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Title: UK solid-wall dwellings - thermal comfort, energy efficiency refurbishment and the user perspective - some preliminary analysis from the CALEBRE project.

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Abstract
The paper discusses the state of solid wall housing in the UK, and the technical and socio-economical challenges that need to be addressed whilst refurbishing this stock. The challenges of improving the thermal performance of the envelope and of reducing space heating-related carbon emissions in solid wall housing are discussed together with issues related to thermal comfort, the 'take-back' process and user-appeal. Preliminary results of the Householder Survey of Project CALEBRE are presented, including the sample selection and survey processes. It is concluded that, irrespective of cost factors, the perceived benefits and aspirational appeal of carbon-reducing technologies need to outweigh the cost associated with disruption from the perspective of the householder. Achieving this, places demanding requirements not only on technologists and designers but also upon those responsible for marketing essential energy saving solutions.

Keywords: UK solid wall housing, Retrofit, Thermal Comfort, Householder Survey

1. Introduction

1.1 Background

An overwhelming body of scientific evidence now clearly indicates that climate change is a serious and urgent issue. The earth's climate is rapidly changing, mainly as a result of increases in greenhouse gases caused by human activities. (Stern review report, 2006). The Stern review report states that if no action is taken to reduce emissions, the concentration of greenhouse gases in the atmosphere could reach double its pre-industrial level as early as 2035, resulting in a global average temperature rise of over 2°C and a 50% chance that the temperature rise would exceed 5°C in the long term. By 2100, the average summer temperature for the UK is expected to rise by between 1 and 6°C, depending on region and emissions scenario. Recognising the need for urgent action, the UK Government in November 2008 introduced the world's first long-term legally binding framework to reduce greenhouse gas emissions (the Climate Change Act 2008). According to this ambitious and legally binding contract, the UK will by 2050 reduce its greenhouse gas emissions to at least 80 per cent below 1990 levels.

1.2 UK Energy Statistics

In the UK, carbon dioxide (CO_2) emissions account for nearly 85 per cent of total UK greenhouse gas emissions. As shown in Fig. 1, net emissions of carbon dioxide in 2008 were provisionally estimated to be 531.8 million tonnes, 11% lower than 1990 levels (DECC, 2008).

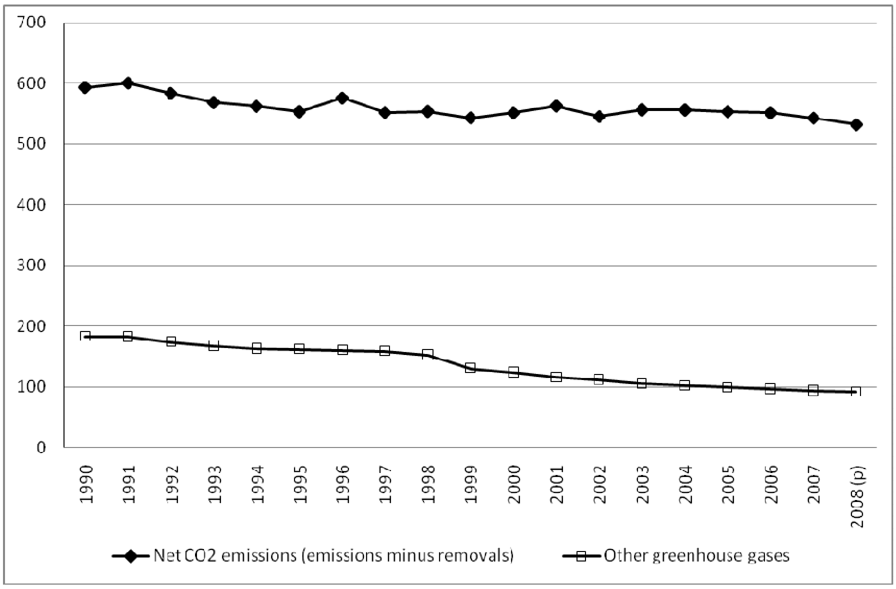

Figure 1: Trajectory of UK carbon dioxide emissions (drawn from DECC Energy Statistics data)

A significant amount of these emissions (up to nearly 70%) are the result of energy used by buildings and industries as a whole with up to 30% of emissions from domestic buildings alone, as shown in Fig. 2.

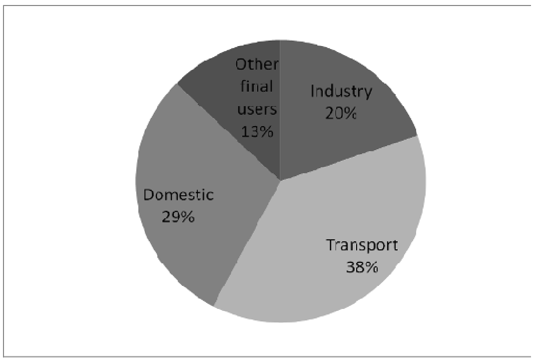

Figure 2: Sector wise end use UK energy breakdown for 2008 (drawn from DECC Energy Statistics data)

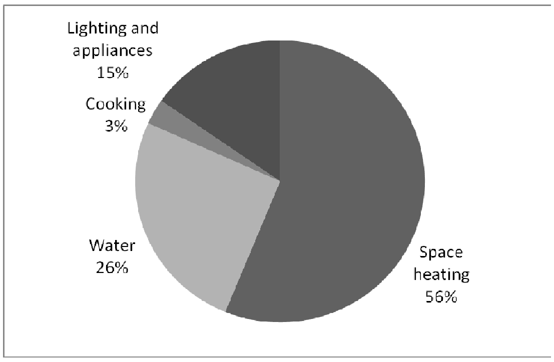

Figure 3: Domestic energy consumption by end use, 2007 (drawn from DECC Energy Statistics data)

Recognising this fact, the UK Government has initiated a process of carbon reduction in buildings through amendments to Building Regulations The proposed target dates for zero carbon domestic buildings is 2016 and for non-domestic buildings is 2016-2019. However, while policies, regulations and technologies are being put in place to deliver new zero carbon buildings, it is the existing stock of domestic buildings that poses the greater threat (and opportunity) for achieving the ambitious 2050 targets. This is due to the fact that up to 75% of the stock that will exist in 2050 is already constructed and has been built prior to 2005 with consequent poorer fabric performance and low energy efficiency standards (Boardman et al, 2005). As shown in Fig. 3, emissions arising from this stock are primarily due to energy used in space heating (56%) and water heating (26%). Hence any attempt to reduce carbon emissions from the existing domestic stock needs to begin with improving the thermal performance of the existing stock, followed by installing energy efficient heating systems and other technologies, as required.

1.3 Solid wall housing- the extent of the problem

The existing stock currently amounts to a total of 26 million dwellings, the majority of it being cavity wall construction. Improvements to these dwellings are well under way through cavity wall insulation under initiatives like 'Warm Front' in England (EAGA, 2009). However, within the context of improving energy efficiency of existing stock, one sector has proved to be particularly difficult and problematic. Known as 'Hard to Treat' and 'Hard to Heat', these homes are defined by the Energy Saving Trust (BRE 2008), as 'homes that, for a variety of reasons, cannot accommodate 'staple' energy efficiency measures offered under schemes such as Warm Front in England'. These homes essentially include those that are off the gas network, solid wall properties, homes without loft space, homes in states of disrepair, high rise blocks and other homes where it is not possible to install staple energy efficiency measures due to technical and practical reasons. Staple energy efficiency measures include wall, loft and floor insulation, double glazing, draught proofing and efficient central heating systems.

According to the English House Conditions Survey 2006, Hard to Treat (HTT) homes currently comprise of 43% of the total stock, amounting to 9.2 million homes. Of these, solid wall dwellings alone constitute 6.6 million homes (72% of the HTT stock and 31% of total stock). These solid wall dwellings were primarily built during the late 18th and 19th centuries and consist of a 230mm (9 inches) thick or greater solid wall construction, either in stone or brick.

The lack of cavity wall construction and hence the inability to conduct standard insulation type retrofits has led to inadequate thermal comfort and high energy consumption in solid wall dwellings. It was observed from the English House Condition Survey 2006 data that up to 80% of solid wall dwellings have a SAP rating less than the mean SAP rating of 48.3 SAP points for all dwellings as indicated in Fig. 4. SAP is the Government's Standard Assessment Procedure for Energy Rating of Dwellings. It is used as a national methodology for calculation of energy performance of existing buildings and to demonstrate compliance with building regulations for new dwellings (BRE, 2005). Furthermore, as shown in Fig. 5, 60% of solid wall dwellings have failed the decent homes standards due to inadequate thermal comfort, excess cold and high levels of condensation and mould. According to the Decent Homes Standards (DCLG, 2006), a decent home is defined as a dwelling that meets the following criteria:

a) Meets the current statutory minimum standard for housing
b) Is in a reasonable state of repair
c) Has reasonably modern facilities and services
d) Provides a reasonable degree of thermal comfort.

It was as a result of damp problems and higher costs, that the solid wall construction was replaced with cavity wall construction during the 1920s and 1930s housing boom (Beaumont, 2007).

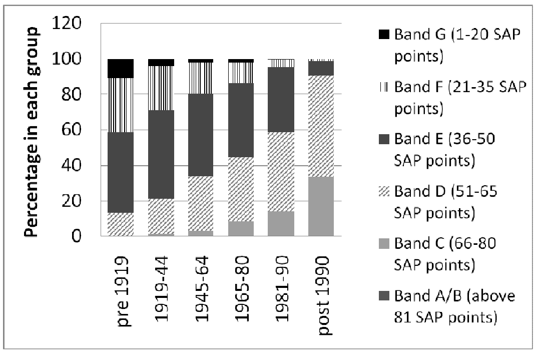

Figure 4: SAP rating of English housing stock

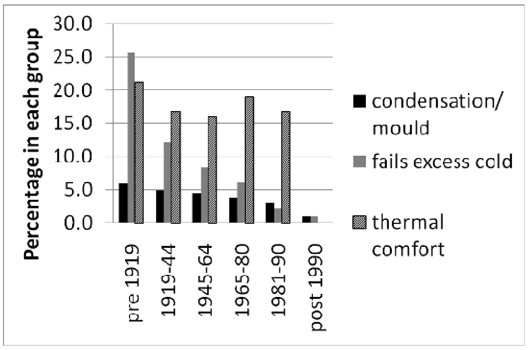

Figure 5: Percentage of solid wall housing failing Decent Homes standards

2.0 Challenges and Opportunities

Recent research (Johnston, 2005; Natarajan, 2007) has suggested that it is not possible to achieve the UK's 2050 carbon reduction target through a single solution or intervention, rather a set of measures is required. This will require a mix of interventions that will include:

- New measures to improve the thermal performance of the building envelope
- Improving the energy efficiency of heating systems and appliances
- Changes in personal attitudes towards energy consumption, lifestyles and thermal comfort- redefining the meaning of comfort
- Decarbonising the electric grid and use of renewables

2.1 Improving thermal performance of envelope and heating systems

Space heating in solid wall housing dominates the overall energy consumption as a result of poor performance of the building envelope. Hence, the biggest challenge in this stock is how to improve the thermal performance of its envelope and reduce heat losses. Due to the lack of cavity, solid wall dwellings will either require internal insulation or external insulation. Application of internal insulation reduces the net usable volume of room space and its installation typically causes disruption to the occupants of the dwelling, thus raising serious questions of appeal and acceptability to householders. Furthermore, with the application of internal insulation, the dwelling loses the moisture and heat storage benefits from the thermal mass provided by the solid wall. This combined with other improvements in the form of reducing air leakages may negatively affect occupant's health and comfort and increase cooling loads. Studies employing future climate change forecasts (Hacker, 2008) have shown that heavyweight buildings tend to perform better in a future over heating scenario, where higher summer temperatures are expected in 2050 in the UK.

Applying external wall insulation to solid wall properties is an alternative to internal wall insulation and offers the advantages of avoiding disruption to the indoor living environment during application, in leaving internal useable floor area intact and more importantly not affecting the thermal mass storage capacity of the solid wall. However, its disadvantage is that it can be a less favourable option for the planning authorities and the heritage bodies in the cases of listed properties. Since the majority of solid wall properties were built before 1919, it is very likely that the majority of them would either have a listed status or come within a conservation area, thus making it very difficult to obtain listed building consent to carry out external insulation work.

Retrofit of current glazing systems and replacing single and double glazing with high performance vacuum glazing is a potential future solution that can achieve significant improvements to the thermal performance of solid wall dwellings and offer the potential to increase window to wall area ratios. According to the ECHS 2006 data, currently 28.4% of pre1919 stock has no double glazing. However, two issues are of primary concern here. Firstly, similar to external insulation, if a home is listed, replacing the glazing will be subject to obtaining listed building consent, decided often on a case-by-case basis by the planning officer and local authority conservation officer (English Heritage, 2008). The second issue related to replacement of double glazing is user appeal in terms of affordability. Pay back times for a replacement double glazing with low-e coating can be anywhere from 50 years (Menzies, 2005) to up to 97 years (DCLG, 2006) as shown in Fig. 6, making the option unattractive to householders, though benefits such as enhanced thermal comfort and reduced window condensation frequently prevail.

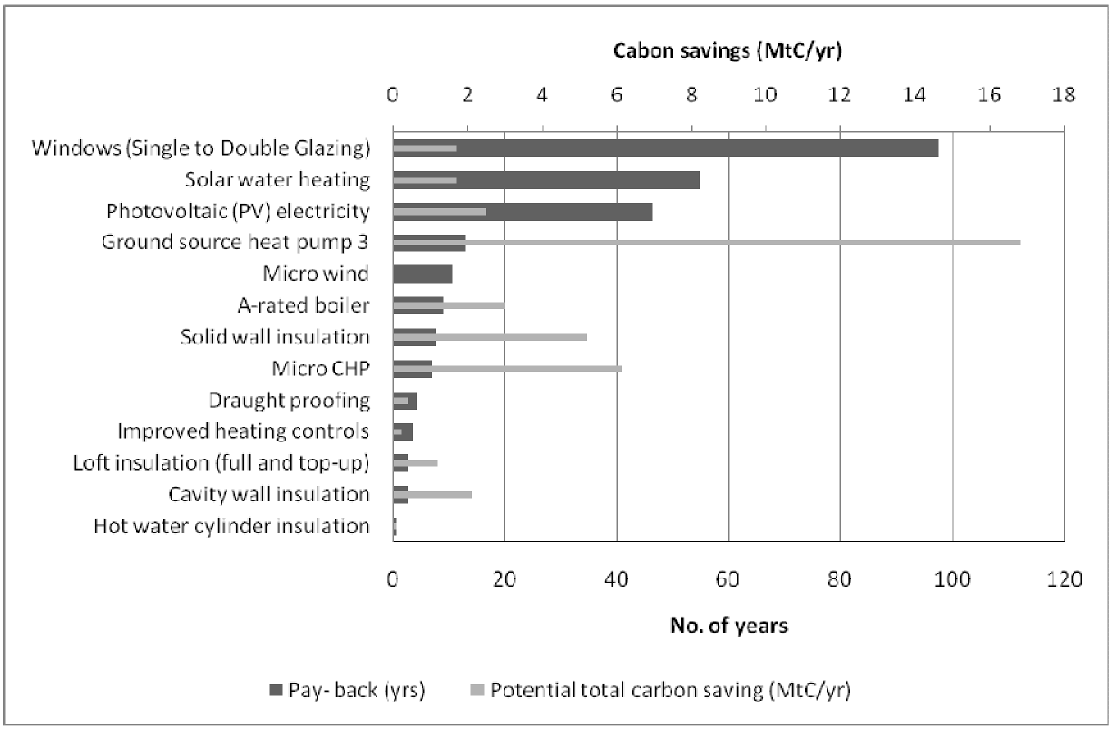

Figure 6: Comparison of pay-back times and carbon saving potential of retrofit technologies. (Drawn from data published in Review of Sustainability of Existing Buildings, DCLG, 2006)

Overcoming these challenges to improve the fabric performance of solid wall properties will itself be insufficient to deliver the required reductions in UK carbon emissions. The supply and management of heat and power is as important an issue as the reduction in heat demand. Gas condensing boilers will need to be replaced with, for example, heat pumps and other microgeneration technologies that offer higher efficiency and carbon reduction potential. However, the extent of uptake of these technologies will again depend on the degree of user appeal that they offer in terms of affordability and payback times, ease of installation, operation and maintenance, size and aesthetics and technical performance. For example, the cost and feasibility of ground source heat pumps vary depending on the geological and environmental conditions of the site and air source heat pumps, an emerging technology and alternative to ground source heat pumps are three times more expensive than an A rated boiler.

2.2 Thermal Comfort, take-back process and user-appeal

Another significant challenge that needs to be addressed is people's attitudes toward energy consumption, together with the 'take-back' process where people choose to improve their thermal comfort through energy efficiency measures introduced as part of retrofit process. Studies of American houses (Steemers, 2009) have shown that while the most important parameter that affects energy use is climate, the second most important factor that affects energy use is occupant behaviour, specifically in terms of the choices made about heating and cooling systems and their control. This aligns with the Warm Front Studies in the UK (Hong et al, 2006), where it was observed that although Warm Front measures did improve SAP ratings and improve indoor temperatures and thermal comfort, there was an increase in overall fuel consumption as a result of the take-back process. This can be explained by the answers received in the qualitative interviews. Respondents said, 'Now we can use the whole house instead of hugging around a living room fire'. Further analysis by Hong et al (2009) revealed that Warm Front measures led to an increase in the whole house neutral temperature from 18.9^{o}C to 19.1^{o}C. This resulted in a reduced clothing level, indicating a take-back associated with behavioural changes. Predicted Mean Vote (PMV) analysis predicted a higher neutral temperature of 20.4^{o}C compared to 18.9^{o}C which was found to be ideal among the average Warm Front households. Hong et al concludes that while a large portion of the take-back from insulation can be explained as the result of improved thermal performance of the building fabric the take-back associated with central heating supports occupancy behaviour as the primary cause. Previous studies by Hong et al (2006) also revealed reductions in space heating fuel consumption (due to cavity wall and loft insulation) of 10% in centrally heated properties and 17% in non-centrally heated properties, as compared with theoretically expected reductions of 45-49%. This was considered partly due to inability to achieve 100% insulation and party due to the take-back process initiated by the improved thermal comfort.

Thus, the challenges in the refurbishment of existing houses to reduce carbon emissions are varied and complex. The refurbishment approach will also have to address not only the technological and socio-economical challenges of retrofit technologies but will have to ensure that acceptable thermal comfort is achieved without the loss of energy savings through the take-back process. These challenges require an in-depth understanding of the relationship between domestic buildings, retrofit technologies and the user needs in terms of acceptability, appeal and thermal comfort so as to deliver low/zero carbon buildings that remain acceptable for comfortable occupation. With this in mind, Project CALEBRE (Consumer Appealing Low Energy technologies for Building REtrofitting), a four year EPSRC / E.ON - funded research project, is investigating user-appealing technology packages that can achieve this for solid-wall housing.

3.0 PROJECT CALEBRE
The overall aim of Project CALEBRE is to establish a validated, comprehensive mechanism for reducing UK domestic carbon emissions within solid walled housing that is acceptable and appealing to users. The project takes the approach of identifying, from a user perspective, the barriers and key challenges to the deployment of retrofit carbon-reduction technologies, and then by using the knowledge gained through householder engagement and surveys to appropriately modify selected technologies for field-trialling and user evaluation including thermal comfort evaluation.

The selected technologies include electric and gas-fired heat pumps, home ventilation heat recovery, energy-efficient vacuum glazing and innovative advanced surface treatments to control temperature and moisture via nano-technology. The technologies will be uniquely informed by the reality of the user perspective, addressing such questions as the degree of disturbance that householders are prepared to tolerate during a refurbishment programme. Having been developed and modified keeping in mind the user perspective, these technologies will be trialled using the newly-constructed occupied E.ON test house, specially built to 1930s standards, and located on the campus of Nottingham University. These technologies will be evaluated not only in terms of their performance and efficiencies but also in terms of their impact on the thermal comfort of the occupants. The outcomes from the work will include a software tool for use by relevant stakeholders, and could form the basis for a 'one-stop-shop' for householders to identify and purchase their carbon reduction package.

At the time of writing this paper, the householder engagement process has begun, based on a 'representative' sample of solid wall dwellings and a selection of case studies. Techniques include recruiting of householders, preliminary site visits, interviews and data collection.

4.0 Householder Engagement:

4.1 Sample Selection
The English House Condition Survey (EHCS) is the most comprehensive national survey of housing stock in England, commissioned by the UK Government's Department of Communities and Local Government. Conducted since 1971, this survey covers all tenures and involves a physical inspection of properties by professional surveyors. The information obtained through the survey provides an accurate picture of the dwelling stock profile in terms of its age, construction, type, size, tenure, household, occupancy, energy efficiency, type of fuel used, decent homes standards, state of disrepair and liveability.

For our study, the statistical analysis software SPSS was used to analyse the EHCS 2006 data to derive a representative sample of a 'typical' solid wall dwelling in England. The following was observed:

- Dwelling Type: 70% of the total solid wall housing stock consists of end terrace, mid terrace, semi detached and detached property types (see Fig. 7).
- Dwelling Size: 85% of solid wall properties have an area of more than 50sqm, the remaining 15% (being less than 50sqm) comprising 1-2 bedroom properties) (see Fig. 8)

- Regional Locations (Government office regions): 30% of the total solid wall housing stock is in London, while less than 3% are in the north east, the rest being located evenly in other regions. (see Fig. 9)
- Regional Location (urban /rural): 75% of the total solid wall housing stock is located in urban centres (not city centres) and suburban residential regions. (See Fig. 10)
- Type of Tenure: 80% of the total solid wall housing stock is owner occupied and privately rented occupied. (see Fig.11)
- Type of Fuel Used: Majority of all solid wall properties (up to 85%) used gas for heating. (see Fig. 12)
- Household Composition: Solid wall properties have an even mix of household composition which includes couples less than 60 years of age with and without dependent children, couples above the age of 60 years with no dependent children, multi person household and lone parents. (see Fig. 13)
- Household Size: 90% of solid wall properties have a household size in the range of 1 to 4 with less than 10% having an occupancy greater than 4 (see Fig.14).
- SAP rating: 50% of solid wall properties have a SAP rating in the range of 30 to 50, the mean rating of all property types being 49.8 SAP points (see Fig.15).
- Failing Decent Homes Standard: Analysis of the ECHS (2006) data indicates that while 60% of solid wall housing stock failed the decent homes standard on insulation measures alone, 30% of the stock failed on heating measures and 10% of the stock failed on insulation and heating measures (see Fig. 16).

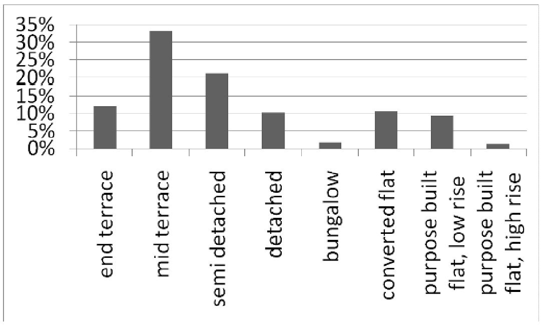

Figure 7: Dwelling types in solid wall housing

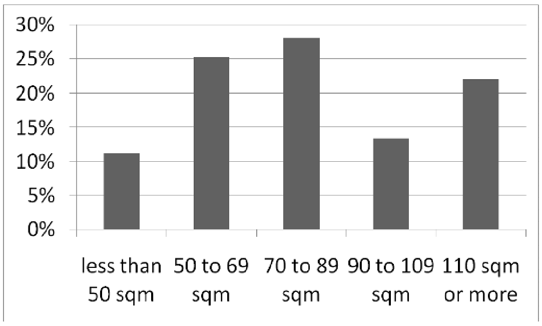

Figure 8: Dwelling sizes in solid wall housing

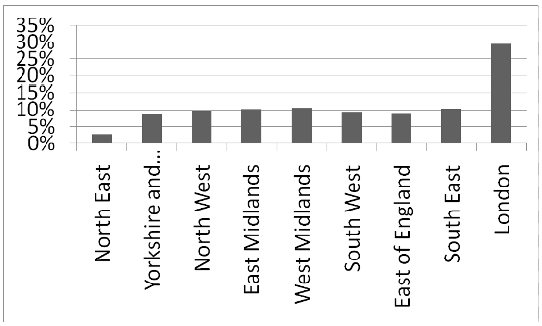

Figure 9: Distribution of solid wall housing in Government Office regions

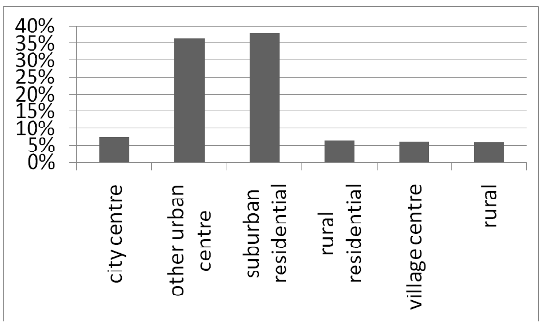

Figure 10: Distribution of solid wall housing (urban-rural)

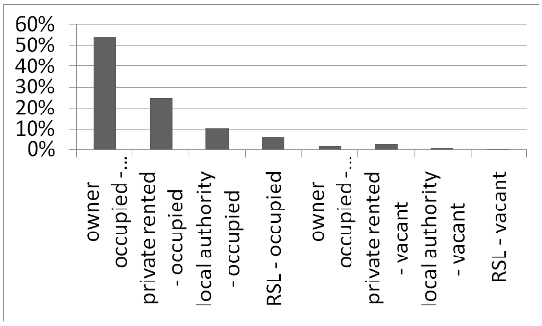

Figure 11: Types of tenure in solid wall housing

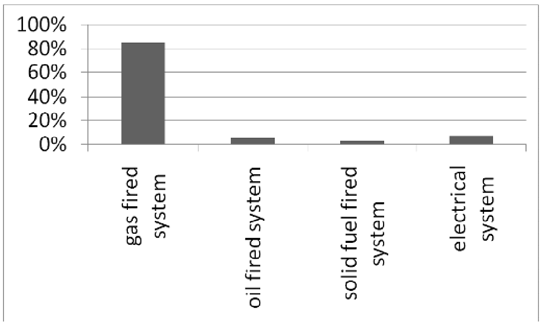

Figure 12: Type of fuel used in solid wall housing

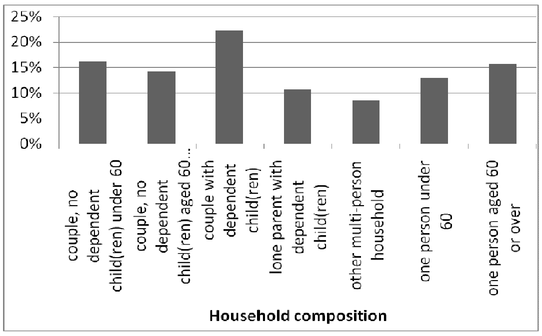

Figure 13: Household composition in solid wall housing

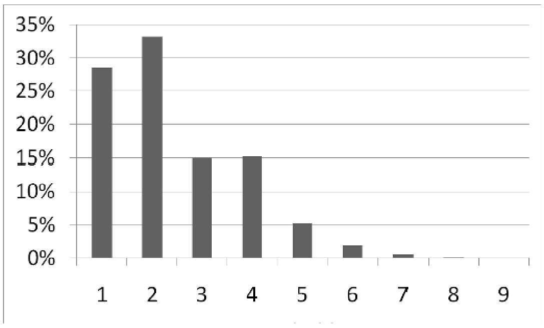

Figure 14: Size of household in solid wall housing

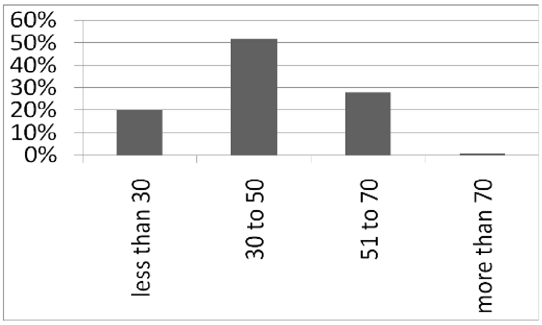

Figure 15: SAP rating of solid wall housing

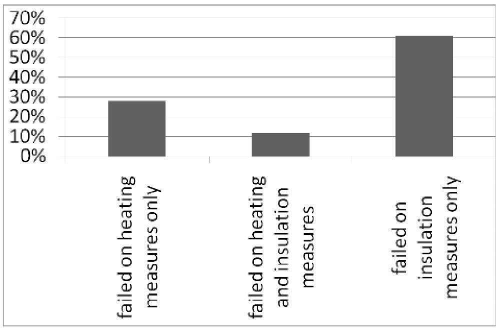

Figure 16: Solid wall housing failing Decent Homes Standard

From the above data, it was concluded that a 'representative' sample of solid wall dwellings in England would be made up from houses that were end terrace, mid terrace, semi detached and detached properties, occupied by owners and private tenants, with household size in the range of 1 to 4, having an even mix of household composition (ranging from singles, couples with and without children and elderly singles and couples) and having mains gas heating. Selecting a location in Leicestershire, East Midlands (around the town of Loughborough, within reasonable distance of the University) would offer similar representation to many Government Office Region (with the exception of London and the North East).

4.2 Householder Survey

The first stage of the research is focusing on engagement with householders, through in depth discussions with householders in their homes. A mixed methodology approach is being used, collecting qualitative and quantitative data focusing on the wider perspective of home improvement. With reference to the selection criteria of section 4.1, twenty households were identified, and formed the sample for this stage of data collection. The sample encompassed a range of house and household types, including young couples, families at different life stages (e.g. new baby, empty nesters) and older people. Snowball sampling was used to recruit participants, focusing on urban and suburban properties in the East Midlands in the UK.

A multi stage approach is being taken:

- Visit One – To understand people's motivations and experiences with home improvements, including issues of disruption, cost and service provision.
- Between Visits One and Two – Comfort investigation – investigating thermal and additional subjective comfort factors and collecting temperature and relative humidity data.
- Visit Two – To explore with householders the consumer appeal and practical acceptability of specific CALEBRE technologies. This includes gathering data on architectural features of the home that might impinge on retrofitting, or space limitations to prevent installation of interventions.
- Visit Three – To conduct an Energy Performance Certificate (EPC) assessment with supplementary survey questions to provide detailed data on the thermal characteristics and performance of each house.

This paper presents initial findings from Visit One only. The methodology for the first visit drew on the principles of participative design (Ehn and Sjögren, 1991) in order to elicit rich data from householders and to establish rapport. Researchers were sensitive to the privacy of the home environment and so this first meeting was conducted in a place in the home where householders would be accustomed to greeting guests – typically round a dining room table. Wherever possible, interviews were conducted with all adult members of the household, as the decision to undertake home improvements is often a collective one. In some cases, older children also participated in the discussions, providing a wider household perspective.

Householders were asked about their past behaviours and experiences of home improvements and renovations in order for the researchers to ground understanding of how people are likely to respond to future retrofit interventions. Prompted recollection techniques (e.g. Mitchell et al 2004) were used to help householders recollect the home improvements made since moving in. This focused around the development of a time line, with key information being built up using magnetic cards to denote key life stages, home improvements and dates. Additional detail was annotated onto the time line as the discussion progressed; see Figure 17 for an overview of a complete time line from one household.

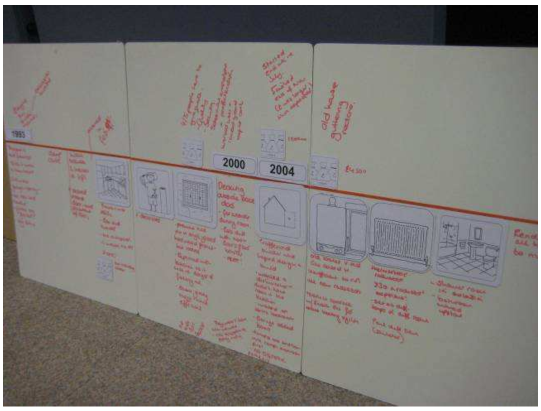

Figure 17: Example time line

Comfort and future aspirations relating to home improvements were also explored.

During Visit One, householders were not explicitly asked about energy efficiency measures in order to provide a broader perspective on the motivations for home improvements. Questions asked during Visit One included the following:

- What major changes have you made to the house and why? Have you decorated as well? What was the cost and level of disruption for changes? What were the barriers / triggers?
- Within your home, what does comfort mean to you? How do you create comfort in your home? What areas of your house are comfortable or uncomfortable and why?

Understanding patterns of home improvement to identify the best opportunities for retrofitting energy efficient measures during the life cycle of a property is an important issue for CALEBRE. Exploration of issues relating to the home improvements process will help determine whether retrofit measures are most acceptably installed as a one-off, or gradually over a number of months or even years.

Between Visit One and Visit Two, householders will record examples of times when they were uncomfortable (too hot or cold, too humid or dry, too draughty or stuffy) and what they did to alleviate this. A record of temperature and humidity levels in two main rooms in the home will also be made, in an attempt to see if there are any link between the subjective responses of the householders and the thermal environment. By analysing the subjective ratings alongside the temperature and humidity in the home at the time, patterns of preference may be identified.

Once this context is established, the second visit will focus on specific energy efficiency measures (interventions) and probe more directly the householders' attitudes to energy conservation.

5.0 Data Analysis and Discussion

Preliminary findings from Visit One are presented in this paper. Data from the visits were transcribed and thematic analysis, a flexible method for identifying, analysing and reporting patterns within qualitative data (e.g. Braun and Clarke, 2006), was used to identify key issues under a range of pre-determined themes.

5.1 Reasons for living in the property

In addition to issues of cost and location, the householders had particular reasons for purchasing older properties. Many cited the character and architectural features of the house as being appealing, features which they felt were lacking in newer properties. The quality of workmanship associated with older properties was valued:

> *"This house feels like it's been built with pride."*

Also, householders often mentioned that they relished the challenge of undertaking the renovation of an older house.

5.2 Patterns of Home Improvement

All householders had undertaken some major home improvements since moving in. These included loft conversions, new kitchens and bathrooms, structural alterations to the house, improvements to the heating system, new windows and doors. It was noticeable that many householders undertook significant home improvements in the first few months after purchase, sometimes before they moved in. This allowed for major renovation to take place during an already disrupted period. This period of intensive renovation typically lasted between two and six months. In some cases this was required to raise the living standard and thermal comfort of the property to an acceptable level, e.g. fitting a central heating system; in other cases the cost of major improvements was more easily assimilated into the overall cost of the move.

Once established in the home, householders continued to improve their properties or adapted their house to changing family circumstances, e.g. the birth of a child, growing teenagers or choosing to work at home. Redecoration was common, but did not always match the cycle of major home improvements and was fitted in whenever time and enthusiasm allowed. The majority of householders undertook significant renovation projects themselves, utilising existing or newly learned DIY (Do-It-Yourself) skills. This meant the cost of improvements was kept to a minimum, the householder could keep control of the job and in some cases, gain personal satisfaction from the achievement. However, there was evidence of householders picking and choosing the jobs they undertook, based on time and motivation, often influenced by particular stages in their lives. Trades people were used where a particular skill was needed or where the householder did not want to do the job themselves, but the early analysis of the data show a trend for these householders to favour a DIY approach, even if this lead to an improvement taking a much longer time to complete.

5.3 Levels of Disruption

Householders tolerated surprising levels of disruption, sometimes living without kitchens or bathrooms for weeks at a time. Jobs that could be fitted around patterns of daily living were not seen as disruptive, as household life could continue as normal. However, unexpected complications or delays caused considerable stress, and some householders commented that if they had known what was involved in advance, they would not have embarked on a particular project. This issue of understanding why disruption is acceptable in some cases and not in others needs to be further understood to inform future retrofitting programmes. It may be necessary to make the acquisition of carbon reducing technologies as appealing to householders as a new kitchen or bathroom, in order for the householder to put up with significant disruption. Such issues are being explored in Visit Two.

5.4 Barriers and Motivations to Home Improvement

Whilst householders were keen for renovations and improvements to be made to their home, a number of barriers have been uncovered from the initial analysis. There were examples of a considerable time lapse between identifying the need for and actually carrying out improvements. Delays could be attributed to:

- Cost – being able to afford to pay for materials or labour.
- Finding an appropriate tradesperson – finding someone the householders trust to do the job, obtaining a range of quotes and scheduling the work to be done.
- Weather – carrying out the work at the appropriate time of the year.
- Time – finding time to begin and complete the job, particularly when it was done by the householder.

- Life events – the arrival of a new baby or the breakup of a marriage, putting a strain on time and resources.

Householders were also motivated to make home improvements by a range of factors:

- Space – extending the house to make more space, or modifications to make better use of existing space.
- Repairs – to deteriorating or damaged features of the home such as windows or roofs.
- Discomfort – replacing windows or floors to minimise draughts.
- Efficiency – improving heating systems or insulation to reduce energy bills.
- Intrinsic factors – personal satisfaction, gaining a sense of achievement or relaxation, pride in restoration and a high standard of workmanship.

Although these results are from only preliminary analysis, as house visits are still on-going at the time of writing, an insight into the home improvement habits of householders in older, solid walled properties is emerging.

6.0 Assessing Thermal Comfort in Solid Wall Dwellings

Alongside the collection of qualitative and quantitative data focussed on the wider perspective of home improvement, Project CALEBRE will also assess the state of thermal comfort in solid wall dwellings in the UK. Assessing people's thermal comfort in their own homes is a challenging task as compared to laboratory-based thermal comfort studies, where the latter offers greater control of environmental conditions and subjects. Hence Project CALEBRE is currently developing ways to regularly, remotely and successfully gather high-quality thermal comfort data in the relatively uncontrolled environment of the UK domestic dwelling (solid-wall dwellings in this study). Assessment of thermal comfort in these situations will be conducted through a comparative analysis of the Actual Mean Votes (AMVs) and the Predicted Mean Votes (PMVs). A standard thermal comfort questionnaire derived from ISO10551 standards is currently being formulated for the domestic environment. This questionnaire is aimed at being simple to understand and quick to complete, and will be handed out to householders during visits to their homes. Householders will be requested to complete this questionnaire after having been seated on their sofa for at least 30minutes, for example after having watched their favourite television program in the evening. In this way, the chance of the occupant being in a steady thermal state will be maximised, together with a means for obtaining reliable knowledge of the thermal insulation afforded by the chair in question (armchair, sofa, etc).

Temperature and humidity loggers will be placed in the same room where the householders complete the questionnaire (the room housing the television). As regards air velocity, assumptions will be made based on house visits. Unless a house is very draughty, air velocity is generally less than 0.1m/sec in winter when windows are usually kept closed. An air velocity of 0.1m/sec is the minimum default value selected by the ASHRAE Thermal Comfort Program (Version 1.0) used to calculate PMV values. Corresponding values for metabolic rate ('met' values) will be used assuming sedentary activity levels (the action of watching television will help ensure this). To calculate clothing insulation level, a simplified clothing insulation list has been developed from ISO7730 standards and this will be given out to householders for them to calculate and report a total value for their clothing insulation (details of this part of the data-gathering process are still being finalised). Given the time scales of the study, it is not possible to measure mean radiant temperature in all houses. Hence, mean radiant temperature will be measured during visits to 20-30 houses and these values will be compared with air temperature values recorded at the same time. Any reliable correlation between air and mean radiant temperatures that may exist for solid wall houses will be identified and applied to the air temperature values logged in the remaining houses to derive a value for mean radiant temperature in those properties.

It is anticipated that the comparison of AMVs and PMVs will lead to a better understanding of the state of thermal comfort in solid wall dwellings in the UK. For example, it will indicate temperatures at which people feel comfortable and whether indoor temperatures must always be at least 21^{o}C in living rooms and 18^{o}C in bedrooms (as assumed in BREDEM, for example) to ensure thermally comfortable occupation.

7.0 Conclusion

The solid wall housing stock constitutes 31% of the total housing stock in the UK and offers a great opportunity to reduce UK domestic carbon emissions. A suite of retrofit solution and technologies will be required to reduce carbon emissions in this stock through a tripartite approach dealing with reduction of heat demand, supply of energy and management of energy. Technological and socio-economical challenges in the deployment of these solutions and technologies will have to be overcome. Human needs of adequate thermal comfort, user appeal and acceptability will have to be considered whist developing these solutions- thus requiring a bottom-up user centred approach towards a low carbon world. Thermal comfort will have to be understood from the householder's perspective and the impact of the take-back process will have to be considered while evaluating the carbon reduction potential of retrofit solutions.

By relating experiences of past home improvements, the barriers and motivations to future retrofitting of energy saving measures can be anticipated. Householders are clearly aware of energy saving measures, although their primary motivations for a home improvement were usually not to save energy. Improving living standards and reducing bills were more significant drivers. Irrespective of cost factors, the perceived benefits and aspirational appeal of carbon reducing technologies need to outweigh the cost of disruption from the perspective of the householder. Achieving this, places demanding requirements not only on technologists and designers but also upon those responsible for marketing essential energy saving solutions.

This paper has presented preliminary results of the Householder Survey only. The ongoing work will collect additional data on householders' motivations for, and barriers against, retrofit energy saving technologies, as well as temperature and humidity recordings related to householders' responses to thermal comfort. CALEBRE is attempting to understand the state of thermal comfort in solid wall houses and get a look behind Britain's front doors!

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