / control studies		20	12,192	0.13*	-0.07-0.29
Intention To Treat (ITT)	5.35*				
ITT approaches		3	3,708	0.01	-0.19-0.22
Non-ITT approaches		33	30,028	0.09*	-0.01-0.19
Age of studies					
Before or after Kyoto Protocol came into force[d]	7.90**				
2005 onwards		15	8,821	0.13	-0.07-0.33
2004 or earlier		21	24,915	0.06*	-0.01-0.12
Before or after Kyoto Protocol was finalised[d]	11.03***				
1998 onwards		22	20,880	0.11	-0.02-0.25
1997 or earlier		14	12,856	0.04	-0.06-0.13

Notes: Q = homogeneity Q statistic, *k* = number of studies, *n* = sample size, *d+* = sample weighted effect size. Significance (*p*) is denoted by *p < .05. **p < .01. ***p < .001.

[a] Vulnerable groups include children, elderly, and those with low incomes or poor health

[b] Poor health group consists of participants screened for a particular condition and patients recruited from a surgery.

[c] Self-reported only vs. Medical tests included, *Q* = 35.86***. Self-reported only vs. Third party information only, *Q* = 7.65** . Medical tests included vs. Third party information only, *Q* = 10.25**.

[d] Kyoto Protocol set binding emissions reductions for 37 industrialized countries and the European Community (UN, 1998), so these milestones were selected to represent global progress on energy issues, including energy efficiency.

The vast majority of studies (*k* = 29, 81%) focused on one or more vulnerable groups (including children, the elderly and those with low incomes or poor health). Significant health benefits from energy efficiency measures were identified for children in particular (d_+ = 0.08), as well as for people in poor health (d_+ = 0.13) and for vulnerable groups as a whole (d_+ = 0.09). There was however no significant difference between the effect size for vulnerable groups and that for the general population (d_+ = 0.06), $Q(1) = 2.12$, *ns*. Similarly, the effects on children and people in poor health were not significantly different to the respective effects on adults and those not in poor health. Greater effects of energy efficiency measures on health were found though in studies focusing on participants with low incomes (d_+ = 0.15) than in other studies (d_+ = 0.08), $Q(1) = 4.60$, $p < .05$.

Energy efficiency measures had comparable effects on health in the four studies (11%) that specified that participants had volunteered for measures (d_+ = 0.12) than where this was not specified (d_+ = 0.08), $Q(1) = 1.56$, *ns*. Half of the studies (50%) limited recruitment to urban communities. These studies reported significantly more positive effects (d_+ = 0.15) than studies that sampled from rural or wider geographic areas (d_+ = 0.02), $Q(1) = 32.37$, $p < .001$.

Thirteen studies (36%) assessed the general health of participants by measuring a range of outcomes – including mental health – or by using a measure of overall health. These studies reported significantly smaller impacts of energy efficiency measures on general health (d_+ = 0.04) than the studies investigating specific medical conditions (d_+ = 0.11), $Q(1) = 9.43$, $p < .01$. Although the studies that measured the effects of energy efficiency measures purely on respiratory function reported significant effects (d_+ = 0.07), these were significantly smaller than in studies examining effects on other specific illnesses or symptoms (d_+ = 0.33),

$Q(1) = 47.80$, $p < .001$, which included skin conditions, ear infections and high blood pressure.

The primary studies employed a range of different measures of health and wellbeing. Studies that employed medical tests tended to report larger effect sizes ($d_+ = 0.24$) than studies using only self-reported measures ($d_+ = 0.05$), $Q(1) = 35.86$, $p < .001$, or information from third parties ($d_+ = 0.12$), $Q(1) = 10.25$, $p < .01$. In turn, studies that estimated health effects using information from third parties reported significantly larger effects ($d_+ = 0.12$) than those using only self-report measures ($d_+ = 0.05$), $Q(1) = 7.65$, $p < .01$. Studies that compared cases with controls found significantly larger effects on health ($d_+ = 0.13$) than purely cross sectional studies with no control group ($d_+ = 0.05$), $Q(1) = 12.91$, $p < .001$. Studies that conducted intention-to-treat analyses found significantly smaller effects ($d_+ = 0.01$) than those using other approaches ($d_+ = 0.09$), $Q(1) = 5.35$, $p < .05$, although relatively few studies ($k = 3$) used intention-to-treat analyses. We were not able to evaluate the effect of length of follow up on the relationship between energy efficiency measures and health as, of the eleven studies (31%) that reported when health effects were measured in relation to the energy efficiency measure, only two (6%) continued this monitoring beyond the first year of installation[21].

The date of publication was found to have a significant influence on the impact of energy efficiency measures on health. Studies published from 1998 onwards produced larger effects on health ($d_+ = 0.11$) than those published earlier ($d_+ = 0.04$), $Q(1) = 11.03$, $p < .001$. Similarly, studies published before 2005, reported

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[21] Participants for most studies were recruited through a medical screening process or as a random cross-section, so the time since installation of any energy efficiency measures was generally not recorded and will have varied considerably within studies. Of the studies that measured health a specific time period after the implementation of a particular retrofit scheme, only two continued past the first year of installation, the remaining five following up mainly between 8 and 12 months.

smaller health effects of energy efficiency measures ($d_+ = 0.03$) than studies (41%) published later ($d_+ = 0.13$), $Q(1) = 15.50$, $p < .001$.

Relationships between moderators

Links between moderators might be expected. For instance, some methods of assessing health may be more suited to particular conditions or population groups. Chi-square was used to investigate the relationship between factors that significantly influenced the impact of energy efficiency measures on health (see Table 29). Where factors were related constructively, i.e. both linked with larger effects, it is difficult to determine which factor influenced effect sizes or whether both factors influenced effects independently[22].

Only five constructive relationships were found. These relationships are shown in bold and their implications are considered in the following discussion.

[22] For instance, studies published recently − 2005 onwards − were more likely to be based in low income areas and may therefore have found larger effects on average because of this setting. Alternatively, there may be other reasons why recent studies found larger effects, so studies in low income areas may also have found larger effects as a consequence.

Table 29: Relationship between study factors that influence effect sizes

Studies…	Are more likely to…	X^2
Published recently[a]	Involve multiple measures than single measures	8.35*
Published recently[a]	**Be based in low income areas**	**4.70***[b]
Published recently[a]	Measure general health than specific health conditions	6.36*
Published recently[a]	**Measure non-respiratory conditions than respiratory health**	**6.22***
Based in low income areas	Involve multiple measures than single measures	5.64*[b]
Based in low income areas	Use Intention To Treat study designs	11.46*[b]
Based in low income areas	**Use case-control study designs**	**4.25***[b]
In urban areas	**Use medical tests or third party data than self-reported only**	**5.46***
Measuring non-respiratory conditions	**Include medical test data**	**14.05****[b]

Notes: *p < .05. **p < .01. Only significant test results where $p < 0.05$ are included. **Bold** indicates that both factors were found to be associated with significantly larger positive effects of energy efficiency measures on health.

[a] Published from 2005 onwards.

[b] Fisher's Exact Test used as a more accurate estimation of significance than chi square for small numbers of studies.

[c] Screened for a particular condition or patient recruited from a surgery.

Discussion

The aim of the present review was to systematically quantify the impact of household energy efficiency measures on health and wellbeing. Thirty-six primary research studies with a combined sample of over thirty thousand participants were synthesised. A small, but significant and positive, effect of household energy efficiency measures on health ($d_+ = 0.08$) was found. The effect is consistent with previous reviews that have reported "modest" physical health improvements following large scale household retrofit schemes (Liddell and Morris, 2010) and mixed, but mainly positive effects of housing improvements on health and wellbeing (PHIS, 2006; Thomson et al., 2009; 2013).

In contrast to recent concerns (e.g., Bone et al., 2010) and the findings from some individual studies (e.g. Windle et al., 2006), the health impacts from household energy efficiency measures were found to be positive in all of the intervention and population subgroups analysed. Significant health benefits were identified for children in particular, as previously noted by Liddell and Morris (2010), and for people with poor health and vulnerable groups in general, supporting the continued use of household energy efficiency improvements to tackle fuel poverty and reduce health inequalities, rather than purely as a tool for carbon reduction. Despite these findings though, no significant differences were found between the effects on these groups and on other populations, suggesting that there are potential health benefits inherent in improving energy efficiency, regardless of the demographics of the recipients and not limited to certain areas of society.

Few differences were found between the effects on subgroups of the sample population. Instead, the majority of the differences identified were related to the nature and design of the studies themselves. Objective measures of health, such as medical tests, identified larger effects than self-report methods, while the sampling procedure and approach to data analysis adopted also led to significant differences in the resulting effect sizes. Significantly larger effects were found on specific medical conditions than on general health, reflecting previous findings such as the impacts of housing improvements on respiratory symptoms in particular (PHIS, 2006; Thomson et al., 2013). Finally, larger health effects were found by recent studies than older studies. Such findings point to the importance of the current meta-analysis and other research seeking to establish the factors that influence the likely impact of energy efficiency measures on health.

Factors influencing the impact of energy efficiency measure on health

By including a diverse range of studies in the analysis, it was possible to identify a number of factors that influence the impact of energy efficiency measures on health outcomes. These included: (1) the scale of the intervention, (i.e. the number of different measures installed); (2) the study participants and setting; and (3) where, when, and how studies were conducted, including what aspects of health were measured and by what instruments.

Age of studies

The present review found a larger impact of energy efficiency measures on health among recent studies than in older studies. This may be the consequence of improvements to the targeting of schemes − reflected in the finding that recent studies more frequently focussed on participants with low incomes − such that recent interventions are more likely than older interventions to reach the people most in need or who would benefit most. The interventions themselves may have become more effective over time as stricter housing regulations (or the push for councils or householders to demonstrate 'green' credentials) drive forward the use of better materials and products. For example, following health concerns, urea-formaldehyde foam insulation was banned in the US and Canada in the 1980s (Norman et al., 1986). A greater ability to detect health changes may also have emerged over the last decade due to improvements in the design of studies. Health improvements found by Thomson et al. (2001) were weakened by the small number of energy efficiency related studies, little controlling for confounders and high attrition rates but similar reviews conducted 8 and 12 years later (Thomson et al., 2009; 2013) identified positive impacts on general health, respiratory symptoms and mental health from a range of sources, including some well-conducted studies.

Regardless of whether the health benefits from energy efficiency measures have increased in recent years or whether their detection has improved, this finding supports the expansion of such programmes at a time when, in the UK, direct public funding for household energy efficiency is being replaced by investment from the private sector and homeowners themselves, e.g., through the ‘Green Deal’ (Energy Act, 2011).

Measurement of health

Larger effects of energy efficiency measures on health were found when measured objectively (e.g., using medical tests), or by asking a third party (primarily a parent), than when health was assessed using self-report measures. These findings might suggest that many interventions impact on health in ways that are not amenable to self-report. For instance, improved lung function (Demissie et al., 1998) or reduced blood pressure (Lloyd et al., 2008) may produce only slight changes in symptoms or take place incrementally over a long period of time and so go unnoticed when rating one's own health. Such health changes might be easier for others to notice, although parental bias or exaggeration could also inflate the health effects identified by third parties. It is also possible that negative feelings toward household energy efficiency measures due to their imposition or disruption might affect self-report ratings of health impacts, masking underlying objective health benefits in a manner that is not possible through, say, a blood test.

Scale of the intervention

The present review found that packages containing two or more types of energy efficiency measure tended to have smaller effects on health than single interventions. At first glance this finding may seem counterintuitive; one might have anticipated that more comprehensive measures will have larger effects than less comprehensive measures. Individual measures, however, may be employed more often as a solution to a known problem (e.g., cold, damp, lack of existing provision). Solving these problems, therefore, can potentially have a greater impact than a non-selective, area-based approach that is designed to raise, for example, baseline thermal performance, regardless of the standard of housing. As Thomson and Petticrew (2007) found, in areas earmarked by providers to receive interventions, not all the residents experience housing problems, disqualifying some from receiving the full package of measures and limiting the potential for improving housing conditions. Some of the package schemes studied were tailored according to the needs of each household (e.g., Howden-Chapman et al., 2007) but a breakdown of the number and nature of partial packages that resulted was not always given.

Participants and setting

Given the focus on fuel poverty and health in national policy, for instance the UK Fuel Poverty Strategy (DECC, 2001), it was unsurprising that the majority of the primary studies included in the present meta-analysis targeted young, old, low income or ill participants. Gratifyingly, positive health effects were found for children and people with poor health, providing further justification for policies that use energy efficiency to tackle social inequalities such as the Affordable Warmth component of the UK's Energy Company Obligation (Energy Act 2011). The health benefits of energy efficiency improvements for some of the most vulnerable in society provides even greater justification for putting health at the centre of fuel poverty strategies and highlights how tackling fuel poverty can help to reduce health inequalities, as recognised by the UK Department of Health (DH, 2012).

The larger benefits of energy efficiency measures among people with low incomes may be due to a greater scope for improvement as starting from a lower baseline in either housing standard or health means less chance of reaching a ceiling where further improvement becomes difficult. Thomson et al. (2013), for example, found that housing improvements targeting people in cold homes or with respiratory problems were particularly likely to yield health benefits. Similarly, Howden-Chapman et al. (2011) identified more significant health effects in a study of asthmatic children than in an earlier study which included all household members, regardless of health status[23]. People with low incomes or, particularly, poor health also tend to spend more time in their homes (Thomson et al., 2009). Therefore it is likely that they will benefit more from any improvement to the indoor environment.

The larger health effects from energy efficiency measures seen in urban areas might be expected, assuming such areas have above average levels of deprivation and, therefore, lower levels of housing standards and health. That said, it should be noted that studies based in urban areas were not found to disproportionately target participants with low incomes or poor health. The larger effects of energy efficiency

[23] The studies, however, investigated different types of interventions: heating and insulation respectively.

interventions on health found in urban areas may be explained by the increased use of medical tests or third party data in such studies, or by the greater likelihood of outdoor pollution, with residents benefiting from being better insulated against industrial or traffic emissions that they formerly suffered.

Implications for future research and investment

The present meta-analysis found that energy efficiency measures, on average, lead to significant, positive health outcomes, supporting the past use of household energy efficiency as a tool for addressing health and other social inequalities (e.g. DECC, 2001). The benefits of a warm, affordable home are intuitive to a certain extent and are backed by epidemiological evidence (Marmot, 2011). The global economic crisis, however, continues to influence policy and impose constraints on public spending in many countries. Future investment decisions (particularly large scale investments from the public purse) are, therefore, likely to be subject to closer scrutiny to ensure that the best value for money options are chosen and that the benefits will be fully realised.

Research on household energy efficiency measures ought to consider study design elements that could mask or uncover health effects. A key issue with the studies in the present review is that few followed up participants after more than twelve months to investigate cumulative or long term health changes, or used medical tests to form an objective assessment of health status. Practical or ethical concerns may restrict the use of such onerous or intrusive methods, at the expense of investigative power. Practicality may also limit the use of case-control designs, which identified larger effects than found by cross-sectional studies. To ensure that the full impacts of interventions are captured, where possible studies and evaluations should conduct longitudinal monitoring over longer periods and use objective measures alongside self-reporting. The relatively large number of studies using parent-reported health measures would benefit from concurrent medical tests to validate this data.

The gap between self-reported and objectively assessed health scores also warrants further investigation to determine whether temporary or avoidable negative factors are skewing results (Carslaw and Wolkoff, 2006). Research into changes in mental health following household energy efficiency interventions could shed some light on the causes of such disparities, while helping fully capture the effects on recipients. While substantial qualitative research into psychological factors, such as the attitudes and behaviours of intervention recipients, has been carried out (e.g., Gilbertson et al. 2006), these were rarely discussed in the quantitative meta-analysed studies. Including data on: (a) whether interventions are voluntary or imposed on recipients, (b) satisfaction levels following installation, (c) guidance provided to recipients regarding the use of new technologies, or (d) the energy- and health-related beliefs of recipients, would help future analyses to determine the influence of these factors on health outcomes. This in turn can inform not just the design and targeting of interventions but also their implementation, as currently there is little scope to analyse how better communication, managing expectations or minimising disruption during installation might affect the health outcomes for residents.

The approach taken when analysing health change data can depend heavily on the remit of the study. Smaller health effects were found by the few studies that used an intention-to-treat (ITT) approach, which keeps participants in the experimental group for analysis even if they eventually refuse or miss out on the intervention, or in the control group even if they acquire the intervention independently. This occurred, for example, with the Scottish Central Heating

Programme where a quarter of the control group used by Walker et al. (2009) also received central heating. The diluted effect that results from an ITT analysis is intended to represent or evaluate the overall impacts of a scheme more realistically, by accounting for the drop-outs and failures that commonly occur. Using a non-ITT approach, however, would provide a more accurate assessment of the *potential* impact of the intervention. As Thomson et al. (2013) noted though, non-ITT studies rarely specify whether contamination of the control group has been accounted for. Research could provide more clarity as to whether the effects found represent the possible impacts from, say, the installation of central heating or the overall impact found by a particular central heating scheme.

Finally, future reviews and meta-analyses would benefit from comprehensive reporting in studies of energy efficiency measures. Where possible, research should provide clearer information regarding the circumstances that led to the health effects found, including: (i) the selection process both for the study (e.g., regarding the contamination issues discussed above) and the intervention scheme itself, (ii) participant demographics including income levels and initial health status, and (iii) potentially influential behaviours, such as time spent indoors and use of heating and ventilation, both before and after installation. Disaggregated data, ideally, should also be reported. Some studies reported health changes for all participants when providing this data for different interventions or groups of participants would have enabled a direct, controlled comparison of the factors affecting health outcomes. As Thomson et al. (2013) found, insufficient data and statistics prevented the extraction of an overall effect from a number of clearly relevant studies, unfortunately leading to their exclusion from the meta-analysis. Fully reporting all effect sizes found, or the data needed to calculate them such as standard deviations, would encourage their inclusion in empirical analyses, helping future reviews to adequately represent a broader and more robust evidence base.

Conclusions and Policy Implications

The present meta-analysis identified a range of impacts on health and wellbeing accruing from household energy efficiency measures. On average, the health of residents was found to improve following the installation of a household energy efficiency measure. Encouragingly, the larger effects found by recent studies suggest that this positive health impact is increasing over time; something that could be attributed to improved interventions that are able reach those who need them most. Energy efficiency measures were found to be detrimental in only a few studies, suggesting that harmful effects are rare, usually avoided (e.g., through better communication with residents) or outweighed by the health benefits. Recipients on low incomes saw greater improvements in health following energy efficiency measures, supporting the inclusion of energy efficiency measures in strategies to tackle social issues like fuel poverty and health inequity.

In order to help policymakers to comprehensively assess the value of investment options, future research should attempt to quantify the short- and long-term impacts of energy efficiency measures on both physical and mental health. Studies should be designed so as to maximise the likelihood of identifying health changes that might otherwise go undetected, not purely by controlling sample sizes but by using medical tests where possible and conducting follow-up health measurements beyond the first year of installation. Determining what characteristics, circumstances and behaviours influence health outcomes will help to ensure that interventions can achieve their potential benefits.

These findings demonstrate that many of the difficulties faced when conducting the empirical studies described in Chapters 2 and 3 are common problems that have limited the investigative power of much of the existing research on household energy efficiency and health. The detection of effects of the magnitude calculated by the meta-analysis is therefore unlikely without a very large sample or an alternative study design that would be difficult to conduct without significant resources. As an alternative to the quantitative approaches used to address the research question and to help contextualise their findings, the perspective of professionals involved in improving household energy efficiency was sought.

What stands in the way of improving health through energy efficiency?

Various reviews have highlighted the potential harm caused by living in cold or damp conditions (Liddell & Morris, 2010; Thomson, Thomas, Sellstrom, & Petticrew, 2013), including cold-related illnesses (Marmot, 2011) and mental health issues such as depression and stress (Liddell & Guiney, 2015; Shortt & Rugkasa, 2007). Living in cold or damp conditions can also have wider social implications including slower educational development in children who have no separate heated area for study or are more prone to cold-related school absences, and social exclusion where householders deter visitors because of the housing conditions (Richardson & Eick, 2006). The meta-analysis described in Chapter 4 found a significant positive relationship between household energy efficiency measures and health, suggesting that such measures have potential to tackle health inequalities by protecting vulnerable people from the impacts of fuel poverty[24]. This potential is not always seen to be realised, however, as evidenced by the studies included in this meta-analysis that found negligible or negative effects on health following energy efficiency improvements.

The discrepancy between the expected and recorded changes in health following the installation of household energy efficiency measures warrants further exploration in order to inform effective housing, energy and health policy. Global economic downturn has led to increased scrutiny and limitations on public spending. In the UK, this is reflected in the withdrawal of national funding for basic heating and insulation measures (e.g., Warm Front, Critchley, Gilbertson, Grimsley, Green, & Warm Front Study Group,

[24] In England a household is considered to be in fuel poverty if their fuel costs are above average and spending this amount would leave them below the poverty line (DECC, 2013).

2007) in favour of encouraging individuals and requiring energy companies to finance higher cost measures through the Green Deal and Energy Company Obligation schemes respectively (DECC, 2011). The impact of such a switch in approach will depend on both the perceived and actual effectiveness of the energy efficiency measures installed. We must ask therefore: why are we not seeing the health improvements expected?

Limitations in existing studies

Firstly there are reasons to suspect that health changes are being missed as evaluations of energy efficiency schemes may not fully capture health outcomes. As noted when analysing the existing evidence base in Chapter 4, the frequent use of short-term, self-reporting measures may mean that studies are failing to identify subtle or incremental health changes such as reduced blood pressure. Such changes might have dramatic consequences in the future (in this case, a lower risk of heart problems) and could be identified using medical tests or long-term monitoring. Unfortunately, practical and ethical issues prevented the use of medical tests and the planned approach to health monitoring in the studies described in Chapters 2 and 3, which restricted their ability to detect these subtle or incremental health changes. Additionally, few existing studies specify whether or not an 'intention to treat' approach was used to evaluate schemes. Health impacts calculated using this approach tend to be lower as households that drop out prior to installation are still counted. A lack of health changes in these unimproved households would therefore dilute the overall impact for a given intervention.

Limited uptake

A wide range of factors influence the decisions of residents to undertake energy efficiency refurbishments according to Organ, Proverbs, & Squires (2013), including three key motivators: money, comfort and, where attitudes are more altruistic, minimising impacts on the environment. However, other research suggests that encouraging residents to invest in energy efficiency or even accept free help may not be as simple as supplying effective technologies or making rational arguments for their worth. For instance, Christie, Donn, & Walton (2011) found an "asymmetrical perception of risk" (p. 456) where more importance is placed on upfront costs than on distant benefits, biasing the status quo. Lack of trust in authority and particularly energy companies can lead to suspicion of any help, advice or information they offered (Mumford and Gray, 2011). Emotional responses are also known to influence or even outweigh rational decision-making resulting in lifestyle choices that harm health such as smoking and drinking (Taylor-Gooby, 2004). These recognised issues could alter residents' perceptions of energy efficiency interventions and impair their ability to assess the costs and benefits, or even their own health and wellbeing.

Failure to improve living conditions

Inadequacies and flaws in energy efficiency measures or their installation could render them ineffective, producing changes to indoor environments below their theoretical potential. Interventions may also have unexpected detrimental impacts. Milner et al. (2015) found that the insulation and sealing of homes typically increases the presence of pollutants from indoor sources, potentially outweighing any health benefits from the improved thermal efficiency. The success of an intervention may therefore depend on the subsequent behaviour of the recipient, such as opening windows for ventilation or turning heating up. Willingness to adapt could be a key issue as behaviour is closely linked to notions of identity. Control and continuity are key elements of self-esteem according to Breakwell (1993) so any pressure to change could provoke a negative response. Energy-related behaviours can also enhance perceived status or avoid perceived stigma (Hards, 2013), providing further motivation to resist change.

Failure to significantly improve living conditions may not be due to the energy efficiency intervention, its installation or the behaviour of its recipient but an indication that the conditions were already near optimal. Such ceiling effects would suggest that the targeting or eligibility of a scheme needs reassessing.

Changes to the indoor environment not improving health

Just as living conditions may already be at a level that is difficult to improve on, there may be limited scope to help people already in good health. Self-reported health is particularly prone to ceiling effects. As stated earlier, small or slow health improvements often go unnoticed by the subject while health might be assumed not to have changed if living conditions were seen to have remained static. Negative feelings towards an intervention, for instance where one was imposed or caused disruption, might also result in low health ratings from recipients. In such cases the measure is perhaps more a reflection of their state of mind than an evaluation of overall health. Mental wellbeing is influenced by various perceptions regarding the home such as its comparative worth (Ellaway, McKay, Macintyre, Kearns, & Hiscock, 2004), status (Kearns, Whitley, Bond, Egan, & Tannahill, 2013), aesthetics and security (Bond et al., 2012). This might help explain why housing improvements have been shown to improve mental health in a number of studies (Egan et al., 2013; Macintyre et al., 2003) but not others (Clark & Kearns, 2012).

The relationship between the home environment, health and residents' perceptions of both is complex. Unnoticed household problems such as damp can affect physical health while imagined household problems can affect mental health. Poor housing conditions can cause stress which can in turn exacerbate physical health problems (Sandel & Wright, 2006), while illness can increase stress and financial problems can harm both physical and mental health (Gilbertson et al., 2012). The connected, circular nature of these various problems is evident in the application of cumulative stress theory to fuel poverty: Liddell & Guiney (2015) assert that as stresses like debt and poor health mount up their impacts combine not linearly but in a quadratic fashion, a second stress quadrupling rather than doubling the risk to the resident's wellbeing. Given the range of potential sources of stress described, the fuel poor should be seen as a particularly vulnerable group.

The role of health in household energy efficiency

To understand how household energy efficiency interventions contribute, or could contribute, to protecting and improving health for vulnerable people it is necessary to determine the role and prominence of health in household energy policy and decision-making. Energy efficiency schemes may feature health and wellbeing issues for a variety of purposes. Health may be used in the marketing or targeting of energy efficiency schemes. For example, promotional material for the Warm Front scheme (Critchley et al., 2007) formerly offered by the UK Government warned that cold homes can damage health, while Bolton Council currently offers a "Healthy Heating" grant (Bolton Council, 2015) specifically for people with ill health or receiving a disability benefit. Health might be monitored before, during and after a scheme's implementation and used to evaluate its success, as took place for a tower block retrofit scheme in Glasgow (Lloyd, Callau, Bishop, & Smith, 2008) where improvements in blood pressure were identified.

The local authority officers involved in promoting, planning and implementing energy efficiency improvement schemes will have researched, discussed and witnessed the impacts of these shifting policies and various technologies. Their experiences dealing with residents may help identify why energy efficiency schemes are accepted or rejected and how they affect energy-related behaviour and living conditions. By investigating each of these issues through a series of interviews with these professionals, the intention is to provide insight into how energy efficiency is currently being used in the UK as a tool for improving health, and how this could be done to greater effect.

Method

Procedure

Semi-structured interviews were carried out with professionals working in the fields of housing, energy, affordable warmth or health, with direct, front line experience of planning, promoting, delivering or evaluating energy efficiency improvement work in England. Potential interviewees were identified through existing contacts or by searching energy efficiency related pages on local authority websites, and were invited to take part in research on the role of household energy efficiency measures. Those that agreed were then interviewed individually (or, in two cases, in pairs) either face-to-face or by telephone in late 2013, with two further professionals contacted and interviewed a year later. The interviews, which lasted between 30 and 45 minutes, were audio-recorded. To ensure that responses would be candid and represent the views of the individual, the anonymity of the interviewees was assured.

Table 30: Interview participants

Interview	Role	Organisation
#01	Affordable Warmth Officer [a]	Metropolitan Borough Council, North West [b]
#02	Affordable Warmth Officer (A) + Housing Officer (B)	Local authority, Yorkshire and the Humber [c]
#03	Project Officer, Energy Team	Metropolitan Borough Council, Yorkshire and the Humber [b]
#04	Housing Strategy Manager	Metropolitan Borough Council, North West [c]
#05	Health Improvement Practitioner for Affordable Warmth [b]	Metropolitan Borough Council, same as above [c, d]
#06	Sustainable Development Officer (A) + Energy Efficiency Officer (B)	City Council, Yorkshire and the Humber [b]
#07	Energy Conservation Officer	Metropolitan Borough Council, West Midlands [c]
#08	Home Energy Technical Officer	City Council, East Midlands [b]
#09	Energy Efficiency Officer	District Council, South East [c]
#10	Business Development Manager	Community Interest Company, across England
#11	Private Sector Housing Manager	District Council, South West [c]
#12	Principal Housing Strategy Officer	Borough Council, North West [c]

Notes. [a] *Affordable Warmth is a scheme aiming to tackle fuel poverty, enabling householders to heat their homes adequately without the need for debt.*
[b] *Fuel poverty was addressed by the local authority only in other strategies (such as housing, energy or health) and in mandatory reporting of energy efficiency and carbon emissions.*
[c] *A specific fuel poverty or affordable warmth strategy was in place at the local authority.*
[d] *The interviewee was part of the Public Health team, formerly under NHS.*

Twelve interviews were conducted with a total of fourteen professionals, see Table 30. The respondents were based across England, some in urban areas, others in more rural districts. Borough size varied, the smallest under 40,000 households and the largest over 200,000, with fuel poverty rates ranging from less than 7% to over 21%. The range of experience of the professionals included managing area-based schemes and supervising the installation of central heating, insulation and various other measures in hundreds of households, plus dealing directly with individuals to assess their needs (housing or otherwise) and referring them to relevant services. Funding for the interventions/schemes was obtained through government schemes such as Warm Front, Decent Homes, Community Energy Saving Programme, and Carbon Emissions Reduction Target (Dowson, Poole, Harrison, & Susman, 2012), as well as from dedicated resources within the host organisations.

Interview protocol

In order to develop an understanding of what drives these professionals and how closely they felt that their own motivations were aligned with the goals of their employers, each interviewee was first asked about:

1. Their role and how they are involved in household energy efficiency work,
2. The personal / organisational drivers behind such work, whether this has changed recently and, if so, how.

Interviewees were then asked about their experiences of planning and implementing energy efficiency schemes to build a picture of what constitutes a typical household energy efficiency scheme as well as what determines the difference between perceived successes and failures. Specifically this included:

3. The energy efficiency improvement schemes that they have been, are currently, or are planning to be involved in; including their purpose, scale and location, the

types of measure employed and the targeting / selection process / eligibility criteria that were applied;

4. Their experiences collaborating with other individuals and organisations;
5. The choices, guidance or other help offered to residents as part of, or alongside, physical improvements to the property;
6. The success of previous schemes and how this was evaluated; and
7. The difficulties or barriers that they have faced and any lessons learnt from their experiences.

Finally, to investigate interviewees' attitudes towards health − how relevant it was deemed to their work and how prominently it featured in both their own decision making and that of the people that they work with − each interviewee was asked:

8. Whether they see a link between energy efficiency and health, and if so what this belief is based on (e.g., direct experience or knowledge of existing research);
9. To what extent health features as a driver behind, or a measured outcome from, household energy efficiency improvement work;
10. Whether they discuss or promote the health impacts from energy efficiency measures as part of their role; and
11. What further research, evidence of information, if any, would benefit or facilitate their work.

The interview protocol is included Figure 39 in the Appendix. Interviews were semi-structured to allow extra questions to be asked or the order to be changed dependent on the responses. To avoid biasing responses, however, health was not mentioned before or during the interview until Question 8, unless the interviewee raised the subject first. The interviewer had previously discussed other health-related research with interviewees #1, #2 and #3 though and their responses were omitted from parts of the analysis where necessary.

Approach to analysis

The interviews were transcribed and then input into NVivo qualitative data analysis software (QSR International Pty Ltd. Version 10, 2012). Thematic analysis was carried out to identify recurring issues and, to facilitate the comparison and refinement of these issues, a framework approach (Gale, Heath, Cameron, Rashid, & Redwood, 2013) was adopted. Two iterations of coding were undertaken, the first analysing all interviewee's responses one question at a time and producing a long list of subjects that had been raised. The second iteration looked at each of these subject codes in turn, recoding the content to identify and collate broader issues. This procedure resulted in a list of categories which were used by an independent researcher to second code each interview. The results were compared by producing a table summarising the key points in each coding category for each interview. Once finalised, the content of each category was then reviewed with specific reference to the research question: the prominence of health as a factor in planning, delivering and evaluating household energy efficiency improvements.

Results

The coding procedure for the interviews produced an initial list of specific subjects raised, such as *affecting behaviour change* or *excess winter deaths*. Subsequent recoding drew out broader issues − e.g., *the need for guidance and education* or *a lack of resources*. The resulting thirteen categories of issues were organised under four overarching themes, as shown in Figure 35.

Theme 1, termed *Practicalities*, covered some of the financial and regulatory obstacles that can hamper the effective delivery of schemes that might improve health, as well as suggested improvements to local and national policy. Theme 2, termed *Reaching vulnerable people*, included identifying the individuals or groups that are likely to be particularly susceptible to, or likely to suffer from, fuel poverty and getting them access to help. Theme 3, termed *Priorities*, concerned how health and social benefits were ranked compared to other issues, by both the individuals at risk of fuel poverty and the organisations that are involved in tackling it. Theme 4, termed *Collaboration*, recognised the extent of joined-up thinking that is needed to address the complex issues of health and housing.

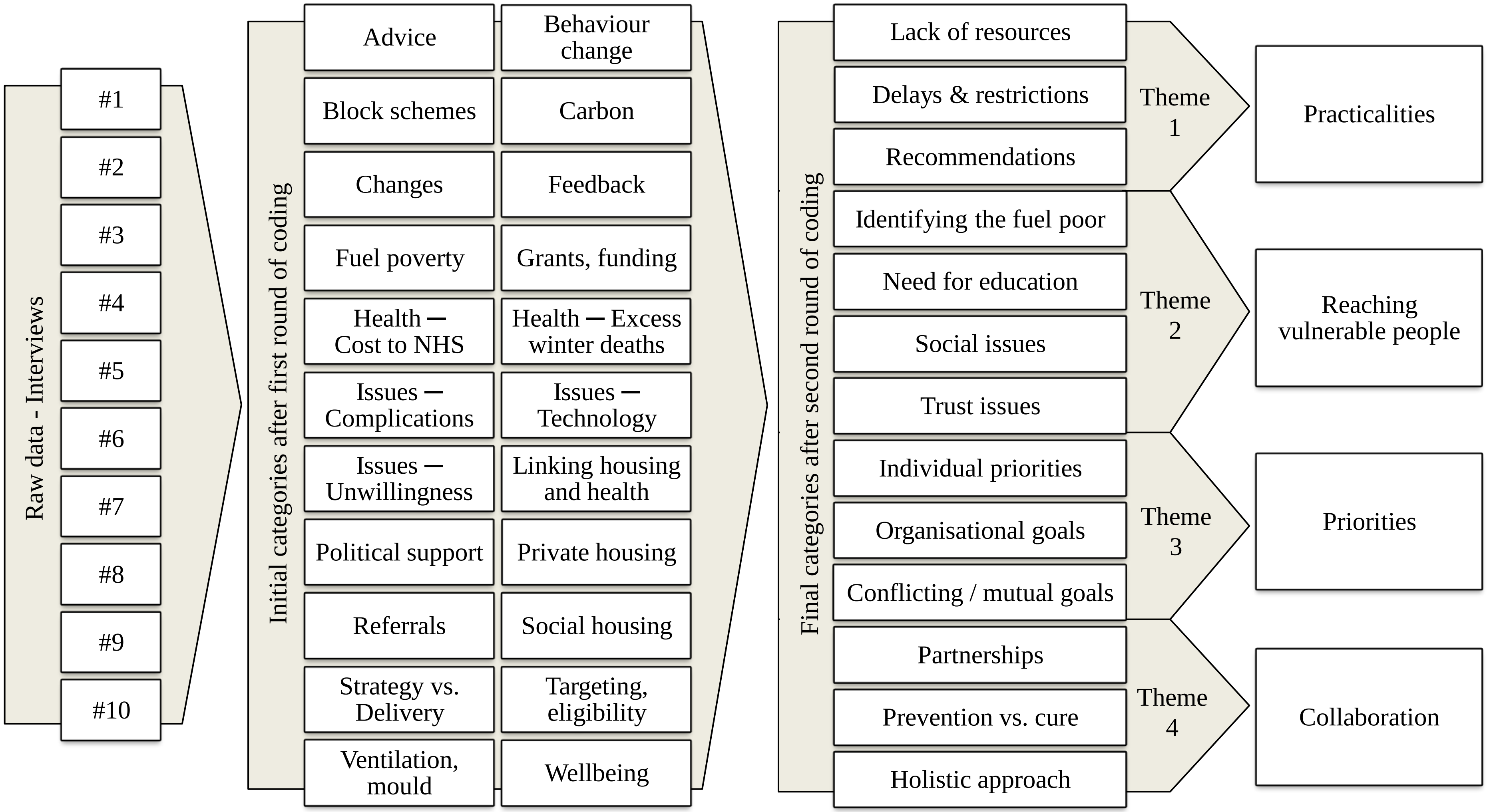

Figure 35: The 4 stages of the coding process: interview transcripts assessed question by question, initial categories from 1st coding round, final categories from 2nd coding round, and 4 key emerging themes

Practicalities

Various direct measures to help alleviate fuel poverty were proposed by interviewees, including improved education and greater investment in physical household improvements:

"People cannot budget... You should spend your entire 5th year in school learning how to budget as far as I'm concerned." [#01]

"...instead of giving people £200 [annual Winter Fuel payments], if you actually said we're going to introduce free loft and cavity wall insulation across the board, and then when you've had that done next year you'll get your £200, that would have been a better way of doing it. But politically that wasn't seen so it didn't happen. So people now think they get all this money but the heat is still disappearing out through the walls and the loft." [#07]

Others recognised the need to raise awareness among both policymakers and the public of the effects and solutions regarding thermally-inefficient housing, through research (Health Impact Assessments of fuel poverty for instance) and better knowledge-sharing. Developing a stronger evidence base in this manner is key to guiding and promoting investment. Despite a general consensus between interviewees of the relationship between the home environment and health, policymakers were seen to be reluctant to speculate on energy efficiency interventions to generate long term health benefits. Minimising perceived risks − that interventions might fail to produce cost-effective benefits − is increasingly important as public budgets are scrutinised and restricted. Investment decisions therefore need more robust evidence of the expected outcomes as a consequence. A lack of resources was a recurring issue, with around half of the interviewees citing a loss of experience due to redundancies, retirements and limited hiring, while all but one discussed financial barriers to the work that they wished to carry out.

"*We're all arguing for a share in a diminishing cake*." [#06A]

Many of the issues described by interviewees are linked to limited resources; the onerous task of finding and engaging with people living in fuel poverty, the need to collaborate to pool resources; the challenge of getting other professionals and organisations to commit their time and efforts with little or no financial reward. Lack of resources appears to be a particular obstacle to the holistic, preventative approach that is considered by many to be cost-effective in the long term, but difficult to make a case for upfront. For instance in a study of over two thousand GPs across Europe (Brotons et al., 2005), half of the respondents reported difficulties conducting health promotion and preventative work, with two thirds citing their work loads and time restrictions as barriers. Preventative measures often meet such obstacles as uncertainty can cause the value of any benefits to be discounted according to the length of time they take to appear, creating a bias towards more immediate impacts (Chapman & Elstein, 1995).

A political preference for short-term gains at the expense of long-term, preventative planning was mentioned by some interviewees, which would seem to preclude action on long term issues like climate change. However, upcoming statutory deadlines for stringent carbon reductions in the UK (Climate Change Act, 2008) have encouraged the Government to place some of the burden of reducing carbon emissions on local authorities (despite also having a national, statutory commitment to eradicating fuel poverty, as far as is reasonable, by 2016). Changes to local government structure, regulation and eligibility criteria for funding were also noted as significant barriers to the delivery of energy efficiency schemes and the associated benefits to residents.

"I think if you had a national policy that actually remained constant, and you had funding that remained constant, and you had advice that remained constant, it would be a damn sight easier than what we've got now." [#07]

Ultimately, the shortfall of resources for tackling fuel poverty was connected to each of the other themes identified during the interviews, either causing or compounding the problems faced. Resource deficiencies were seen to limit the ability to find those most vulnerable to fuel poverty and supply the energy efficiency measures that might make most difference. For potential providers and recipients of interventions alike, having limited resources places greater importance on decisions between competing priorities such as health, money and the environment. One response for providers is collaboration between different departments and organisations which, if effective, could create opportunities to pool resources, overcome structural inadequacies and achieve shared goals. Each of these themes will be discussed in more detail.

Reaching vulnerable people

The professionals interviewed expressed an awareness of the potential social impacts of fuel poverty or thermally-inefficient housing, particularly for those who are already considered 'vulnerable', and a drive to tackle these impacts. Concerns for those who struggled to adequately heat their homes reflected the findings of recent research: half of the interviewees cited deterioration of mental health (Shortt & Rugkasa, 2007), educational attainment issues for children or social exclusion (Richardson & Eick, 2006).

"Obviously, it's well documented that if anyone's living in a cold, damp property, whether it's due to the house being inefficient or fuel bills being too high that they can't actually afford to have their heating on too much, or it's a big house and only a couple of people living there etc, all the factors that we all know, clearly it can have an impact on physical and mental health." [#03]

Some interviewees categorised vulnerable people in terms of widely accepted definitions, such as that used by the UK Fuel Poverty Strategy (DECC, 2001); namely, the elderly, children and those with poor health. Others − in particular the Affordable Warmth Officers working directly with householders to resolve debt, housing and health problems − seemed to work on an individual basis and categorise vulnerable people both more literally and more liberally; for instance, describing situations where divorce or the imprisonment of a partner had resulted in financial problems. While six of the ten local authorities employing the interviewees had specific fuel poverty or affordable warmth strategies in place, the other four at the time only considered fuel poverty as part of wider strategies on housing, energy or the environment, and in the energy efficiency / carbon emissions reporting required by the Home Energy Conservation Act (1995).

None of the interviewees disputed a link between housing conditions and health but there were differences in how health impacts were described. Those working to a fuel poverty strategy tended to mention health explicitly and refer to aspects like GP / hospital admissions or cold-related illnesses, particularly when describing their role and what drives them:

"...we are looking at key illnesses linked to fuel poverty... at excess winter deaths..." [#04]

By contrast, in the three interviews at organisations without a specific, separate strategy for fuel poverty (excluding those where health research had been discussed with the interviewee previously), the word "health" was used just once in total before the subject was raised by the interviewer. Instead the interviewees tended to define their roles and motivations more around the delivery of schemes and achieving wider social benefits, touching on issues such as inclusion, development and stress:

"...I currently run several schemes to help reduce carbon emissions, to get people out of fuel poverty and to improve their living conditions if possible." [#08]

It is likely that the health benefits of tackling fuel poverty were assumed even when not expressed explicitly, as the interviewees unanimously acknowledged this relationship when questioned directly later in the interviews. However, the lack of explicit mentions of health highlights a disparity in the initial focus of the interviews, suggesting a possible influence of top-down policy. Even those that were critical of gaps in strategy seemed motivated primarily by helping vulnerable people to improve their *overall* quality of life. For instance, one interviewee expressed frustration that their Joint Strategic Needs Assessment for health and wellbeing (DH, 2013) contained only one line about housing conditions yet initially discussed their work in terms of improving comfort and alleviating worries about debt (although health may have been an implicit motivation). This disparity was also reflected in the experiences of interviewees as scheme evaluations tended to be linked with health only where fuel poverty strategies were in place.

The different perceptions interviewees had of their roles, and of the aims of their organisations, likely have implications for the delivery of interventions. Those not working to specific fuel poverty strategies appeared to have broader remits for helping vulnerable people. These remits enabled the interviewees to address a wider range of issues simultaneously; for instance, tackling problems with debt and warmth together, based on their assessment of the individual's particular needs:

"...the focus is much more about 'Are you struggling at home?' but they can also pick up on all the other wellbeing issues rather than just sending a domestic energy assessor out, which invariably is not actually that helpful." [#09]

Those with stricter remits based on fuel poverty strategies (incorporating local policy, departmental targets and national funding) seem to have less scope to tailor their help to the person in need, meaning that they potentially miss opportunities for immediate impacts (e.g., improving comfort). However, where these policies and funds are based on evidence of benefits and cost-effectiveness the resulting interventions have more potential to provide for communities' long term needs, such as physical health:

"...a lot of the work that I do is domestic retrofit but then it's the reason why we are doing it, it's trying to fight or tackle fuel poverty... so we look at excess winter deaths as well when it comes to backing our cause." [#04]

Regardless of the approach used, identifying vulnerable people was a common issue in the planning and implementation of energy efficiency schemes. Finding and accessing the relevant data or proving the eligibility of householders for particular schemes appeared problematic. Communication issues were also raised. While the majority of interviewees offered technical, financial or behavioural guidance, some encountered problems engaging with the public; for instance, where internet access was rare or incentives were needed to persuade those in need to come forward. Distrust seemed the root of many of the problems that interviewees encountered dealing with residents, colleagues and other organisations; particularly, an unwillingness to share information and the refusal to accept free help, which was often deemed 'too good to be true'.

"...we tried so hard... just to get people to understand that we really weren't sending someone round to ransack the house..." [#09]

Four interviewees described residents' suspicious reactions to proposed work; either because they did not trust that the stated benefits would occur (or outweigh the upheaval of installing the measures) or because they did not trust the provider, assuming there to be a catch. One example given saw an insulation scheme fail to attract any real interest from marketing directly:

"I think the first 12 months... people didn't believe that they'd get it for nothing. What we then found is you did one address in a road and they talked to their neighbour, and then all of a sudden you get all these application forms in from that road, and it actually worked beautifully." [#07]

The quoted increase in applications following an initial installation may have occurred because people had the chance to see the physical results but also because of word of mouth. Residents were seen to listen to their neighbours more than the scheme providers, trust commonly being stronger between peers than in hierarchical relationships (Mumford & Gray, 2010). In deprived areas, where energy efficiency interventions are needed most, Kearns et al. (2013) found that how neighbours perceive their neighbourhood has more influence on a person's mental wellbeing than how the neighbourhood is perceived by people living elsewhere. As deprived areas can be culturally diverse, they are more likely to develop low-trust environments (Thiede, 2005). Overcoming potential negative or misinformed views of interventions is made more difficult as people may reiterate these views in order to reinforce their sense of belonging to the group (Mumford & Gray, 2010). If services provided by authorities are to be used, therefore, they must demonstrate not only their social benefits but how these align with community values. Spending time persuading one frugal person that insulation is a cost-saving measure rather than an unnecessary expense may lead to this message being spread to like-minded people quicker than a marketing campaign that falls on deaf ears. Similarly, a community that equates consumption with status (Hards, 2013) may respond better to the message that insulation is a key part of providing a warm, comfortable environment for the family than any cost-saving arguments.

Other interviewees, however, were sceptical about the impact of word of mouth and stressed the importance of expert advice for potential recipients, for instance regarding community switching schemes where individuals group together for better fuel prices:

"What they need is... that trusted resource that will work with people to actually take them through the process. Rather than this... just because your neighbour's in it it's a good idea... utility companies don't buy into the process... But that's just my opinion." [#07]

Attitudes towards energy efficiency, like many things, are often governed by self-interest (Organ et al., 2013), with immediate interests generally prioritised over longer-term risks and rewards (Taylor-Gooby, 2004). One interviewee however demonstrated that there is scope to use small financial incentives to overcome distrust and promote larger but less tangible goals like improving health. Having initially struggled to attract people from deprived areas to workshops on energy efficient behaviour, they found that simply offering £10 to use in prepayment meters encouraged the people most in need to participate, despite previously (and paradoxically) dismissing these money-saving workshops as useless. Alternatively, for many householders health benefits may be a more relevant and persuasive argument for energy efficiency than tackling climate change, as it appeals to self-interest. Identifying the most powerful and appropriate motivator is an important task, highlighted by interviewees who work with a diverse range of residents.

Priorities

The third theme reflects interviewee’s perceptions of the reasons why efforts to engage with vulnerable people regarding energy efficiency have been hampered, limiting the health protection or improvement that might otherwise have been achieved. This includes misplaced priorities on the part of both the recipients and providers of the improvements.

Priorities of the intervention recipient

Frustrations with the public were common where the decisions they made were judged to be detrimental to their own quality of life. The interviewees often disagreed with how highly individuals prioritised their health compared to other factors and questioned both their understanding of the relevant issues and their willingness to base decisions on rational arguments. Householders' priorities were often seen to conflict with the uptake of new measures (e.g., refusing free external insulation or solar panels on aesthetic grounds) or with the use of new measures after installation (e.g., keeping the indoor temperature low and taking the resulting financial savings instead). Some interviewees appeared to view vulnerable people as a single group requiring a single set of solutions. Others though described a clear distinction between the priorities of old and young people regarding health and money in particular, suggesting greater susceptibility to health issues or financial problems, respectively:

"With the older people it's very rare that you get fuel debt - they'll stop eating, they will not have food but they will pay their gas and electric bill, or they'll just turn it off. With the families with young children it's more about they've got fuel debt..." [#01]

Accounts of interviewees' dealings with vulnerable people painted a picture of elderly people in fuel poverty as debt-averse prioritising the payment of their bills even where this meant switching off heating or going without food. This frugal behaviour was seen in the older participants of a study of low income households (Anderson et al., 2012) who also found detrimental health effects from the resultant cold housing. By making a warm home more affordable energy efficiency improvements have the potential to relieve some of these financial pressures, perhaps removing the need to make such stark choices. However, in practice this was not always successful. While insufficient guidance on the healthy and energy efficient use of the new measures was a frequently cited issue, a fear of, or unwillingness to learn about, new technologies was also seen as a barrier, regardless of the support offered. Interviewees also described recent recipients of new heating and insulation keeping their homes at the same temperature in order to save money:

" She's just that tight and not bothered that she doesn't put [her heating] on anyway! She's got every energy efficiency measure you can have but it's still cold."

[#02B]

This leaves them susceptible to the same cold-related problems and perhaps worse damp problems, if ventilation is reduced without increasing warmth. Improving the health of vulnerable older people may therefore require going beyond the provision of energy efficiency measures and advice to affecting real changes in attitudes and behaviours. For instance, the choice to maintain low temperatures may, like many energy-related behaviours, be rooted in their character and identity

(Hards, 2013). Lifelong habits are hard to break but where these are allied to values held dearly, such as independence, frugality and the ability to *get by* or *make do*, affecting change may be even harder. For example, such mindsets based on less privileged upbringings were found to be common in the older people interviewed as part of the KWILLT project (Allmark & Tod, 2014) and affected their ability to heat their homes. Breakwell (1993a) described continuity and control as key principles contributing to self-esteem and, consequently, identity. Householders pushed to use new heating systems efficiently (e.g., not just in certain rooms or at certain times) may feel a loss of control over their environment or misguidedly see it as an extravagance, against their *no nonsense* character. Therefore, advice intended to improve someone's quality of life may be seen by the recipient as a push to change their identity and disassociate them from peers who share their social values (Hards, 2013), resulting in the kind of negative responses that arose in the KWILLT project. In summary, the need to tailor and communicate energy efficiency interventions to fit with values such as independence was recognised by the professionals responsible for planning and implementing these schemes. Clearly more needs to be done though to ensure that planners have the ability, resources and scope to apply research on recipients' identities to their schemes.

In contrast to the debt-averse nature seen in the elderly, interviewees stated that younger people were considered more likely to go into debt to preserve their living conditions. This is despite some previous research finding that working-age households are more likely to ration energy use than older households (Anderson et al., 2012). Consequently the concerns raised regarding young families were less about direct physical health impacts and more focused on the stress and anxiety of living in increasing 'fuel debt' and how this can impair wellbeing, mental health and quality of life over time. Interviewees were sympathetic towards people left susceptible to fuel debt by their situation, e.g., where life events such as illness, divorce or imprisonment left lone parents raising families on little or no income, but less so where lifestyle choices were considered higher priority than basic human needs:

"...they've got fuel debt but they're paying off Brighthouse because they'll take the telly away." [#01]

"Well, they've got habits to feed..." [#02B]

The implication that entertainment or more harmful habits such as smoking, alcohol and drugs often take precedence over health suggests that some interviewees deem certain residents as less deserving of help than others. While their professional experience may help them to identify which households would benefit most from improvements and where investment would likely be wasted, the reasons behind residents' behaviour might not be so simple. With debt increasingly normalised (credit cards and pay day loans, for example) and increasing consumption and materialism (Eckersley, 2006), younger people might be expected to frame their identity in terms of possessions and achievements − nice house, comfortable living conditions − rather than character and behaviour. Contrary to the perceptions of some interviewees though, a strong aversion to debt has been identified in a high proportion of young families (Anderson et al., 2012, Nelson et al., 2013). People should not have to choose between heating and eating and, while self-esteem might be derived from living a frugal life themselves, providing for the family is likely to be both a conscious priority and an underlying value, integral to a parent's identity (Hards, 2013). In such cases, conveying the message that an energy efficiency intervention is about providing a better environment rather than focusing on savings might logically have more sway.

Interviewees faced resistance to change not just in behaviour, but in agreeing to the installation of the improvements themselves, even when these were offered free of charge. One reason given was aesthetics:

"*There's absolutely no accounting for taste. At the end of the day you can give people a million and one reasons, sensible reasons why they should improve the energy efficiency of their property, but if you're going to mess with the aesthetics and they really are obsessed with the way their house looks, you'll never get it past them unless you're happy to leave their house exactly how it looked when you started*." [#09]

While aesthetic and emotional concerns have been seen to outweigh objective arguments for other housing improvements, financial concerns are key in many decisions regarding energy efficiency (e.g., Wilson, 2008). Refusal of a household energy efficiency measure may therefore be tied into deeper notions of identity. Although impacts are not consistent, there are numerous examples linking housing improvements to psychosocial benefits (Clark & Kearns, 2012) and increased mental wellbeing (Kearns et al., 2013). Ellaway et al. (2004) in particular found that those with negative opinions of their housing had higher levels of anxiety and depression, lower self-esteem and less perceived control over their problems. This suggests that the home is an important part of a person's status and self-image.

By refusing any visible change to the home, however positive or widely adopted, the householder may feel that they keep control, maintain continuity and remain distinctive. According to Breakwell (1993) these three elements are key to self-esteem so relinquishing control by admitting to needing outside help might lead to some people feeling helpless and alienated. Addressing the aesthetics of interventions to minimise change and, where possible, provide choices could help recipients retain control, distinctiveness and continuity. This approach might also protect self-esteem by avoiding stigmatising the recipient. Visible energy efficiency measures like external wall insulation can make people's financial or health needs public, particularly where residents must be on certain benefits to qualify. However, where residents feel that the change in appearance is positive the aesthetics of an energy efficiency measure can become a key selling point and benefit (Scott, Jones, & Webb, 2014).

Priorities of the intervention provider

Conflicting priorities were also noted within local and national government, with current policy often seen to lean towards either the economy or the environment at the expense of some of the more vulnerable members of society. Reductions in carbon dioxide emissions and fuel poverty were frequently discussed together. Many interviewees highlighted the potential to tackle both issues through household energy efficiency interventions and expressing frustration that such opportunities were often missed:

"*...they're constantly trying to apply climate change policy not health policy to energy efficiency and fuel poverty, and ignoring the fact there's a fundamental* *health problem... energy's being treated like it's some kind of luxury commodity and not some sort of essential part of life*." [#09]

" *If we just went and set a target that looked at helping people rather than carbon... you'd see all these reductions anyway*." [#01]

Conveying both fuel poverty and climate change messages in the marketing of energy efficiency schemes was seen as effective in generating uptake. This is supported by social cognition models successfully used to predict health-related behaviours, where 'perceived benefits' and 'evaluation of outcomes' are respectively key elements of the Health Belief Model (Becker & Maiman, 1975) and the Theory of Planned Behaviour (Ajzen, 1991). Framing energy efficiency as a tool primarily for environmental protection places the onus on personal responsibility, diminishing or disregarding the financial and health arguments that would appeal to a potential recipient's self-interest.

The targeting of energy efficiency schemes was also discussed regarding the recent shift in national policy to introduce the Energy Company Obligation, ECO (DECC, 2011), which requires investment in carbon reduction. Opinions were split over whether this supported or distracted efforts to alleviate fuel poverty. Most interviewees were involved in ECO-funded schemes and three highlighted new opportunities ECO afforded, such as the use of carbon savings to encourage energy companies to fund costlier measures for hard-to-treat homes. Interviewee #6 for example considered that much of the "low-hanging fruit" had already been taken care of through cost-effective schemes like free loft and cavity wall insulation. Every interviewee though cited fuel poverty or helping vulnerable people when asked to characterise their own motivations for carrying out energy efficiency improvements, with only two also mentioning carbon emissions or climate change. The low level of income needed for a household to become ineligible for help was a concern for interviewee #1, who suggested counting certain health conditions as alternative eligibility criteria. Other interviewees felt that environmental targets were incentivising and empowering energy providers to bypass those most in need and instead invest in more cost-effective carbon reduction measures for less vulnerable fuel-poor households:

"It's just the wrong way around, and I think whilst you have the carbon targets people will look to save as much carbon with as little money as possible, regardless of thinking about the end user." [#07]

"*...you normally get 100% grant if you just want a boiler swapped... But if you've never had the money to install a heating system and you're stuck with poxy little electric fires and an array of things around your house, the grant won't actually help you... if you need a boiler then the grant should just give you a boiler rather than do some hypothetical calculation of how much carbon you're going to save. It's irrelevant; it's a health issue not a carbon issue*." [#09]

When asked about the drivers behind energy efficiency improvement work, seven of the interviewees alluded to a 'top-down' structure where their own actions were directed or limited by council objectives, based on the perceived needs and priorities of the electorate or on the preferences of individual council members. Commitment to the green agenda ahead of fuel poverty, for instance, was seen to vary markedly depending on factors like levels of deprivation within the authority. Some interviewees cited health specifically when describing their roles and motivations, and used health outcomes when evaluating energy efficiency schemes. Unlike those that defined their roles in terms of wider social benefits or simply project delivery, those that focused on health tended to work to existing local strategies to combat fuel poverty and promote affordable warmth. Such strategies may reflect existing thinking within the authority that already places health and wellbeing high on the agenda however it may also help create a different outlook. Local authorities make a commitment to improving health and wellbeing when they adopt a fuel poverty strategy. This commitment both justifies and necessitates funding, making health more prominent in the roles of local authority officers and increasing the need for measuring health outcomes.

Interviewees not governed by specific fuel poverty strategies were, however, generally more able to align their work to the perceived needs of the residents. As people tend to place overly high importance on immediate risks (Christie et al., 2011) and prioritise near, tangible rewards over distant, abstract ones (Taylor-Gooby, 2004), a bias is created towards achieving immediate impacts from housing improvements rather than longer term, incremental improvements in health. Consequently, efforts to tackle debt and stress are favoured as the effects can be witnessed on a day-to-day basis. Also, without defined objectives, other strategies may push resources in other directions such as reducing carbon emissions. This effect was most evident in dealings with health professionals; interviewees described a general consensus over the importance of housing but also recognised that other health targets and messages, such as smoking and obesity, tended to take precedence due to 'top down' pressures.

Collaboration

Interviewees were asked about their experiences of working with other individuals, departments and organisations, and the need for collaboration was a recurring theme throughout all of the interviews. A collaborative approach was deemed effective, even necessary, for solving many of the problems encountered: limited resources, a perceived lack of political support, and difficulties finding and communicating with vulnerable people. Working with partners was seen to facilitate finding and accessing funding sources, as well as delivering the schemes themselves. Interviewees discussed their involvement in management-led, cross-organisational partnerships working towards shared goals as well as their own efforts to proactively build informal relationships to help residents beyond their own individual work remits. For example, many of the interviewees had developed networks of relevant services to which householders could be referred, such that once an individual has been identified as vulnerable their various needs can be addressed, regardless of the first point of contact. Some strong relationships between council and health services as well as voluntary organisations were described, although the majority of interviewees had worked with partners who were unable to provide the commitment or resources required:

"One of our main partners in the community sector has just had to make their manager redundant. So obviously the scope there is going to be drastically reduced..." [#06A]

"The voluntary organisations is a really tough one because their resources are always going up and down... they always aim quite high, but in reality they're never sure how well they're going to be able to deliver something." [#09]

Interviewees recognised that tightening budgets have focused services and organisations on their own key priorities but argued that a more holistic approach − pooling resources to tackle issues like health, wellbeing and quality of life, debt, housing, energy and the environment together − could be far more cost-effective. This would require strong working partnerships between housing, affordable warmth and health at a time when restructuring of the UK National Health Service (NHS) through the Health and Social Care Act (2012) has placed public health responsibilities under the remit of local authorities. Some interviewees saw current health policy that focuses on cure rather than prevention (Baggott & Jones, 2011) as short-sighted, highlighting the potential financial benefits for the NHS of preventative household warmth measures. For example, interviewees described people with cold-related illnesses locked in a cycle of hospital stays as they became ill again each time that they returned to their cold home or were kept in hospital to avoid this, when paying to improve their living conditions would be much cheaper:

"...if we can keep people warm and safe in their own home... they're not using services that cost the authorities or the Government money, like going to GPs, like going into hospital... and it's very simple to do." [#07]

" *..the ultimate goal is to get leverage with the clinical commissioning group for them to actually fund some direct interventions*." [#06A]

Such an approach would require a major shift in perspective. The values and principles of the NHS (DH, 2012), state that the service "is designed to diagnose, treat and improve... health" and "aspires to put patients at the heart of everything it does", positioning the NHS primarily as a resource for people in ill health. While these values also indicate a duty to protect the health of the wider population through research and innovation − "improving lives" for both patients and local communities is part of the core values − prevention is not specifically addressed. The protective duties outlined in these NHS values and principles (DH, 2012) might therefore be construed instead as a promotional role to help "people and their communities take responsibility for living healthier lives".

The NHS in the UK is accountable to the public and it is often difficult to measure the impact of preventative measures. As long term benefits are harder to prove than more tangible, immediate benefits from the direct treatment of patients, curative measures tend to receive much more investment: in OECD countries, less than 4% of health expenditure is on prevention (OECD, 2013). One simplified healthcare model (Bishai, Paina, Li, Peters, & Hyder, 2014) found that private investment in treatment led to increased revenues and therefore greater power to draw public funding away from prevention and into curative measures. The conflict between preventative and curative approaches is reflected in the communication issues encountered between housing and health departments. One interviewee cited a particular language barrier:

"...local authorities speak in one language, and the health section speak in a completely different language. Even to the point where we call them customers or residents or tenants, Health call them patients." [#01]

The solution put forward was for greater joined-up thinking to agree a common language and, more importantly, common goals. This may already be taking place in many authorities as other interviewees indicated that public health departments coming under local authority control has already created opportunities for them to work together on preventative health measures. One interviewee described a system in use that estimated the cost to the NHS of Category 1 Hazards within the home, including fires and accidents but also cold living conditions due to thermal inefficiency. Such a system could be used to justify funding remedial measures to remove the hazard, for instance by raising the energy efficiency rating of the home. The current Affordable Warmth Strategy at another authority, written jointly with the NHS, includes a chapter on health detailing the costs arising from health service use due to cold living conditions.

Progress towards a more joined-up approach is also being made at a wider level. In the winter of 2012/13, the UK Department of Health provided half a million pounds to the Foundations Independent Living Trust Ltd. Warm Homes Service to fund fuel poverty assessments and interventions by home improvement agencies (HIAs) throughout the country. A recent evaluation of the scheme (Bashir, Gilbertson, & Wilson, 2013) found that local delivery agents were able to reach vulnerable households missed by other services and to use the funding flexibly, applying the appropriate measures, whether this involved installing a new central heating system and insulation or simply adding thermostatic radiator valves. Residents reported through in depth interviews that they had received substantial benefits in warmth, comfort, and feelings of control and inclusion, as well as in health and wellbeing, both physical and mental. If these self-reported improvements in health and wellbeing were assumed to result in reductions to the costs associated with health service use, residential care and excess winter deaths, the findings of the evaluation would support the working partnerships advocated by the interviewees of the current study. The effects of the public spending cuts are still being felt however, with some HIAs forced to close (Bashir et al., 2013). If the success of schemes like this is to be built on, then professionals responsible for planning and implementing energy efficiency schemes will need to look beyond short term competition for funding to see the opportunity for mutually-beneficial, long term goals.

Policy implications

While the dangers of living in cold, damp housing are widely accepted (Liddell & Morris, 2010) and the epidemiological evidence regarding cold- and damp-related illnesses strong (Marmot, 2011), empirical evidence regarding health benefits from energy efficiency interventions aimed at improving these living conditions is limited (Thomson, Thomas, Sellstrom, & Petticrew, 2009). The professionals interviewed, however, overwhelmingly supported improving energy efficiency to improve health, based on both their understanding of the current research and their direct experiences working with people vulnerable to fuel poverty. Any weaknesses in the evidence needed to justify this work were seen as an indication of the misapplication of interventions or, as noted in Chapter 4, deficiencies in the quality or quantity of evaluations that mean health effects could be going unnoticed. Further research is needed therefore to implement energy efficiency measures, direct their use and demonstrate their value to householders and policymakers alike.

Frustrations that arose when trying to deliver these improvements were seen to come from two directions: top-down and bottom-up. Interviewees encountered reluctance among some people to come forward and accept help, whether in the form of physical energy efficiency installations or advice on behaviour. While protecting health should appeal to everyone's self interest, the consequences of failing to do so are often distant or vague and therefore easy to ignore (Christie et al., 2011). When considering household energy efficiency, more immediate factors like cost and comfort are indeed often more influential (Wilson, 2008). Deeper psychological factors linked to identity and self-esteem were also seen to govern behaviour regarding both the uptake and the use of energy efficiency interventions (Breakwell, 1993; Hards, 2013). More needs to be done to understand the differing attitudes and situations of those in need of help in order to craft and communicate relevant messages more effectively and, ultimately, affect long-lasting change.

Short term thinking was also identified in policy, for instance diverting the focus of funding (e.g., DECC, 2011) from vulnerable people to carbon reduction deadlines (admittedly set to address long term, wide reaching issues), or in health services that wait to treat the sick when keeping people healthy was judged by interviewees to be the cheaper option. A perceived lack of support from management and colleagues unwilling or unable to focus on health left some interviewees feeling restricted in their ability to help the people most in need. To address these structural failings interviewees called for changes to national and local policy, firstly by placing people at the heart and therefore match health service principles (DH, 2012). To do this, policymakers were encouraged to speculate to accumulate. Household energy efficiency interventions were judged to be cost-effective for producing long-term health benefits that, while difficult to quantify (see Chapter 4), were thought to lead to substantial savings for health services, as found by Shortt & Rugkasa (2007) and better quality of life for residents (Gilbertson, Stevens, Stiell, & Thorogood, 2006). This is one example of the joined-up thinking interviewees hoped to see materialise between services. While reduced budgets can result in silo-thinking and a narrowing focus on key priorities (Taylor-Robinson et al., 2012), interviewees highlighted the increased importance of a more holistic approach. This would require initial commitment and investment. However, services would be able to pool resources and expertise to address a wide range of issues. In this way help for residents may be tailored better to meet their individual needs and potentially achieve greater impacts on their quality of life (Bullen et al., 2008). Measures such as energy efficiency that can produce a diverse range of benefits in the areas of housing, energy, economy and health may also be justified more readily if the relevant organisations and individuals are working together with the overarching goal of serving the best interests of their residents.

Conclusions

A common drive to improve people's lives was demonstrated during the interviews, along with a belief that these improvements to housing, finances, health and wellbeing could be achieved with household energy efficiency interventions. While some interviewees sought to improve wellbeing by tackling immediate issues like debt and stress, others focused more on physical measures that should benefit long term health. Both approaches have strengths and, if resources were less scarce, a holistic approach that addressed both short and long term needs would be ideal. However, even providing these resources would give no guarantee of health improvements as decisions regarding energy efficiency measures are not just based on their availability and effectiveness. Their uptake and use depends on the attitudes of the householder, how they fit with the householder's identity and values, and potentially how they are perceived by the householder’s peers and neighbours. Approaches that rely on the public assessing the full costs and benefits of energy efficiency measures themselves and making rational decisions to invest may therefore be flawed. Such forward-thinking behaviour seems even less likely where the prospects of personal gains in health and money are diluted by messages of charity and responsibility regarding environmental protection. Interviewees wanted a stronger focus on helping people, particularly vulnerable people, jointly across various public services and organisations. Working towards this shared objective would potentially provide more opportunity to identify and respond to a resident's needs and attitudes, and greater justification for investment in energy efficiency measures that generate more diverse and distant benefits, like health.

Discussion

This project began as an affiliate of the Big Energy Upgrade (BEU), a programme of energy efficiency improvements in homes across the Yorkshire and Humber region. The University of Sheffield, in partnership with the various local authorities and housing providers involved in the implementation of the programme, conducted a set of research projects to help better understand the impact on the energy performance of the improved buildings and also the range of economic, environmental and social impacts that such improvements can generate, both for the building occupants and for the wider community. The current project added to the BEU research and further broadened its scope to incorporate impacts on health, including mental health and wellbeing, as their relationship between energy efficiency improvement programmes and health remained uncertain (Thomson et al., 2009). Health further warranted investigation due to changes in UK legislation and funding that moved the focus away from protecting the individual and instead placed climate change and reductions in carbon emissions at the heart of energy efficiency policy (Critchley et al., 2007).

An initial review of the existing literature concerning the relationship between energy efficiency and health (Chapter 1) identified a clear disparity between predicted and measured impacts. Extensive epidemiological evidence details the range of illnesses and health conditions that cold and damp environments can cause or exacerbate (Marmot, 2011), supported by empirical data that identifies worse states of health for people living in cold and damp homes (Liddell & Morris, 2010). In theory, then, household energy efficiency measures designed to reduce heating costs and facilitate a warmer, drier environment should result in substantial health benefits for residents where they are installed. Evidence of these beneficial impacts though is limited as relatively few empirical studies that analysed the effects of household energy efficiency measures on health were identified. If the sheer weight of epidemiological and theoretical research concerning cold and damp household conditions and health has led to household energy efficiency measures being intuitively linked with health improvements, then evaluations that would test this relationship might be dismissed as redundant. Where such evaluations have been conducted, however, the results were inconsistent. While some studies have detected a protective effect from household energy efficiency measures (e.g., Howden-Chapman et al., 2007), some found little or no health improvement (e.g., Hopton & Hunt, 1996) while other research has suggested negative health impacts (e.g., Bone, 2010).

This lack of agreement coupled with the overall absence of research formed the rationale for an investigation into the relationship between household energy efficiency measures and the health of residents. The relationship was examined using three different approaches: the collection of new empirical data from households involved in a retrofit energy efficiency scheme, an analysis of the existing evidence, and interviews with professionals experienced in the planning or provision of such schemes. The aim was to triangulate the results (Jick, 1979) to generate confidence and a deeper understanding of the findings common to each research method.

Three approaches to investigating the health impacts of household energy efficiency measures

Empirical studies using household surveys and indoor environmental monitoring

Primary data was collected independently from nine case study homes, monitoring the indoor environments continuously for a three month winter period (Chapter 2), and from 117 residents in the same area of Scunthorpe, North Lincolnshire who completed questionnaires regarding the characteristics of their homes and their perceptions of their home environments, along with details about themselves, their energy-related behaviours and their health status (Chapter 3). Neither the survey nor the case studies found a direct relationship between the presence of energy efficiency measures and better ratings of health, although this is not evidence that no relationship exists. Practical issues regarding local authority resources and schedules (outlined in Chapter 3) prevented similar, supplementary studies from proceeding. This limited the size of the sample, thereby restricting the methods of analysis available and the statistical power of the study. Effects would therefore have needed to be larger than the average effect calculated by the meta-analysis in Chapter 4 to be detected[25]. Larger effects may have been expected had the study used a pre-post design and had physical tests been used to assess health, according to the findings of the meta-analysis (Chapter 4). However, the local authority resource / scheduling issues that had obstructed other studies also obstructed the collection of baseline data prior to the household improvement work, while ethical concerns prevented the use of physical medical tests. The studies therefore relied on a retrospective design, comparing homes with and without household energy efficiency measures using data collected solely after installation, and on self-reporting to measure health.

When the findings of the case study monitoring (Chapter 2) and the questionnaire-based survey (Chapter 3) were analysed and compared, however, a potential chain of associations could be traced from household energy efficiency measures to the indoor environment, to perceptions of this environment and, finally, to health. As outlined in Chapter 2 and in line with previous research findings (e.g., Hong,

[25] The questionnaire-based survey would have detected a significant correlation if it produced an effect size of d = 0.3. This is considered a small effect (Cohen, 1992) but is greater that the average effect d = 0.08 calculated in the meta-analysis in Chapter 4.

Gilbertson, Oreszczyn, Green, & Ridley, 2009), homes with more types of household energy efficiency measures maintained a warmer indoor environment on average than those with fewer energy efficiency measures, while residents from warmer homes reported more positive perceptions of their home environment. More positive perceptions of the home environment (specifically higher levels of satisfaction) correlated to higher self-ratings of health, as shown in Chapter 3, supporting the findings of Gilbertson et al. (2012): that alongside any direct physical effects, psychological benefits that arise from improved, more comfortable environments lead to improved health ratings.

Higher temperatures and, more importantly, levels of satisfaction with the home environment were found to be the key indicators of higher health ratings, contrary to concerns that insulation would result in reduced ventilation and, consequently, damp-related illness (Milner et al., 2015). However, even the higher levels of relative humidity and CO_2 measured in the case study homes were still within typical design parameters (BSI, 2008; CIBSE, 2015). Health may be impaired where resident behaviour or housing conditions generate greater levels of relative humidity or CO_2 (or particularly low temperatures). Analysis of the small sample of homes monitored in Chapter 2 also indicated that installing, in this case, external wall insulation (EWI) can result in dramatic savings. The homes without EWI were estimated to be losing the equivalent amount of energy through their walls as the total gas usage of the average UK household (see Table 14). The indoor temperature following installation though was found to have relatively little effect on energy savings. Recipients of similar measures might therefore be encouraged to maintain a warmer environment as the improvements in comfort and health are likely to outweigh the slight reductions in the money saved from maintaining a lower temperature.

Assessment of the existing evidence by meta-analysis

As the empirical studies had not identified a direct, significant relationship between energy efficiency and health but were limited by sample size, a study was developed to apply greater statistical power to the investigation. Consequently a meta-analysis of the existing evidence was conducted, examining the health impacts of household energy efficiency measures on a sample of over 32,000 participants. This process identified a significant link between the presence or installation of a household energy efficiency measure and improved health, supporting the existing theoretical evidence of a protective effect from such measures (e.g., Liddell & Morris, 2010) and the chain of associations indicated by the findings from the empirical research.

The average effect size identified was small though, reflecting concerns raised in the initial literature review (Chapter 1) that the potential health benefits from household energy efficiency measures were not being realised. Many of the studies included found small, negligible or, in a few cases, negative effects. Few studies though reported other relevant information that might help determine why health benefits were inhibited, such as housing conditions or the behaviour of residents. Analysis of the factors that moderate the relationship between household energy efficiency measures and health, however, found no particular characteristics of either the measures or their recipients that tended to result in poorer health. In line with previous research findings (e.g., Howden-Chapman et al., 2005), the protective effect of household energy efficiency measures was most prominently found in vulnerable groups (children, the elderly and those with low incomes or poor health), perhaps due to their susceptibility to housing and health problems providing greater scope for improvement. This sends a clear message to policymakers that household energy efficiency measures are a useful tool in addressing health inequalities to help those most in need.

The broad inclusion criteria applied for the meta-analysis resulted in a greater sample size, and therefore increased power to detect effects, than some other reviews (Thomson et al., 2013). Studies deemed weaker (and therefore rejected by other reviews) found smaller effects on average than those with more robust designs. The broad criteria were therefore justified as rather than introduce erroneously large effects as may have been feared, the inclusion of the weaker studies resulted in a more conservative estimate of the overall effect of household energy efficiency measures on health. The greater sample also provided the opportunity to further investigate the particular circumstances and factors that influence health outcomes, as described above. A similarly inclusive approach was since taken by Willand, Ridley, & Maller (2015), who conducted a 'realist' review that focused on relevance over study quality in order to help explain, rather than measure, the relationship between household energy efficiency measures and health.

Future evaluations of household energy efficiency interventions would benefit from objective and long term health measurement. Studies that used physical medical tests to measure health outcomes (e.g., Demissie, Ernst, Joseph, & Becklake, 1998; Homoe, Christensen, & Bretlau, 1999; C. R. Lloyd, Callau, Bishop, & Smith, 2008) found larger positive health impacts on average than studies that relied solely on subjective health ratings reported by the participant, their parents or their GP (e.g., Austin & Russell, 1997; Jones, Hughes, Wright, & Baumer, 1999). The long term impacts of measured changes in health could not be assessed in the meta-analysis though as studies rarely collected data before and after the household energy efficiency measure was installed or continued subsequent monitoring beyond a few months. Also, a number of clearly relevant studies had to be excluded from the meta-analysis in Chapter 4 as the full data was not available; only the statistics pertinent to their specific research question were reported. Studies therefore ought to report statistics in full, or provide access to the data collected, in order to allow their inclusion in meta-analyses such as this and therefore contribute to the wider evidence base. For this reason, the aggregated (and anonymised) survey results are provided in Chapter 3 (see Table 16 to Table 19) and the case study results are given in Chapter 2 and the appendix, allowing other researchers to use the data in the future for their own research purposes.

Interviews with professionals working in the field of energy efficiency interventions

To compliment the quantitative research carried out and develop a more thorough understanding of their findings, a qualitative study was designed to utilise available expertise in the fields of energy, housing, fuel poverty and health. Fourteen professionals involved in providing energy efficiency improvements were therefore interviewed regarding their motivations and experiences. Alongside the practical difficulties many had encountered − particularly resource shortfalls due to the withdrawal of funding streams such as Warm Front (Dowson, Poole, Harrison, & Susman, 2012) and the onerous nature of identifying and approaching those most in need − conflicting priorities emerged as a recurring problem. Collaboration between departments and organisations, in terms of better communication and the pooling of resources and expertise to meet multiple, cross-departmental objectives, was cited by many as a potential solution.

Vulnerable residents were described as failing to adequately prioritise their own health in a number of instances for different reasons. As vulnerable groups are also most likely to derive health benefits from household energy efficiency measures (Chapter 4), it is important to understand and address their motivations in order to encourage engagement and investment in energy efficiency for health purposes. The professionals interviewed attributed the misuse or refusal of interventions due to financial hardship (other outgoings both essential and lifestyle-related taking precedence), ignorance (of how to use energy efficiency measures optimally and the extent of the benefits that might be derived), and habit (particularly keeping homes cold regardless of the help provided). Previous research has identified similar financial, educational and change-resistant barriers. In a study by Long et al. (2014a) for instance, residents most frequently cited disruption as the reason for not participating in a free insulation scheme, with cost and the guarantee of energy savings the most common factors given for future decisions to install energy saving measures.

The professionals interviewed in Chapter 5 described attempts to promote the benefits of household energy efficiency schemes in order to overcome the objections or disinterest of residents. This approach is in line with the knowledge deficit model that assumes public disagreement with expert opinion to be ignorance, in need of education (Sturgis & Allum, 2004). This assumption, however, has been criticised as simplistic (Brunk, 2006) as it ignores any gaps in knowledge and understanding on the side of the experts. The failure to engage residents through rational argument reported by some interviewees (Chapter 5) points to deeper seated causes than merely being uninformed. Previous research has shown a strong link between a person's home and their identity (Davidson, 1982) so interventions that reduce feelings of control and consistency over the home environment are likely to harm self-esteem (Breakwell, 1993b). Similarly if a cold home is indicative of the resident's frugal and hardy identity, health concerns will have less weight than the potential for financial savings (Hards, 2013). Interventions are therefore more likely to be accepted and engaged with if they minimise superficial change, provide choice and promote benefits that are in tune with the attitudes of the recipients. Previous research has also highlighted psychological barriers that prevent residents from taking action to achieve long-term benefits. Promotion of household energy efficiency measures must therefore overcome any distrust of authority and perceived risks of change (Gifford, 2011) and the higher value placed on immediate costs than on distant benefits (Christie, Donn, & Walton, 2011).

National and local government also have misplaced priorities according to some of the professionals interviewed, primarily in placing greater importance on climate change targets than tackling fuel poverty. Some interviewees welcomed recent funding changes (DECC, 2011) as opportunities to reach and help different vulnerable groups. Others though saw energy companies being given more leeway to protect their own business interests by selecting which of the eligible, vulnerable households to improve according to the cost effectiveness of reducing carbon emissions rather than the needs of the residents (Powells, 2009). These interviewees felt that help should be people-focused although opinion was split on whether to prioritise providing immediate impacts, for instance by reducing debt and stress (Liddell & Guiney, 2015), or more gradual improvements to physical health (Howden-Chapman et al., 2007). The goal for most interviewees was a holistic approach that addressed all of a resident's needs and, given the increasingly limited resources available, collaboration between departments and organisations was considered necessary. Referral networks had been set up by some interviewees so that once a person had been identified as vulnerable by one agency (housing, health, emergency services for instance) they could be put in touch with others to provide relevant advice and resources[26]. Others hoped for greater pooling of funds and expertise, citing the potential savings for the NHS if health funding was spent on housing improvements to prevent cold-related illnesses being exacerbated by living

[26] For example, the Scottish Government have provided guidance for staff in identifying and referring clients in fuel poverty at http://www.gov.scot/Publications/2005/04/20858/54696.

in cold homes (Osman et al., 2008) and therefore breaking the cycle of repeated hospitalisations.

Research findings

Triangulation of the results from different methods

The three approaches used in this research produced differing but complementary findings that provide insight into the relationship between household energy efficiency measures and health, particularly when considered as a whole. In order to better understand and highlight the overall findings of the research, triangulation (Jick, 1979) was used to identify common themes emerging from the empirical qualitative and quantitative studies and the review of existing literature. By using this approach, limitations in one study can be balanced against the strengths of others hence more confidence can be generated for findings that are uncovered or explained by more than one research method as the likelihood of chance effects or associations is reduced.

The key finding of this research in terms of importance and validity, given the sample size, is the significant, positive link between household energy efficiency measures and health identified by the meta-analysis of the existing evidence in Chapter 4. This headline result is explored and explained further though by the empirical quantitative and qualitative research conducted. The association identified by the survey study (Chapter 3) between perceptions of the home environment and improved health supports the consensus expressed by the interviewees in Chapter 5 of the benefits of improved warmth, comfort and financial stability for residents. However, this association is based on self-reported health which might, in theory, improve without any underlying physical change. For instance, increased comfort (Gilbertson et al., 2012) or improved aesthetics (Bond et al., 2012) could improve mood and, therefore, be reflected in higher health ratings, or expectations of health benefits could lead to a placebo effect. However, as the meta-analysis in Chapter 4 found the protective effect of household energy efficiency measures to be larger when measured objectively (e.g., via medical tests rather than self-report), it would appear that the health impacts of household energy efficiency measures are not entirely subjective and that physical benefits are being realised.

As the meta-analysis found that the protective effect of household energy efficiency measures on residents was moderated by how the effect was measured and by the type of resident, certain study design features were recommended to ensure that health impacts would be adequately captured by future research. While not all of these had been included in the empirical research in Chapters 2 and 3 (e.g., the medical tests mentioned above were not used due to ethical concerns), these studies were designed to investigate a broad range of relevant factors in order to gain a better understanding of the potential moderators. For instance, previous research has indicated that the health of residents may be influenced by the temperature and air quality within the home (Frey, Destaillats, Cohn, Ahrentzen, & Fraser, 2014), heating and ventilation patterns, and other activities or behaviours that affect the indoor environment (Long, Young, Webber, Gouldson, & Harwatt, 2014a), and how this environment is perceived and experienced by residents, e.g., their levels of comfort and satisfaction (Clark & Kearns, 2012; Gilbertson et al., 2012). All of these factors were captured by either the questionnaire or the household monitoring.

The lack of significant links between household energy efficiency measures and health found by the survey in Chapter 3 was explained to some extent by the meta-analysis in Chapter 4 which, despite the overall positive impact, included a number of individual studies that found little or no effect. While practical issues concerning monitoring methods were deemed to limit studies' ability to detect small, incremental or long-term changes in health, the complexity of the relationships between housing conditions and residents' health and wellbeing was apparent. This is reflected in the range of responses from interviewees in Chapter 5 regarding their experiences of helping vulnerable people, their views on the causes of fuel poverty problems for different individuals (bad luck, lack of knowledge, lifestyle choices, misguided policy) and their contrasting approaches to tackling the issue (e.g., via short-term debt relief or long-term warmth improvements).

The case study data from Chapter 2 indicated the potential of energy efficiency measures in helping maintain warmer home environments and generate cost savings. Following this, the survey in Chapter 3 found that residents who reported greater satisfaction with the home environment and fewer financial problems tended to report significantly better health as well as improvements in mood and mental wellbeing. As such this set of associations forms a potential route from energy efficiency to increased warmth, to a better perceived home environment and, ultimately, to improved health. While the associations are purely correlative, not causal, and no overall effect was detected, the notion that household energy efficiency measures may improve health via this route is supported by the meta-analysis in Chapter 4. A positive health impact from household energy efficiency measures was identified, suggesting that health effects may be sometimes difficult to measure, diluted or counteracted by other effects. The impact was also found to be particularly noticeable in vulnerable groups more susceptible to fuel poverty − those whose poorer housing and health conditions presented more scope for improvement. It is therefore likely that this affect is taking place either through reductions in energy bills and therefore reduced stress (Gilbertson et al., 2012), or through warmer home environments and therefore reductions in cold- and damp-related illness, as per the process suggested originally in Figure 2.

Regardless of the mechanism that links household energy efficiency measures to improved health (Chapter 2), this association helps to dispel concerns of widespread harmful effects arising due to tightly-sealed, thermally-efficient homes, as raised by some interviewees in Chapter 5 as well as Milner et al. (2015). While presence of external wall insulation on the case study homes in Chapter 2 was not found to have led to damp indoor environments that might cause adverse health effects, the similarity and standard of the housing meant that these results could not be generalised. However, the meta-analysis in Chapter 4 found no evidence of adverse health effects from household energy efficiency measures when looking at all the existing evidence or any subgroup of the evidence, suggesting that adverse health impacts either occur rarely or are outweighed by other health benefits. The possibility that this problem may exist in certain housing types, such as new builds, has not been discounted though.

To summarise the key findings, an examination of the existing evidence by meta-analysis (Chapter 4) confirmed that residents are healthier, on average, when household energy efficiency measures are present in their homes. A questionnaire-based survey (Chapter 3) and indoor environmental monitoring (Chapter 2) of homes following a council energy efficiency retrofit programme identified a set of associations that helped explain this relationship: household energy efficiency measures were associated with higher indoor temperatures, higher indoor temperatures were associated with increased satisfaction with the home environment, and increased satisfaction with the home environment was associated with better self-reported health. An alternative route to health improvements was suggested by the substantial financial savings estimated for installing external wall insulation (Chapter 2) and the association between financial worries and poorer self-reported health (Chapter 3). Finally, the professionals working in the fields of housing, energy, affordable warmth, and health interviewed in Chapter 5 cited an insufficient prioritisation of health by both providers and recipients, and described their efforts to reach people in fuel poverty and affect positive change limited by diminishing resources. Collaboration between services and the pooling of resources was proposed in order to best identify the vulnerable and provide a holistic approach to improving quality of life.

Comparison to relevant research

The present research supports the findings of a recent review (Willand et al., 2015) that identified warmth and satisfaction with the home as the key mechanisms by which energy efficiency improvements generate health improvement. Contrary to the findings discussed in Chapters 2 and 3, these were seen as two separate routes with warmth lowering the risk of mould and indoor pollutants, and greater satisfaction leading to better social functioning (though the pathways were also seen to interact, with less risk of mould causing greater satisfaction). Temperature and satisfaction with the home were also shown to be key by the monitoring and survey studies described earlier (Chapters 2 and 3) although, due to the correlation found between the two factors, they were considered part of a single primary route between household energy efficiency measures and health. Willand et al.'s review (2015) also proposed a secondary 'affordability' pathway, supported by similar findings in Chapters 2 and 3[27], and a potential health pitfall from reducing ventilation and therefore indoor air quality, though little evidence of such detrimental health impacts was found by the current research. While the possibility of adverse health impacts from reduced ventilation is

[27] Estimates of savings on energy bills from installing external wall insulation (Chapter 2) and correlations between reductions in problems paying bills and improvements in health (Chapter 3).

discussed in Chapter 1, neither the empirical studies (Chapters 2 and 3) nor the meta-analysis (Chapter 4) provided evidence of such impacts. However, the low levels of relative humidity and CO_2 indicate that even after interventions the houses had high levels of infiltration.

Both the present research and the recent review by Willand et al. (2015) reflect some of the key findings of Gilbertson et al.'s (2008) Health Impact Assessment of the Ealing Decent Homes programme. This identified a number of possible interweaving pathways to health resulting from energy efficiency improvements including reduced fuel poverty, higher indoor temperatures (hence less condensation, damp or mould), greater thermal comfort and reduced stress.

Focusing resources on those most in need

The interviews in Chapter 5 provided experienced perspectives on the decision-making processes regarding the acceptance and use of household energy efficiency measures by residents. Many residents previously assisted or targeted by the interviewees were considered vulnerable[28] and had demonstrated reluctance to install or engage with household energy efficiency measures. Resistant attitudes can be just as important as demographic or cultural factors in making residents 'hard to reach' (Mackenzie et al., 2012), a key theme to emerge from the interviews. It is important to understand the causes of such resistance as the meta-analysis in Chapter 4 demonstrated that vulnerable residents are the group most likely to derive health benefits from household energy efficiency measures.

The influence of psychological factors is highlighted by the 'cycle of risk' model proposed by Liddell & Guiney (2015) where living in cold, damp homes harms mental and physical health, which in turn harm each other and cause harmful behaviours and

[28] Vulnerable defined by the UK Fuel Poverty Strategy (DECC, 2001) as the elderly, children, and those with poor health or low incomes.

financial problems that perpetuate the decline in mental and physical health. Analysis of the case studies in Chapter 2 indicated that household energy efficiency measures may provide the opportunity to break this cycle by simultaneously addressing a number of stressors − principally financial strain, lack of thermal comfort, and cold-related illness[29]. However, as each stressor in the model is cumulative (multiplying rather than adding to the risk of harm), removing even one stressor may produce substantial health benefits. For example, health effects from household energy efficiency measures may have been limited due to the ability of the case study participants to maintain relatively healthy indoor environments (Chapter 2) and the broad study samples of both the questionnaire-based survey in Chapter 3 and the meta-analysis in Chapter 4. According to Liddell & Guiney's (2015) model, the health impacts on the most vulnerable residents − those living in extreme cold and damp conditions without the means for change − may be particularly severe. The potential benefits such residents might experience from the installation of household energy efficiency measures might therefore be considerably larger than for those whose standard of housing or financial situation offers even slight protection (such as the case study participants in Chapter 2). Consequently, as also suggested by interviewees in Chapter 5, resources for improving health would be utilised well in locating the poorest residents in the least thermally-efficient housing and providing household energy efficiency measures.

Warmth or satisfaction, health or wellbeing

The differing opinions expressed in Chapter 5 for how to best help the fuel poor reflected the different mechanisms by which energy efficiency improvements might improve health, as identified in Chapters 2 and 3 and outlined by Willand et al. (2015).

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[29] Shrubsole, Macmillan, Davies, & May (2014) discussed other potential outcomes from improving energy efficiency that might reduce stress, such as increased security, social inclusion, children's educational development, and greater use of the home.

Although long- and short-term needs would ideally be addressed together, a lack of resources drove interviewees to select a preferred approach. Some interviewees focused on improving housing conditions in order to reduce the risk of illness and protect long-term health, for instance using non-standard technology on *hard to treat* homes[30] (Dowson et al., 2012). Others focused on relieving debt and improving comfort to produce more immediate improvements in wellbeing, helping the *hard to reach* who may have been resistant to more permanent, physical intervention (Mackenzie et al., 2012).

The potential effectiveness of the latter psychological approach is supported by the data collected from the survey respondents in Chapter 3. Self-reported health was found to align more closely with reported levels of satisfaction with the home environment than with the actual environment, whether measured or self-reported[31]. Due to the small sample sizes, neither study found a direct significant link between household energy efficiency measures and improved health, in line with much of the existing evidence. As shown by Thomson et al. (2013) and in Chapter 4, few evaluations measure health objectively and those that use self-report measures rarely find large changes in health. It could therefore be argued that psychosocial benefits have been the main factors affecting measured health outcomes in previous research and that changes in physical health have been overestimated. This would, however, ignore the larger physiological impacts identified by the few studies included in the meta-analysis in Chapter 4 that used physical, objective measures of health. Perceptual and psychological factors may therefore have a different role to play in tackling fuel poverty.

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[30] External wall insulation for solid wall properties, for example.

[31] Significant correlation was seen between satisfaction with the home and health ratings, but not between household problems (such as damp or mould) and health ratings.

While comfort, satisfaction, and financial stress each contribute to a resident's wellbeing (Gilbertson et al., 2012) they do not equate to overall health. Health, however, can be invasive, onerous, and expensive to measure objectively, as the practical and ethical difficulties encountered while planning and conducting the studies in Chapters 2 and 3 attest. Many studies of the impacts of household energy efficiency measures therefore rely on health ratings provided by the participants soon after installation. Consequently, health effects may be underestimated as some health changes are likely to go unnoticed or occur over longer periods of time (Chapter 4). Where long-term, objective health monitoring is not employed, specific elements of wellbeing that are expected to be affected immediately should be measured. Short-term boosts to comfort, satisfaction, and stress relief from household energy efficiency measures or improved indoor environments were noted in Chapters 2 and 3, and have been found in previous studies (e.g., Chapman et al., 2009; Hong et al., 2009). Assessments of changes in wellbeing, specifically comfort, satisfaction and stress, may therefore be preferable to measurements of overall health, as a confident evaluation of specific, measurable impacts might prove more meaningful than an evaluation of health unable to capture all possible health changes comprehensively.

Engaging with residents in energy-inefficient homes

Residents are more likely to accept or invest in household energy efficiency measures if they can be confident of the energy savings and resultant benefits they would receive (Long et al., 2014a). If certain health benefits of household energy efficiency measures have not been adequately captured in previous research as the findings in Chapter 4 suggest, the value of such measures may have been underestimated and undersold. This knowledge gap can be addressed to some extent by the assessment of changes to levels of comfort and satisfaction with the home environment, and to energy bills following installation. In addition to being desired outcomes in their own right (Gilbertson, Stevens, Stiell, & Thorogood, 2006), comfort, satisfaction, and reduced financial stress are linked with better self-reported health (Chapters 2 and 3) and can lead to improvements in social inclusion and education development (Richardson & Eick, 2006). Promotion of the benefits of household energy efficiency measures would therefore be able to cite empirical evidence of immediate impacts on the home environment and the wellbeing of residents, and use existing epidemiological evidence (e.g., Marmot, 2011) to support the physical health benefits that follow.

The professionals interviewed in Chapter 5, however, described instances where compelling arguments for the installation or better use of household energy efficiency measures failed to convince residents. Residents had refused free interventions purely on aesthetic grounds while others, unwilling to make any financial outlay to improve their comfort or health, continued to wear coats indoors rather than use newly-installed central heating. While some interviewees dismissed this reluctance as irrationality or misplaced priorities, the present research noted the importance of the home in feelings of identity and status (Hards, 2013; Kearns, Whitley, Bond, Egan, & Tannahill, 2013) that might fuel resistance to change. Such resistance may be rooted in the need for control and consistency (Breakwell, 1993) and therefore may be overcome in schemes that give residents choices or minimise aesthetic changes. Promotion of household energy efficiency measures may also need to go beyond the simple provision of information in order to align with the attitudes and identities of residents. For example, a warm home environment could be pitched as an essential health need rather than a luxury to elderly residents who are proud of frugal, unfussy lifestyles (Allmark & Tod, 2014), or as a key element of providing for the family to parents with other spending priorities (Anderson et al., 2012). This need to reassess how best to engage with residents echoes the findings of other research conducted as part of the Big Energy Upgrade (BEU), the programme that launched the current research. Through focus groups with recipients of household energy efficiency measures provided by the BEU, Jones, Webb, and Scott (2014) found that residents focused less on the energy savings and more on the wider individual and communal benefits. Successful engagement with residents was, therefore, seen to depend on addressing these local priorities through tailored communications that promote improvements to quality of life and the regeneration of the local area.

A holistic approach to improve health and quality of life

One theme that recurred throughout the interviews in Chapter 5 was the need for a collaborative approach to help the fuel poor. Many of the housing, energy, affordable warmth, and health professionals interviewed had attempted to improve communication and pool resources with their respective departments and other relevant organisations, such as charities and emergency services, in order to work towards a shared set of goals. Household energy efficiency measures were seen as a particularly useful tool for achieving these goals due to their range of potential benefits − reductions in energy usage and, therefore, costs and carbon emissions (Chapter 2), the prevention of cold-related illnesses and stress (Gilbertson et al., 2012; Osman et al., 2008; Thomson et al., 2013), improvements in overall health (Chapter 4), and cost savings for health services (e.g., Shortt & Rugkasa, 2007).

However, while preventative strategies are supported in theory by UK health policy and by many individual health professionals, the focus often remains on cure (Baggott & Jones, 2011; Brotons et al., 2005). Health services tend to allocate a greater proportion of finite resources to curative care even where prevention is more cost effective (Bishai, Paina, Li, Peters, & Hyder, 2014; Taylor-Robinson et al., 2012). Oversimplified approaches that fail to integrate multiple objectives, such as the co-benefits of preventative strategies outlined above, may result in unintended consequences and, ultimately, policy failure (Shrubsole et al., 2014). Where the holistic approaches called for by interviewees in Chapter 5 have been applied though, there is evidence of a wide range of benefits being realised. In the UK, the Department of Health-funded FILT Warm Homes Service improved temperatures, comfort, wellbeing, and physical and mental health for vulnerable residents by providing energy advice and interventions (Bashir et al., 2013), while New Zealand's Healthy Housing Programme developed beyond its initial objective of tackling specific health risks to address a wider range of residents' needs and, therefore, enhance social inclusion, cohesion, and overall wellbeing (Bullen et al., 2008).

Research limitations

Experiences of conducting fieldwork

The difficulties and barriers encountered during the planning, preparation and data collection for the studies in Chapters 2 and 3 provided some explanation for the limitations found in the extant evidence regarding household energy efficiency measures and health, as discussed in the preceding chapters. The meta-analysis in Chapter 4 noted that few existing studies used objective measures of health, such as physical, medical tests or data from health records, or conducted this health monitoring over long periods. Consequently, researchers were recommended to assess health objectively over periods of years rather than weeks or months in order to fully capture any small or cumulative health benefits that may otherwise go unnoticed[32]. However,

[32] Evaluations of household energy efficiency schemes included in the meta-analysis tended to assess the health of residents by self-report within a few weeks of the

neither the objective medical tests nor the monitoring periods judged necessary to identify health effects missed by other studies proved possible within the constraints of the empirical elements of the project.

Local authorities were initially contacted to help identify homes where energy efficiency improvements were planned so that the residents could be approached prior to installation to collect baseline data on health, and on behaviours and perceptions related to energy use and the indoor environment. The local authority staff consulted understandably felt a duty to protect their residents and were reluctant to condone even simple medical tests for cold-related health issues (lung function and blood pressure tests for respiratory and cardiovascular health respectively). The most frequently expressed concern was ethical in nature: that the tests would not be performed by a medical professional and therefore expert advice could not be provided to contextualise the results. Misinterpretation of the test results by residents might then have caused unnecessary anxiety or, perhaps worse, false confidence regarding their health state and led to harmful consequences (for which the researcher could be considered liable). A secondary concern was invasiveness: the need to ask members of the public on their doorstep to submit to medical tests rather than advertise for volunteers to attend a health or laboratory setting as can be offered in other forms of health research.

Some previous studies utilised health service involvement and funding for medical tests, while Lloyd et al. (2007) were able to conduct blood pressure tests as two of the researchers were themselves residents of the tower blocks being studied and therefore known to the participants. Despite this familiarity many residents refused to

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installation and, therefore, were not able to detect physiological changes that had not yet affected the residents' perceptions of their own health. For instance, reductions in blood pressure have been shown to reduce the risk of coronary heart disease and stroke, and therefore the need to use health services (Lloyd, McCormack, McKeever, & Syme, 2008).

take part and nearly half of those that agreed initially withdrew before the study was complete. As the present case study research was conducted on a much smaller scale with limited monitoring equipment available, similar problems with recruitment and, particularly, attrition would have jeopardised the study as a whole. Medical tests were therefore deemed too great a potential deterrent to respondents, as was the use of health records which some local authorities had attempted to access previously for research purposes and had experienced reluctance to give permission from both residents and health professionals. As vulnerable groups, the key targets for this research as per the findings in Chapter 4, are traditionally hard to engage with (Mackenzie et al., 2012), both of these forms of objective health measurement were dismissed.

The approach and timing of the health assessments also had to be adapted significantly from the original research plans due to the schedules and requirements of the local authorities implementing energy efficiency improvements. The initial questionnaire pilot was not expanded into a full study as planned due to a lack of access to the residents receiving free insulation and the withdrawal of CESP funding (DECC, 2011) that subsequently led to closure of the scheme (see Chapter 3). A number of the schemes considered for study suffered continuing delays due to political or financial pressures. In one scheme that proceeded some months later than planned, permission for the research was withdrawn at the last minute by senior management within the local authority who cited data protection concerns. Another scheme eventually went ahead and used the original questionnaire design for pre- and post-installation data collection to evaluate health impacts of hundreds of insulation retrofits. However, as this scheme was not due to start until towards the end of the current research project and was subsequently delayed by more than a year, none of the data was available in time for analysis. It was clear that an alternative approach to data collection was needed.

While continuing to communicate with local authorities regarding potential collaborations, options for conducting independent research were considered in order to avoid reliance on local authority resources and schedules. A compromise approach was agreed with staff at North Lincolnshire Council who provided informal advice without taking part in or endorsing the research. Unfortunately, this prevented the identification of homes prior to the installation of household energy efficiency measures and so a retrospective approach was adopted instead. The questionnaire was amended accordingly (see Chapter 3) and distributed in an area where many homes had received visible improvements − primarily external wall insulation − 12 to 18 months previously. Although longer periods had originally been planned for assessing health changes, this had assumed the collection of baseline data. Without baseline data, 12 to 18 months was considered appropriate as the greater the time period between installation and health measurement, the more difficult it would be to ascribe health changes to the household energy efficiency measures installed. The changes to the study design, however, did limit the power to detect health changes and prompted a revised approach to the analysis, described in the following section.

Study limitations

The meta-analysis of the existing evidence of health impacts from household energy efficiency measures (Chapter 4) used broad selection criteria so included a number of studies deemed weaker or less robust, and therefore excluded, by other reviews (e.g., Thomson et al., 2013). According to Mackenzie (2010), however, robust methods such as randomised controlled trials can be inappropriate and impractical for studies that aim to evaluate complex interventions. While the inclusion of less robust study designs was justified by the reduction, rather than inflation, of the overall effect size calculated in Chapter 4, this conservative estimate of health impacts prompted further investigation into the mechanisms by which household energy efficiency measures affect health, as appealed for by Thomson & Thomas (2015) (Thomson & Thomas, 2015). The greater sample size provided some opportunity for such analysis as described in Chapter 4, though more detailed investigation was warranted.

By contrast, the questionnaire-based survey study in Chapter 3 was limited by a relatively small sample size due to the inability to supplement it with a similar study conducted elsewhere as originally intented. This small sample restricted both the analyses that could be conducted and statistical power of the study, as discussed in more detail in Chapter 3. Had any of the other schemes considered for further studies proceeded within the timescale of the project, a meta-analysis of the combined survey results could have been conducted to determine the overall effect of household energy efficiency measures on health and to investigate the factors moderating health outcomes. As this was not the case, two further studies were developed to focus on the latter, investigating how and when (rather than whether) health changes result from the installation of household energy efficiency measures.

The case study research described in Chapter 2, which incorporated indoor environmental monitoring and frequent self-completion questionnaires over a three month period, was limited to nine participating households primarily due to the availability of monitoring equipment. Although it was designed to gather detailed information from a small sample, the study would have benefited from a larger number of participants to increase confidence in the findings. It is unlikely though that statistically significant relationships would have been identified without drastic changes to the study design to allow a much larger sample.

For the study in Chapter 5, fourteen professionals with experience in planning and providing household energy efficiency interventions were interviewed. Ten interviews had been conducted and analysed originally: the final interviews were carried out a few months later to check that no new issues had arisen. This was the case, suggesting further interviews with similar participants would have added little value. Other stakeholders could have been included to broaden the range of perspectives, particularly to look at the issue from the top down (e.g., representatives from central government or Health and Wellbeing Boards) and the bottom up (e.g., recipients of energy efficiency interventions, charities that work with the fuel poor). However, the scope was purposefully kept narrow, interviewing just the 'key players' − the front line professionals dealing with energy efficiency and vulnerable people on a day-to-day basis − to ensure a thorough and focused examination of their experiences and opinions.

Triangulation of the findings from the empirical studies unearthed similar negative experiences and issues. The main difficulties encountered during the data collection for the studies in Chapters 2, 3 and 5 bore some similarity to the obstacles faced by professionals when implementing household energy efficiency schemes, as described in the interviews in Chapter 5. The lack of resources cited by interviewees reflected the limited availability of equipment in Chapter 2 and the inability to conduct physical health tests without medically-trained staff in Chapter 3. The interviewees also described difficulties identifying and engaging with the people most in need of help, which reflected the problems finding schemes suitable for research in Chapter 3. These recruitment issues resulted in a small sample that cannot be assumed to represent the wider population and so the study results cannot be generalised. The findings are transferable though, in that there was a sufficient number of survey responses in Chapter 3 to expect that residents in a similar area receiving similar interventions might experience similar outcomes. Likewise, it cannot be assumed that the views expressed by interviewees in Chapter 5 represent a consensus of opinion held throughout the public sector, particularly as not all issues raised during the study garnered agreement. There was enough consistency though between the experiences described by interviewees to suggest that their responses are indicative of the opportunities and barriers typically faced by staff in similar roles, planning and implementing household energy efficiency improvements.

The findings of the study described in Chapter 2 also cannot be generalised across all housing stock, though this is due more to the homogeneity of the sample than the size. Despite being situated in a deprived area highlighted by the local authority for the poor standard of thermal efficiency of the housing, the environmental readings taken at each of the case study homes (including those that were not improved through the council retrofit scheme) showed the temperature, relative humidity, and levels of carbon dioxide to be within acceptable parameters. The findings are again transferable as it is fair to expect similar homes to experience similar effects from similar interventions. Newer and better constructed homes though may not struggle to maintain a warm environment and, therefore, not see improvements to the same extent as calculated in Chapter 2. The airtightness of newer housing might also contribute to the build up of harmful indoor pollutants and the development of damp and damp-related illness (Milner et al., 2015). No evidence of these impacts was found by the present research, although they are less likely to occur in older homes such as those studied; a side-benefit of otherwise unwanted levels of infiltration. Conversely, homes with significantly worse standards of construction and thermal efficiency might have colder, harmful environments (or warm environments that are expensive to maintain). However, much larger benefits would be expected in terms of temperature or financial savings, either of which may improve health.

Implications

For policy

Household energy efficiency measures should be targeted at those most in need. While some potential for household energy efficiency measures to improve health for all was found (see Chapter 4), the empirical evidence conducted in Chapters 2 and 3 and reviewed in Chapter 4, plus the anecdotal evidence presented in Chapter 5, all point to greater health benefits for the most vulnerable members of society. This is supported by a wealth of existing theoretical, epidemiological, and empirical evidence on the health impacts of living in cold, damp homes and fuel poverty (Liddell & Morris, 2010; Liddell & Guiney, 2015; Marmot, 2011) and of energy efficiency improvements (Howden-Chapman et al., 2007; Thomson et al., 2013).

Unfortunately, focusing on the fuel poor is contrary to recent changes in UK policy. There are currently no direct sources of government funding for household energy efficiency measures in the UK as schemes to improve energy efficiency and alleviate the impacts of fuel poverty − e.g., Warm Front, Decent Homes, CERT, CESP − have all been withdrawn in recent years. These have been replaced by the Green Deal (DECC, 2011), a loan scheme focused on reducing environmental impact and stimulating economic growth which critics predicted would have limited appeal to consumers or investors (Dowson et al., 2012) and has seen relatively slow uptake so far (Pettifor, Wilson, & Chryssochoidis, 2015). Alongside the Green Deal, the Energy Company Obligation requires private investment to improve the energy efficiency of vulnerable households (DECC, 2011). However, as discussed in Chapter 5, there is scepticism and disagreement among the professionals involved in targeting and implementing such work as to the extent to which this help will reach the people who need it most.

The present research supports the adoption of preventative, holistic approaches to tackle fuel poverty and improve health, with energy efficiency as a key component. Improved communication between services that work with the vulnerable is needed so that the fuel poor, who are often hard to reach (Chapter 5), can be identified and referred for help efficiently. The installation of household energy efficiency measures can provide such help as they are linked with improved health for vulnerable groups in particular (Chapter 4) and provide multiple benefits (such as the improved warmth and comfort, financial savings and reductions in carbon emissions estimated in Chapter 2). A number of the public-sector staff interviewed proposed pooling housing and health resources to improve housing conditions and prevent cold- and damp-related illness (see Chapter 5). This holistic, long term approach was found to yield a range of additional social benefits in some cases (e.g., Bashir et al., 2013), particularly where residents were allowed to retain control and, therefore, enhance their feelings of identity and wellbeing (Bullen et al., 2008). Consequently, to maximise the impacts of energy efficiency interventions their design should take account of not just performance and cost-effectiveness but also residents' needs and opinions, providing choice and minimising superficial change where possible.

While technical, financial or other structural changes can be implemented to encourage behaviour change, this will only succeed if the barriers preventing such behaviour are addressed (Steg and Vlek,2009). The promotion of interventions therefore needs to go beyond educating the public if it is to be heard (see Chapter 5). Messages to promote household energy efficiency measures and their optimum use need to be tailored to show that such measures are in line with the attitudes and values of potential recipients, and can contribute to their aspirations. Although communal benefits such as regeneration of the local area may help foster engagement (Scott et al., 2014), the experiences of the interviewees in Chapter 5 suggest that residents will demonstrate a variety of attitudes that might hinder the adoption of an energy efficient lifestyle. Multiple strategies may therefore be needed, as noted by Steg and Vlek (2009), featuring a range of distinct, potentially conflicting messages to position household energy efficiency measures as the solution to the needs of each individual. Given the withdrawal of government funding for energy efficiency, one of the most important messages is the need to speculate in order to accumulate the individual benefits evident throughout the present research; financial savings, comfort and health. This message may be counterintuitive for residents on low incomes and, consequently, difficult for local authorities to convey through large scale promotion. Professionals who work directly with vulnerable residents, such as Affordable Warmth Officers, may be better placed to generate investment as they can develop a thorough understanding of an individual's needs in order to discuss the relevance and value of household energy efficiency measures.

Encouragingly, there are already signs of progress towards some of the goals discussed above. Guidelines on health risks from cold homes published by the National Institute for Health and Care Excellence earlier this year (NICE, 2015) include a number of recommendations that reflect the findings of the present research. Among the NICE recommendations are:

- a joint health and housing service providing tailored solutions to people in cold homes,
- training housing, health, and social care professionals to identify those at risk of harm, assess their heating needs and provide appropriate help, and
- ensuring that vulnerable people return to warm homes when leaving health or social care settings.

Hopefully these guidelines signify a shift in health, housing and energy policy that will encourage a collaborative, holistic approach to develop preventative schemes (e.g., Bashir et al., 2013; Bullen at al., 2008) that find the most vulnerable residents, address their range of needs and use household energy efficiency measures to help protect their long-term health.

For future research

The present research has demonstrated the importance of providing assistance for the most vulnerable members of society. Those who work with the fuel poor have highlighted examples of dire need for help (see Chapter 5) while existing studies have found household energy efficiency measures to have the greatest health impacts on vulnerable residents (Chapter 4). Further research is needed to help shift policy focus on to the vulnerable, particularly in the UK where energy efficiency is increasingly positioned as a tool primarily for reducing carbon emissions. Quantifying not just the direct environmental, health and financial impacts of improving energy efficiency but also the range of social benefits (e.g., inclusion and educational development) and economic benefits (from fewer work absences and less use of health services) would help demonstrate the value of a people-focused approach.

Before people in need can be helped they must be *reached*, i.e. found and engaged with. Research can help in this regard, for instance by identifying the households that are least able to maintain a warm environment due to either low incomes or thermally inefficient homes. The health impacts seen from improvements to already relatively healthy indoor environments (Chapter 2) and the greater health benefits identified for vulnerable groups in the meta-analysis (Chapter 4) raise the possibility that those living in extreme cold or damp conditions may benefit more from an improved environment. For instance, a cost-effective approach to improve health may be the provision of basic household energy efficiency measures to homes where insulation, central heating, or double glazing are absent (e.g., hard to treat homes or privately rented properties ineligible for area-based retrofit schemes), although the prevalence of such measures prevented the assessment of their impacts in the present research[33]. While particular cold- and damp-related illness could be used to target those susceptible to fuel poverty, identifying people who are suffering from multiple stresses related to cold housing may be a more effective option. The analysis of data from local authorities and services in order to identify people with poor health, low incomes, and thermally inefficient homes would provide a platform for the use of household energy efficiency measures to generate benefits addressing each of these problems. In practice, it may prove far less onerous and, therefore, more cost effective to focus on either hard to treat properties or hard to reach individuals. If hard to reach residents in hard to treat or thermally-substandard housing can be found efficiently though − for instance by looking at the private rental market − the potential to achieve multiple benefits may be particularly high.

In addition to identifying the vulnerable, the issue of how to engage with them and promote positive change remains. While decisions regarding improvements to the home have been linked to notions of identity and status (see Chapter 5), further research is needed to understand how interventions can be designed to align with residents' attitudes and values in order to encourage the uptake of household energy efficiency measures and their efficient use. Interviews or focus groups, such as those carried out as part of the Big Energy Upgrade (Scott et al., 2014) could delve deeper into the connections between residents and their home environments, and shed light on the underlying reasons behind any resistance to change.

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[33] For instance, 95% of the homes surveyed had central heating so the group without central heating was too small for a meaningful comparison.

Engagement with health services is also needed, primarily to quantify and convey the impacts of improved home environments on health and health service use in order to develop sound business cases for the use of household energy efficiency measures in the prevention of cold- and damp-related illness. Long-term, objective monitoring would be required to fully capture the range of health impacts. Where this is not available though, evaluations of household energy efficiency measures and schemes may underestimate overall health impacts so the specific effects on comfort, satisfaction, and financial stresses should be measured instead. This would provide a meaningful estimate of the immediate impacts on mental health and wellbeing that might be expected. Any improvements identified could then be used for promotion, in conjunction with epidemiological evidence of long-term physical health benefits.

Conclusion

The present research has highlighted the complexity of the relationship between household energy efficiency measures and health. Consequently, larger scale, better designed studies are needed to help inform a) the design and implementation of interventions, and b) the direction of energy, fuel poverty, housing and health policy. Analysis of the existing evidence though found that the presence of household energy efficiency measures has a positive, if small, overall effect on health on average. No evidence of detrimental health impacts was found which may, to some extent, allay concerns regarding the impact of sealing homes to improve their thermal efficiency (though the existence of such effects was not ruled out). As vulnerable residents were found to benefit in particular, the findings support the use of household energy efficiency measures to combat the impacts of fuel poverty and therefore contradict the current policy direction in the UK that increasingly targets climate change. This shift in priorities was questioned by some public sector staff involved in the planning and delivery of energy efficiency improvements, who expressed concerns that opportunities to help people in need and simultaneously reduce carbon emissions were being missed.

A key set of associations was identified to help explain the health effects described above: from the presence of household energy efficiency measures to a warmer home environment, to greater satisfaction with the home environment and, finally, to better self-reported health and wellbeing. As the alleviation of financial stresses also corresponded with improved health ratings, satisfaction through increased comfort and reduced anxiety appears to be the main determinant of perceived health. However, analysis of the existing evidence demonstrated that household energy efficiency measures can have larger but unnoticed impacts on the physiological health of residents and, therefore, reduce the risk of future illness and health service use.

If the full potential of household energy efficiency measures is to be realised, a narrow focus on a single issue such as carbon reduction (or indeed, health improvement) is not sufficient. Instead, the wide range of issues that can be addressed through energy efficiency must be taken into account. This range was illustrated recently by the IEA (2015) who produced an exhaustive list of the benefits of energy efficiency improvements including, but not limited to, energy security, public budgets, GHG emissions, industrial productivity, employment, local air pollution, poverty alleviation and, of course, health and wellbeing.

For research into health specifically, this holistic approach means the inclusion of different measures to capture a range of health effects; short and long term, perceived and actual, psychological and physical, health and wellbeing, individual and communal, social and financial. Comprehensive health evaluations such as these would feed into holistic strategies that aim to address the various needs of vulnerable residents. Even where the evidence of multiple benefits is available though, these strategies would need to go beyond the provision of information and rational arguments in order to break habitual behaviours and overcome resistance to change. To foster engagement, the impacts of household energy efficiency measures must be shown to chime with the specific values of the residents and communities in need of help. While this individual, targeted approach may be onerous and expensive, communication and collaboration within and between relevant organisations (including public sector housing, energy, affordable warmth and health departments, charities, debt and emergency services, and housing and energy providers) may help to overcome structural barriers that inhibit the effectiveness of energy efficiency schemes. A holistic approach that shares financial resources and expertise in order to first identify the most vulnerable people and their needs, and then implement preventative interventions designed to achieve the maximum overall benefit from a wide range of goals may prove to be the most cost-effective option in the long term. While some examples of such progress have been seen, further research is needed to test and support this approach. The present research though has demonstrated that household energy efficiency measures can generate health improvements alongside environmental, social and economic benefits and, therefore, can play a key role in policies that target multiple objectives.

Appendices

Figure 36: Pilot survey information sheet and questionnaire

The University Of Sheffield. Sheffield Hallam University MANCHESTER CITY COUNCIL

GET ME TOASTY

Tell us how you feel

As you may be aware, your local council has been working with the Greater Manchester Energy Advice Service on 'Get Me Toasty', a scheme designed to help you keep your homes warm by providing free or heavily discounted loft and cavity wall insulation. As part of a project run by Manchester City Council and the University of Sheffield, with the help of Sheffield Hallam University, we are asking residents involved in the scheme about their experiences. As a thank you, any household participating in the research will be entered into a free prize draw to win £50 in Argos vouchers. Our hope is that this research will lead to further home improvement schemes in your area and across the country.

This questionnaire will ask you about your home and the health of the people who live there. Please ask each person who lives at this address for at least 6 months of the year to complete the 'About You' section of the survey for themselves, if possible. For children or anyone unable to respond for any reason, please complete the questions on their behalf and indicate that you have done this in question 3. We will then contact you again in a few months for your thoughts and feelings after the insulation has been installed.

In some homes we would like to take further measurements by taking meter readings and leaving a 'data logger' in your living room and one in your bedroom for a week or two. These are very small pieces of equipment that monitor the temperature, humidity and carbon dioxide levels in a room - they do not record anything else.

All of this is entirely **voluntary** - filling in the questionnaire does not commit you to anything and you may withdraw from part or all of the project at any time, without giving a reason. You may leave any question blank if you would prefer not to answer it. Your responses and any other data collected will remain **confidential** and will not influence any of the services or benefits that you receive.

If you have any questions regarding this project, please contact either Chris Maidment or Dr. Chris Jones at the University of Sheffield (Tel: 0114 222 6514 or 0114 222 6592, email: pcp11cdm@sheffield.ac.uk or c.r.jones@sheffield.ac.uk). For questions about the 'Get Me Toasty' scheme, please contact Manchester City Council (Tel: 0800 009 3363) or for any questions regarding your health, please contact your GP.

Title of Research Project: *The impact of domestic energy efficiency measures on the*
health *and well being of residents.*

Name of Researcher: *Chris Maidment*

Participant Identification Number for this project: ____________ Please initial box

1. I confirm that I have read and understood the information sheet dated 22nd June 2012 explaining the above research project and I have had the opportunity to ask questions about the project. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

3. I understand that my responses will be kept strictly confidential. I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐

4. I agree for the data collected from me to be used in future research. ☐

5. I agree to take part in the all or part of the above research project. ☐

________________________ ________________ ____________________

Name of Participant Date Signature

_________________________ ________________ ____________________

Lead Researcher Date Signature

To be signed and dated in presence of the participant

The project has been ethically approved via the Psychology department's ethics review procedure at the University of Sheffield. If you wish to make a complaint, please contact Dr. Chris Jones (Tel: 0114 222 6592, email: c.r.jones@sheffield.ac.uk) or, if you are not satisfied with how your complaint has been handled, the Registrar and Secretary (Tel: 0114 222 1100, email: registrar@sheffield.ac.uk).

A blank copy of this form & information sheet will be left with the resident and a copy of the signed form will be handed over at the second visit to retrieve any equipment, or posted out if necessary. The original will be kept on file securely at the university.

About you

Please note that your answers will remain confidential

Office use only:
Ref No:

What is your full name? ______________________

What is your address?

Postcode:

How long have you lived at this address? ______________________

What is your gender? ☐ Male ☐ Female

How old are you?

☐ Under 18 ☐ 35 to 44 ☐ 65 to 74
☐ 18-24 ☐ 45 to 54 ☐ 75 to 84
☐ 25 to 34 ☐ 55 to 64 ☐ 85 or over

Which of these best describes what you are doing at present? *If more than one of these applies to you, please tick the main ONE only*

- ☐ Full-time paid work (30 hours or more each week)
- ☐ Part-time paid work (under 30 hours each week)

If working full or part time, what is your occupation? ______________________

- ☐ Full-time education at school, college or university
- ☐ Unemployed
- ☐ Permanently sick or disabled
- ☐ Fully retired from work

If retired or sick / disabled, what was your occupation? ______________________

- ☐ Looking after the home
- ☐ Doing something else

How would you describe your general health and wellbeing?

Very bad	Bad	Fair	Good	Very good
☐	☐	☐	☐	☐

In the last 12 months, how many times have you visited the following health services **regarding your own health?**

Doctor / GP _______ Walk-in centre _______ Hospital _______

Are your day-to-day activities limited because of a health problem or disability which has lasted, or is expected to last, at least 12 months?

(Include problems related to old age)

☐ Yes, limited a lot

☐ Yes, limited a little

☐ No

Do you suffer from any of the following problems and, if so, have you seen a doctor or health professional about it in the last 12 months?

*(Please tick **one** box in **each** row)*

	No, I do not suffer from this	Yes but I have not seen a doctor	Yes and I have seen a doctor
Joint pain, arthritis	☐	☐	☐
Respiratory problems, breathing, wheeze	☐	☐	☐
Psychological / emotional conditions	☐	☐	☐
Heart problems, angina	☐	☐	☐
Circulatory problems, high blood pressure	☐	☐	☐
Persistent flu symptoms, headaches	☐	☐	☐
Allergies, hay fever	☐	☐	☐
Other(s), please state:			
_______________	☐	☐	☐
_______________	☐	☐	☐

By placing a tick in one box in each group below, please indicate which statements best describe your own health state today.

Mobility

I have no problems in walking about ❑

I have some problems in walking about ❑

I am confined to bed ❑

Self-Care

I have no problems with self-care ❑

I have some problems washing or dressing myself ❑

I am unable to wash or dress myself ❑

Usual Activities

(e.g. work, study, housework, family or leisure activities)

I have no problems with performing my usual activities ❑

I have some problems with performing my usual activities ❑

I am unable to perform my usual activities ❑

Pain/Discomfort

I have no pain or discomfort ❑

I have moderate pain or discomfort ❑

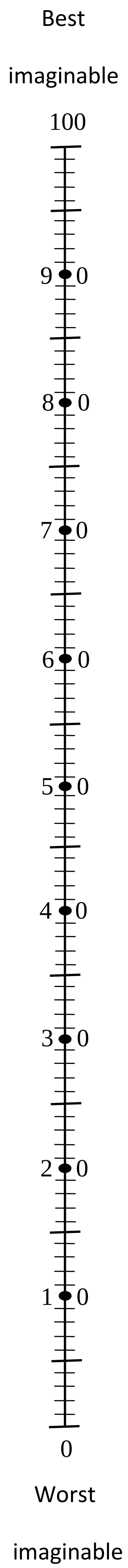
I have extreme pain or discomfort ❑

Anxiety/Depression

I am not anxious or depressed ❑

I am moderately anxious or depressed ❑

I am extremely anxious or depressed ❑



To help people say how good or bad a health state is, we have drawn a scale (rather like a thermometer) on which the best state you can imagine is marked 100 and the worst state you can imagine is marked 0.

We would like you to indicate on this scale how good or bad your own health is today, in your opinion. Please do this by drawing a line from the box below to whichever point on the scale indicates how good or bad your health state is today.

Your own health state today

About your home

What type of house do you live in?

- ☐ Detached house
- ☐ Terraced house
- ☐ Semi-detached house
- ☐ End-terraced house
- ☐ Flat
- ☐ Other

Roughly when was your house built? ______________

How many rooms does the property have, **not** including hallways, landings or cellars?

Total ____ How many of these are bedrooms? ____ ..and bathrooms? ____

How many people live in your household? Adults ______ Children ______

Does anyone regularly smoke inside your home? ☐ Yes ☐ No

Are there any pets in the home? ☐ Yes ☐ No

What animals if so? ________________________________

Do you own or rent your home?

- ☐ Own outright
- ☐ Rent
- ☐ Own with a mortgage or loan
- ☐ Live here rent free
- ☐ Shared ownership
- ☐ Other

If renting, who is your landlord?

- ☐ Housing association
- ☐ Employer of a household member
- ☐ Council (local authority)
- ☐ Relative or friend
- ☐ Private landlord or letting agency
- ☐ Other

What fuel do you mainly use for heating?
(e.g. gas, electricity, coal)

Which of these measures do you have currently have in your home?

					Did you pay for the installation?			
	Yes	No	Not sure	**If yes**, when was it installed?	*Yes, in full*	*Yes, through a grant or scheme*	*No, installed by housing provider*	*No, other (e.g. here when we moved in)*
Loft insulation	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Cavity wall insulation	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
External wall insulation	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Internal wall insulation	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Solar electricity panel	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Solar thermal heating	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Other renewable energy *(wind turbines etc)*	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Double or triple glazing	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Home energy monitor	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Draught proofing	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Efficient 'a-rated' (condensing) boiler	☐	☐	☐	________	☐	☐ ________	☐	☐ ________
Central heating	☐	☐	☐	________	☐	☐ ________	☐	☐ ________

Does your home have any problems with the following?
(Slight = barely noticeable, Extreme = making the home unliveable)

	Not at all	Slight problems	Moderate problems	Large problems	Extreme problems	Don't know
Condensation	☐	☐	☐	☐	☐	☐
Damp	☐	☐	☐	☐	☐	☐
Mould	☐	☐	☐	☐	☐	☐
Draughts	☐	☐	☐	☐	☐	☐

How satisfied are you with your home regarding the..

	Not at all	Slightly	Somewhat	Very	Extremely
...standard of housing?	☐	☐	☐	☐	☐
...indoor temperature?	☐	☐	☐	☐	☐
...humidity indoors?	☐	☐	☐	☐	☐
...freshness of air indoors?	☐	☐	☐	☐	☐

In general, how often do you...

	Never	Seldom	Sometimes	Often	Almost always	Don't know
...have problems paying energy bills?	☐	☐	☐	☐	☐	☐
...open a window for ventilation?	☐	☐	☐	☐	☐	☐
...use an extractor fan when cooking?	☐	☐	☐	☐	☐	☐
... use an extractor fan in the bathroom?	☐	☐	☐	☐	☐	☐
...hang clothes to dry indoors?	☐	☐	☐	☐	☐	☐
...heat living areas and bedroom(s) in winter?	☐	☐	☐	☐	☐	☐
...heat the same rooms in summer?	☐	☐	☐	☐	☐	☐

And, finally..

Will you be installing insulation through the 'Toasty' scheme?

☐ Yes ☐ No ☐ Don't know

What effect, if any, do you think the scheme will or would have on your life?

Very negative	Negative	No effect	Positive	Very positive
☐	☐	☐	☐	☐

If you would like to pass any comments or questions about the scheme to Manchester City Council, please use the box below:

Thank you for your time

Please return the completed questionnaire in the envelope provided

If you have any questions regarding this project, please contact Chris Maidment at the University of Sheffield (Tel: 0114 222 6514, email: pcp11cdm@sheffield.ac.uk).

For questions about the 'Get Me Toasty' scheme, please contact Manchester City Council on Freephone number 0800 009 3363.

For any questions regarding your health, please contact your GP.

Figure 37: Information sheet and questionnaire used in North Lincolnshire

Your home and you

Tell us how you feel

At the University of Sheffield, we are researching the different ways in which housing can impact on the lives of residents. We are interested in your views and would be very grateful if you could complete the enclosed questionnaire - which should take no longer than 10 minutes - and return it in the envelope provided. The questionnaire will ask various things about you, including your health and how you feel. It will also ask you about your home and your experiences living there.

As a thank you, respondents will be entered into a free prize draw to win £50 in Argos vouchers. Our hope is that this research will lead to home improvement schemes in your area and across the country.

More information about the research is included over the page. If you have any further questions, please feel free to contact me.

Chris Maidment

University of Sheffield

Frequently asked questions

- *Who is conducting this research?*

This project is being run by the University of Sheffield, with the help of Sheffield Hallam University. My name is Chris Maidment and I am a PhD student at the University of Sheffield.

- *What do I need to do?*

The questionnaire will ask you about your home and health, and should take no longer than 10 minutes to complete. Please return it in the envelope provided.

- *Will you share my personal details with anyone?*

No, your responses will be kept strictly confidential and will **not** influence any of the services or benefits that you receive. Members of the research team will have access to the anonymised responses but your name will not be linked with the research materials, and you will not be identifiable in the reports that result from the research.

- *Can I change my mind?*

Yes - all of this is entirely **voluntary**. Filling in the questionnaire does not commit you to anything and you may withdraw from part or all of the project at any time, without giving a reason. You may leave any question blank if you would prefer not to answer it.

- *Who should I contact if I have any questions?*

For questions regarding this survey, please contact the University of Sheffield:

Chris MaidmentTel: 0114 222 6647 email: pcp11cdm@sheffield.ac.uk

Dr. Chris Jones Tel: 0114 222 6592 email: c.r.jones@sheffield.ac.uk

For questions about housing improvements, please contact your local council or housing provider.

For any questions regarding your health, please contact your GP.

- *What if I need to make a complaint?*

The project has been ethically approved via the Psychology department's ethics review procedure at the University of Sheffield. If you wish to make a complaint please contact Dr. Chris Jones (see above) or, if you are not satisfied with how your complaint has been handled, the Registrar and Secretary on 0114 222 1100 or email registrar@sheffield.ac.uk.

About you

Please note that your answers will remain confidential

Office use only:

Ref No:

IF YOU WOULD LIKE TO BE ENTERED INTO THE **PRIZE DRAW**, PLEASE PROVIDE YOUR NAME AND ADDRESS.

If not, you can leave the box blank.

Postcode:

How long have you lived at your current address? ______

What is your gender? ☐ Male ☐ Female

How old are you?

☐ Under 18	☐ 35 to 44	☐ 65 to 74
☐ 18-24	☐ 45 to 54	☐ 75 to 84
☐ 25 to 34	☐ 55 to 64	☐ 85 or over

Which of these best describes what you are doing at present? *If more than one of these applies to you, please tick the main ONE only*

- ☐ Full-time paid work (30 hours or more each week)
- ☐ Part-time paid work (under 30 hours each week)

If working full or part time, what is your occupation? ______

- ☐ Full-time education at school, college or university
- ☐ Unemployed
- ☐ Permanently sick or disabled
- ☐ Fully retired from work

If retired or sick / disabled, what was your occupation? ______

- ☐ Looking after the home
- ☐ Doing something else

How would you describe your..	Very bad	Bad	Fair	Good	Very good
..mood and happiness?	☐	☐	☐	☐	☐
..energy levels?	☐	☐	☐	☐	☐
..relationships with others?	☐	☐	☐	☐	☐

In the last 12 months, how many times have you visited the following health services **regarding your own health?**

Doctor / GP ______ Walk-in centre ______ Hospital ______

Total number of nights spent in hospital in the last 12 months ______

Over the last year, has your health...

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

And has your general mood and mental wellbeing...

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

Do you suffer from any of the following problems and, if so, have you seen a doctor or health professional about it in the last 12 months?

*(Please tick **one** box in **each** row)*

	No, I do not suffer from this	Yes but I have not seen a doctor	Yes and I have seen a doctor
Joint pain, arthritis	☐	☐	☐
Respiratory problems, breathing, wheeze	☐	☐	☐
Psychological / emotional conditions	☐	☐	☐
Heart problems, angina	☐	☐	☐
Circulatory problems, high blood pressure	☐	☐	☐
Persistent flu symptoms, headaches	☐	☐	☐
Allergies, hay fever	☐	☐	☐
Falls or accidents in the home	☐	☐	☐
Other(s), please state:			
______________________	☐	☐	☐

By placing a tick in one box in each group below, please indicate which statements best describe your own health state today.

Mobility

I have no problems in walking about ❑

I have some problems in walking about ❑

I am confined to bed ❑

Self-Care

I have no problems with self-care ❑

I have some problems washing or dressing myself ❑

I am unable to wash or dress myself ❑

Usual Activities

(e.g. work, study, housework, family or leisure activities)

I have no problems with performing my usual activities ❑

I have some problems with performing my usual activities ❑

I am unable to perform my usual activities ❑

Pain/Discomfort

I have no pain or discomfort ❑

I have moderate pain or discomfort ❑

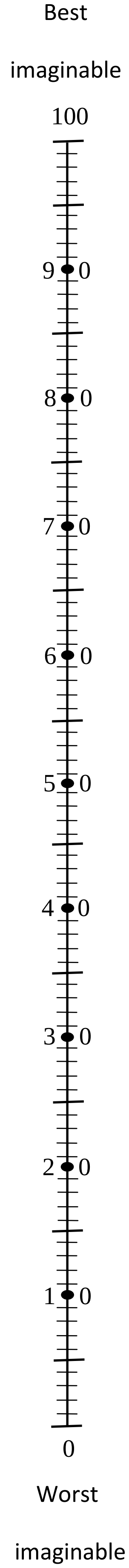
I have extreme pain or discomfort ❑

Anxiety/Depression

I am not anxious or depressed ❑

I am moderately anxious or depressed ❑

I am extremely anxious or depressed ❑



To help people say how good or bad a health state is, we have drawn a scale (rather like a thermometer) on which the best state you can imagine is marked 100 and the worst state you can imagine is marked 0.

We would like you to indicate on this scale how good or bad your own health is today, in your opinion. Please do this by drawing a line from the box below to whichever point on the scale indicates how good or bad your health state is today.

Your own health state today

About your home

What type of house do you live in?

- ☐ Detached house
- ☐ Terraced house
- ☐ Semi-detached house
- ☐ End-terraced house
- ☐ Flat
- ☐ Other

Roughly when was your house built? ____________

How many rooms does the property have, **not** including hallways, landings or cellars?

Total ____ How many of these are bedrooms? ____ ..and bathrooms? ____

How many people live in your household? Adults _____ Children _____

Does anyone regularly smoke inside your home? ☐ Yes ☐ No

Are there any pets in the home? ☐ Yes ☐ No

What animals if so? ______________________________

Do you own or rent your home?

- ☐ Own outright
- ☐ Rent
- ☐ Own with a mortgage or loan
- ☐ Live here rent free
- ☐ Shared ownership
- ☐ Other

If renting, who is your landlord?

- ☐ Housing association
- ☐ Employer of a household member
- ☐ Council (local authority)
- ☐ Relative or friend
- ☐ Private landlord or letting agency
- ☐ Other

What fuel do you mainly use for heating? *(e.g. gas, electricity, coal)* ☐

Which of these measures do you currently have in your home?

For the measures you have in your home only, please circle below to tell us..

	Yes	No	Not sure	how long ago was it installed?			.and, who paid?			
Loft insulation	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Cavity wall insulation	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
External wall insulation	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Internal wall insulation	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Renewable energy *(e.g. solar panels)*	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Double or triple glazing	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Home energy monitor	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Draught proofing	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Efficient 'a-rated' (condensing) boiler	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*
Central heating	☐	☐	☐	*0-2 years*	*2-5 years*	*Over 5 years*	*I / We paid*	*Received a grant*	*Landlord or Council*	*Other*

Does your home have any problems with the following?

(Slight = barely noticeable, Extreme = making the home unliveable)

	Not at all	Slight problems	Moderate problems	Large problems	Extreme problems	Don't know
Condensation	☐	☐	☐	☐	☐	☐
Damp	☐	☐	☐	☐	☐	☐
Mould	☐	☐	☐	☐	☐	☐
Draughts	☐	☐	☐	☐	☐	☐

How satisfied are you with your home regarding the..

	Not at all	Slightly	Somewhat	Very	Extremely
...standard of housing?	☐	☐	☐	☐	☐
...indoor temperature?	☐	☐	☐	☐	☐
...humidity indoors?	☐	☐	☐	☐	☐
...freshness of air indoors?	☐	☐	☐	☐	☐

In general, how often do you...

	Never	Seldom	Some-times	Often	Almost always	Don't know
...have problems paying energy bills?	☐	☐	☐	☐	☐	☐
...open a window for ventilation?	☐	☐	☐	☐	☐	☐
...use an extractor fan when cooking?	☐	☐	☐	☐	☐	☐
... use an extractor fan in the bathroom?	☐	☐	☐	☐	☐	☐
...hang clothes to dry indoors?	☐	☐	☐	☐	☐	☐
...heat living areas and bedroom(s) in winter?	☐	☐	☐	☐	☐	☐
...heat the same rooms in summer?	☐	☐	☐	☐	☐	☐

And, finally..

Compared to this time last year, has the standard of your housing...

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

Has the indoor environment (such as the temperature, humidity, air freshness)...

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

Have any problems with damp, mould and condensation..

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

Have any problems with paying your bills..

☐ ..worsened a lot? ☐ ..worsened a little? ☐ ..not changed? ☐ ..improved a little? ☐ ..improved a lot?

Over the last year, have you made any changes to how you use your heating, how you dry clothes, how often you open windows for ventilation or use extractor fans?

If so, or if you have any general comments or questions, please provide details:

Would anyone else living at your address be willing to complete a shorter version of this survey? Or would you be happy to complete it on their behalf? If so, please tick the box below and I will post some more questionnaires.

☐ Yes, please send more questionnaires for the other members of my household

We may carry out further monitoring, for instance by leaving small devices in a few homes that record things like temperature and humidity. You would be given more details before deciding whether to take part and those who do will receive some vouchers as a thank you

☐ Yes, I would like to know more ☐ No, I do not want to take part

If you have answered 'Yes' to question 17 or 18, please provide your name and address on the front page of the questionnaire.

Thank you for your time

Please return the completed questionnaire in the envelope provided

Table 31: Case studies - Recruitment, monitoring equipment, installation, and data collection

Recruitment	Potential participants were approached randomly, providing information sheets and explaining the research in person. Those that agreed to participate (on a first come first served basis given the scale of the study) were given time to reread the material and confirm their involvement before being visited in December 2013 to install and activate the monitoring equipment.
Monitoring	Temperature, relative humidity and carbon dioxide levels were recorded at participating households at 15 minute intervals for a minimum of a three month period using either Wöhler CDL 210 data monitors or Hobo U12-013 data loggers with Telaire 7001 CO_2 sensors. Both types of monitor provided high levels of accuracy and resolution and showed strong correlation between each other when tested (Correlation between Wöhler and Hobo/Telaire measurements using the Spearman rank order coefficient: CO_2, $r_s = 0.90$, $p < .01$. Temperature, $r_s = 0.99$, $p < .01$. Relative humidity, $r_s = 0.90$, $p < .01$.). To ensure consistent carbon dioxide measurement the Wöhler monitors were automatically calibrated together in fresh air (assumed to contain 400ppm CO_2) prior to instalment. The monitor outputs also included records of the dew point, the temperature below which moisture in the air would start to condense on surfaces in the home. These were checked by calculating the dew points from the temperature and relative humidity readings using the August-Roche-Magnus approximation (Lawrence, 2005).
Specifications	*Wöhler CDL 210 monitors:* ▪ Measurement of CO_2: Resolution: 1 ppm. Accuracy: .. ± 50 ppm ± 5 %. ▪ Temperature: Resolution: .0,1 °C. Accuracy: .. ± 0.6 °C. ▪ Air humidity: Resolution: 0,1 % r.H. Accuracy 10-90 %, 25 °C: ± 3 % r.H., otherwise: ± 5 % r.H. *Hobo U12-013 data loggers with Telaire 7001 CO_2 sensors:* ▪ Measurement of CO_2: Resolution: ±1 ppm. Accuracy: ±50 ppm or 5% of reading, whichever is greater. ▪ Temperature: Resolution: 0.03°C at 25°C. Accuracy: ± 0.35°C from 0° to 50°C. ▪ Air humidity: Resolution: 0.03% r.H. Accuracy: ±2.5% from 10% to 90% r.H., max ±3.5%.

Monitor positioning	Two monitors were set up in each case study household: one in the room that the main participant stated they spent most of their waking hours when at home (in each case a downstairs reception room henceforth referred to as the living room), and one in the bedroom where the main participant slept. As far as was possible the monitors were positioned to measure a representative sample of the air that would be breathed by people in the room: ideally between one and two metres off the ground, away from sources of heat or cold such as radiators or windows, and placed in an inhabited area. The long-term nature of the monitoring however meant that practical considerations often took precedence. Monitors needed to be plugged into a wall socket or extension lead in a safe and inconspicuous manner to avoid trip hazards, interference with the data logging (e.g., by children playing with the monitors) and general irritation to the participants. Consequently this led to most monitors being placed in the corner of a room on a low table or other piece of furniture.
Outdoor monitoring	The outdoor temperature was also recorded at hourly intervals throughout the monitoring period on four Maxim iButton Thermocron data loggers. These were placed in four of the case study gardens in solar radiation screens and attached to posts at head height. As with the indoor monitors the data was downloaded from the monitors every 6 to 8 weeks and the readings from the four iButtons were averaged to calculate a single hourly outdoor temperature value.
Participation from case studies	In addition to the environmental monitoring participants were asked to complete shortened versions of the original survey (see Figure 38 that follows in the appendix) on random days roughly every two weeks throughout the monitoring period. These 2 page 'diary surveys' asked for further details regarding health, household problems and behaviours related to energy or air quality, as well as any changes to themselves or their homes since the original survey. Participants were also asked to provide access where possible to their gas and electricity meters at each visit in order to calculate the energy used between visits.
Thermal images	Thermal images were taken of each home exterior using a FLIR T Series infrared camera. To ensure reliable and comparable images, the photographs were all taken on 21st February 2014 after a period of relatively unchanged weather, having stayed dry for the previous few days, and all between 9 and 10pm to allow any radiant heat from the sun to dissipate from the building faces. At this time the outdoor temperature was around 5°C and there were low winds and some cloud. In some pictures patches of clear sky may have been reflected making the roofs of the households appear colder than they actually were.

Figure 38: Information sheet and diary questionnaire given to case study participants in North Lincolnshire

Your home and you

Would you like £100 for helping with our research?

We would like to say thank you. A few weeks ago you filled in a questionnaire for the University of Sheffield about your household and your health, which was very helpful. Our hope is that this research will lead to home improvement schemes in your area and across the country. In the questionnaire, you also indicated that you would like to hear more about some further research we are conducting. This will be starting shortly and **we will pay each household that takes part £100 in vouchers** for Argos (or another seller of your choice if possible).

In order to investigate further how housing can impact on the lives of residents, we will do three things:

(1) Leave some data loggers − small pieces of monitoring equipment − in a few homes for up to 6 months. These data-loggers can be plugged in and left alone to automatically record the temperature, humidity and carbon dioxide in the living areas and bedrooms. I will visit once every 6-8 weeks to collect the data from the loggers, as well as taking meter readings to record the energy usage.

(2) During some of these visits I will take photos of the outside of the house using a thermal imaging camera to see if and how heat is escaping.

(3) A resident at each home will also be contacted by phone or text on ten random days throughout this period and asked to fill in a shortened, 2-page version of the survey you have already completed about your health and home. I will collect these when I collect data from the loggers.

More information about the research, including a list of frequently asked questions, is provided over the page. If you would be willing to take part (and be paid £100!), or have any further questions, please contact me on XXXXX-XXXXXX.

Chris Maidment

University of Sheffield

The University Of Sheffield. Sheffield Hallam University

Frequently asked questions

- *Who is conducting this research?*

  This project is being run by the University of Sheffield, with the help of Sheffield Hallam University. My name is Chris Maidment and I am a PhD student at the University of Sheffield.

- *Will you share my personal details with anyone?*

  No, your responses will be kept strictly confidential and will **not** influence any of the services or benefits that you receive. Members of the research team will have access to the anonymised data but your name will not be linked with the research materials, and you will not be identifiable in the reports that result from the research.

- *Can I change my mind?*

  Yes - all of this is entirely **voluntary**. You may withdraw from part or all of the project at any time, without giving a reason. You may leave any question blank if you would prefer not to answer it.

- *Who should I contact if I have any questions?*

  For questions regarding this survey, please contact the University of Sheffield:

  Chris Maidment Tel: 07867 977858 email: pcp11cdm@sheffield.ac.uk

  Dr. Chris Jones Tel: 0114 222 6592 email: c.r.jones@sheffield.ac.uk

  For questions about housing improvements, please contact your local council or housing provider.

  For any questions regarding your health, please contact your GP.

- *What if I need to make a complaint?*

  The project has been ethically approved via the Psychology department's ethics review procedure at the University of Sheffield. If you wish to make a complaint please contact Dr. Chris Jones (see above) or, if you are not satisfied with how your complaint has been handled, the Registrar and Secretary on 0114 222 1100 or email registrar@sheffield.ac.uk.

The University Of Sheffield.   Sheffield Hallam University

Data logging FAQs

- *What will be measured?*

  The data loggers record temperature, humidity and carbon dioxide - and nothing else.

- *How do they work?*

  Once they are in place you can ignore them: they will take regular readings. The 2 main data loggers need to be plugged in so please try not to move them. If absolutely necessary, please plug them in elsewhere and return them as soon as possible. The other loggers are battery powered.

- *Where will they be put?*

  The main data loggers will be placed in the living room and your bedroom. The other loggers will be placed in the kitchen and any other living areas or bedrooms. Which rooms and where they are placed can be discussed.

- *How will data be collected?*

  I will need to visit once every 6-8 weeks to download the data from the loggers onto my laptop. This should take half an hour or so, or I can taken them away and bring them back later in the day.

- *What if there is a problem?*

  The main loggers have an alarm function which will be disabled. If they do make any noises or there are any other problems, please let me know as soon as possible. If at all possible, do not move or unplug them but if you need to, again let me know.

Title of Research Project: *The impact of domestic energy efficiency measures on the health and well being of residents.*

Name of Researcher: *Chris Maidment*

Participant Identification Number for this project: ____________ Please initial box

5. I confirm that I have read and understood the information sheet dated 13th November 2013 explaining the above research project and I have had the opportunity to ask questions about the project. ☐

6. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

7. I understand that my data will be kept strictly confidential. I give permission for members of the research team to have access to my anonymised data. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐

8. I agree for the data collected from me to be used in future research. ☐

9. I agree to take part in the all or part of the above research project. ☐

________________________ ________________ ____________________

Name of Participant Date Signature

________________________ ________________ ____________________

Lead Researcher Date Signature

To be signed and dated in presence of the participant

The project has been ethically approved via the Psychology department's ethics review procedure at the University of Sheffield. If you wish to make a complaint, please contact Dr. Chris Jones (Tel: 0114 222 6592, email: c.r.jones@sheffield.ac.uk) or, if you are not satisfied with how your complaint has been handled, the Registrar and Secretary (Tel: 0114 222 1100, email: registrar@sheffield.ac.uk).

A blank copy of this form & information sheet will be left with the resident and a copy of the signed form will be handed over at the second visit to retrieve any equipment, or posted out if necessary. The original will be kept on file securely at the university.

Office use only:
Ref No:

Date and time ____________________

Name and address ____________________

We'd like to ask you a few questions about how you are feeling TODAY.

Please rate the following out of 10 *(where 0 is the worst state imaginable and 10 is the best)*	*Score (out of 10)*
Your own health state today	
Your mood and happiness	
Your vitality and energy levels	
Your relationships with others	
Your satisfaction with the standard of your housing in general	
Your satisfaction with the indoor temperature	
Your satisfaction with the humidity indoors	
Your satisfaction with the freshness of air indoors	
How would you describe the health of any other people living in your household?	

Does your home CURRENTLY have any of the following problems?

	Not at all	Slight problems	Moderate problems	Large problems	Extreme problems	In which rooms?
Condensation	☐	☐	☐	☐	☐	
Damp	☐	☐	☐	☐	☐	
Mould	☐	☐	☐	☐	☐	
Draughts	☐	☐	☐	☐	☐	

Any other problems (e.g. with your heating, glazing or insulation)?

Please specify: ____________________

Please tick if, in the last 24 hours, you have...

slept in a room with an open window ☐

opened a window for ventilation during the day in the..
...living room ☐ ...kitchen ☐ ...bathroom ☐ ...any other room ☐

cooked using a gas hob ☐

used an extractor fan when cooking ☐

used an extractor fan in the bathroom ☐

hung clothes to dry indoors ☐

had the heating on in...
...the main living area(s) ☐ ... occupied bedroom(s) ☐ ...any other room ☐

worn a jumper or other thick clothes **inside your home** to keep warm ☐

worn outdoor clothes (coats, hats, gloves) **inside your home** to keep warm ☐

worried about your finances or bills ☐

taken any steps to cut down your energy usage ☐
...and if so, what steps? ____________________

And, finally...

How many hours did you spend inside your home today? ____________________

Have you made any changes to your home recently? ____________________
(e.g. redecorating, building work, installing equipment)

Have you made any changes to your lifestyle recently? ____________________
(e.g. to your job, diet, exercise or how you spend free time)

Do you have any further comments about your housing or your health today?
____

Thank you for your time

Please text or email me when you have completed this. I will collect it next time I visit.

Table 32: Case study participants - Demographics and health service use

Demographics	A	B	C	D	E	F	G	H	I
Years at address	13	2	8	28	2	1	13	20	3
Gender	Male	Male	Female	Female	Female	Male	Male	Female	Female
Age	45 to 54	55 to 64	25 to 34	65 to 74	35 to 44	18 to 24	45 to 54	65 to 74	25 to 34
Working status	Sick or disabled	Looking after home	Full-time work	Retired	Looking after home	Full-time work	Full-time work	Retired	Full-time education
Health service use in the previous year									
Visits to doctor / GP	20	4	0	3	1	4	1	2	6
Visits to hospital	10	2	0	2	0	2	0	0	0
Total nights in hospital	2	0	0	0	0	0	0	0	0

Notes: Survey respondents were also given the option of 'Walk in centre' but none of the case study participants had used one.

Table 33: Case study participants - Self-reported medical conditions, including whether or not the participant had seen a doctor regarding the condition during the previous year

	A	B	C	D	E	F	G	H	I
Joint pain, arthritis	Yes, but no GP	No	No		No	No	No	Yes, but no GP	Yes, but no GP
Respiratory problems, breathing, wheeze	Yes, seen GP	No	No		No	Yes, seen GP	No	Yes, but no GP	No
Psychological / emotional conditions	Yes, but no GP	Yes, seen GP	No		No	No	No	No	Yes, seen GP
Heart problems, angina	Yes, seen GP	No	No		No	No	No	No	No
Circulatory problems, high blood pressure	Yes, seen GP	No	No	Yes, seen GP	No	No	No	Yes, seen GP	No
Persistent flu symptoms, headaches	Yes, but no GP	Yes, seen GP	No		No	No	No	No	Yes, but no GP
Allergies, hay fever	Yes, but no GP	No	No		No	Yes, seen GP	No	Yes, but no GP	Yes, but no GP
Falls or accidents in the home	Yes, but no GP	No	No		No	No	No	No	No

Table 34: Case study participants - Health (self-reported using the EQ-5D health instrument) and wellbeing (certain aspects self-reported on a 5 point Likert scale)

EQ-5D	A	B	C	D	E	F	G	H	I
Problems with mobility	Some	None	None	None	None	None	None	Some	None
Problems with self-care	Some	None	None	None	None	None	None	None	None
Problems performing usual activities	Some	None	None	None	None	None	None	Some	None
Pain / discomfort	Moderate	None	None	None	None	None	None	Moderate	Moderate
Anxiety / depression	Moderate	Moderate	None	None	Moderate	None	None	None	Moderate
Current health (EQ-VAS score out of 100)	35	50	100	90	70	77	95	50	70

Aspects of wellbeing (Very bad to Very good)									
Mood and happiness	Fair	Fair	Very good	Good	Good	Bad	Very good	Good	Fair
Energy levels	Bad	Fair	Very good	Fair	Fair	Bad	Good	Bad	Bad
Relationship with others	Fair	Good	Very good	Good	Good	Fair	Very good	Very good	Bad

Table 35: Case study participants - Household characteristics (building and occupancy)

	A	B	C	D	E	F	G	H	I
No of adults	2	2	2	2	1	2	2	1	1
No of children	0	5	2	0	4	0	2	0	2
Smokers	No	No	No	No	No	No	No	No	No
Pets	No	No	Yes	No	No	Yes	No	No	Yes
Own or rent	Rent	Rent	Own: mortgage	Own outright	Rent	Rent	Own: mortgage	Own: mortgage	Rent
Landlord	Local authority	Local authority	N/A	N/A	Local authority	Private landlord	N/A	N/A	Private landlord
Type of house	Semi-detached	Semi-detached	End-terraced	Terraced	Semi-detached	Semi-detached	Semi-detached	Semi-detached	Semi-detached
When built	Do not know	1955	1945	1935	Not sure	1935	1933	1925	1935
No of rooms	8	5	7	7	6	7	7	7	7
No of bedrooms	3		3	3	4	3	3	3	3
No of bathrooms	1		1	1	1	2	1	1	1
Heating fuel	Gas	Electricity	Electricity / gas	Gas	Electricity	Gas	Gas	Gas	Gas

Table 36: Case study participants - Perceptions of the home: Household problems related to the indoor environment and levels of satisfaction with the home environment

Household problems	A	B	C	D	E	F	G	H	I
Condensation	Not at all	Not at all	Slight problems	Slight problems	Slight problems	Not at all	Moderate problems	Not at all	Slight problems
Damp	Not at all	Not at all	Slight problems	Not at all	Slight problems	Not at all	Not at all	Not at all	Large problems
Mould	Not at all	Not at all	Slight problems	Not at all	Slight problems	Not at all	Moderate problems	Not at all	Large problems
Draughts	Slight problems	Not at all	Not at all	Not at all	Not at all	Slight problems	Slight problems	Not at all	Large problems
Paying energy bills	Seldom	Never	Never	Never	Some-times	Never	Never	Seldom	Almost always
Satisfaction with the home environment									
The standard of housing	Not at all	Very	Extremely	Extremely	Somewhat	Somewhat	Very	Very	Slightly
The indoor temperature	Slightly	Very	Extremely	Very	Somewhat	Somewhat	Very	Very	Slightly
The humidity indoors	Slightly	Very	Extremely	Very	Somewhat	Somewhat	Somewhat	Very	Slightly
The freshness of air indoors	Not at all	Very	Extremely	Very	Somewhat	Very	Very	Very	Slightly

Table 37: Case study participants - Household behaviours related to energy and the indoor environment and changes to the home environment over the previous year

Household behaviours	A	B	C	D	E	F	G	H	I
Opened windows for ventilation	Sometimes	Sometimes	Sometimes	Almost always	Often	Almost always	Often	Sometimes	Almost always
Used kitchen extractor fan	Sometimes	Never	Almost always	Almost always	Often	Almost always	Almost always	Often	Never
Used bathroom extractor fan	Never	Sometimes	Often	Almost always	Often	Never	Never	Seldom	Never
Hang clothes to dry indoors	Never	Sometimes	Never	Often	Sometimes	Sometimes	Often	Never	Sometimes
Heated living areas in winter	Often	Sometimes	Almost always	Often	Almost always	Often	Often	Almost always	Almost always
Heated living areas in summer	Never	Never	Seldom	Never	Sometimes	Never	Seldom	Seldom	Seldom

Changes over the last year									
The standard of housing	Not changed	Improved a lot	Improved a little	Improved a little	Improved a little	Improved a little	Improved a little	Not changed	Worsened a little
The indoor environment	Not changed	Not changed	Improved a little	Improved a little	Not changed	Improved a little	Improved a little	Not changed	Worsened a little
Problems with damp, mould & condensation	Improved a little	Improved a lot	Not changed	Not changed	Not changed	Improved a little	Improved a little	Not changed	Worsened a lot
Problems with paying bills	Not changed	Improved a lot	Not changed	Not changed	Not changed	Improved a little	Not changed	Not changed	Worsened a little

Table 38: Case study participants - Energy efficiency measures present in the home: how long ago they were installed and who paid

	A	B	C	D	E	F	G	H	I
Loft insulation	0-2 years	0-2 years	2-5 years	+5 years		0-2 years	0-2 years	+5 years	0-2 years
Cavity wall insulation		0-2 years	2-5 years		2-5 years				
External wall insulation	0-2 years	0-2 years	0-2 years	0-2 years	0-2 years				
Internal wall insulation		0-2 years							
Renewable energy	0-2 years	0-2 years			0-2 years				
Double or triple glazing	2-5 years	+5 years	+5 years	+5 years	0-2 years	+5 years	+5 years	+5 years	
Home energy monitor									
Draught proofing	2-5 years	2-5 years	+5 years				2-5 years		
Efficient ‘A-rated’ boiler	2-5 years		2-5 years	0-2 years		0-2 years			
Central heating	+5 years	+5 years	+5 years	0-2 years	+5 years	0-2 years	+5 years	+5 years	+5 years
Loft insulation	Landlord	Landlord	Landlord	Resident		Landlord	Landlord	Landlord	Grant
Cavity wall insulation	Landlord	Landlord	Landlord		Landlord				
External wall insulation	Landlord	Landlord	Landlord	Landlord	Landlord				
Internal wall insulation	Landlord	Landlord							
Renewable energy	Landlord	Landlord			Landlord				
Double or triple glazing	Landlord	Landlord	Landlord	Resident	Landlord	Landlord	Resident	Resident	
Home energy monitor	Landlord								
Draught proofing	Landlord	Landlord	Landlord				Resident		
Efficient ‘A-rated’ boiler	Landlord		Landlord	Resident	Landlord	Landlord			
Central heating	Landlord		Landlord	Resident	Landlord	Landlord	Other	Resident	Landlord

Table 39: Indoor temperatures (°C) of case study homes at the time thermal image photographs were taken (21st February 2014, between 9pm - 10pm)

	A	B	C	D	E	F	G	H	I
Living room	18.6	-	19.9	23.3	18.3	17.1	17.8	20.9	19.6
Living room winter average[a]	*19.0*	*20.7*	*21.2*	*20.2*	*18.5*	*16.4*	*18.3*	*20.0*	*19.2*
Bedroom	15.7	-	21.6	23.1	20.7	-	22.5	22.6	19.1
Bedroom winter average[a]	*16.1*	*21.3*	*21.5*	*20.7*	*19.3*	*17.4*	*19.5*	*21.3*	*19.8*

Notes: [a] *For the monitoring period 18th December 2013 to 31st March 2014*

Figure 39: Interview protocol

Motivations

- Please start by explaining your role and how you are involved in energy efficiency improvement work.
- What are the main drivers behind energy efficiency work and have these changed?

Experiences

- Please describe current, planned or completed energy efficiency schemes you are involved with; for instance, the type of intervention, the purpose, how it was targeted.
- Have you worked in collaboration with other individuals or organisations?
    - What were your experiences?
- What steps were taken to help or guide residents?
- How successful have these schemes been?
    - In what ways? And how was this evaluated?
- Have you learnt any particular lessons (from either successful or difficult schemes)?

Health

- Do you see a link between energy efficiency and the health / wellbeing of residents?
- Did health feature as a driver and/or measured outcome? (if not answered earlier)
- In your role do you discuss the health impacts of energy efficiency measures with others?
- What further research, evidence or information (if any) would help you in your work?
- Finally, is there anything further you would like to add?

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* *An asterisk precedes studies that were included in the meta-analysis in Chapter 4.*

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