Centre for
Low Carbon Futures
2050

The Retrofit Challenge: Delivering Low Carbon Buildings
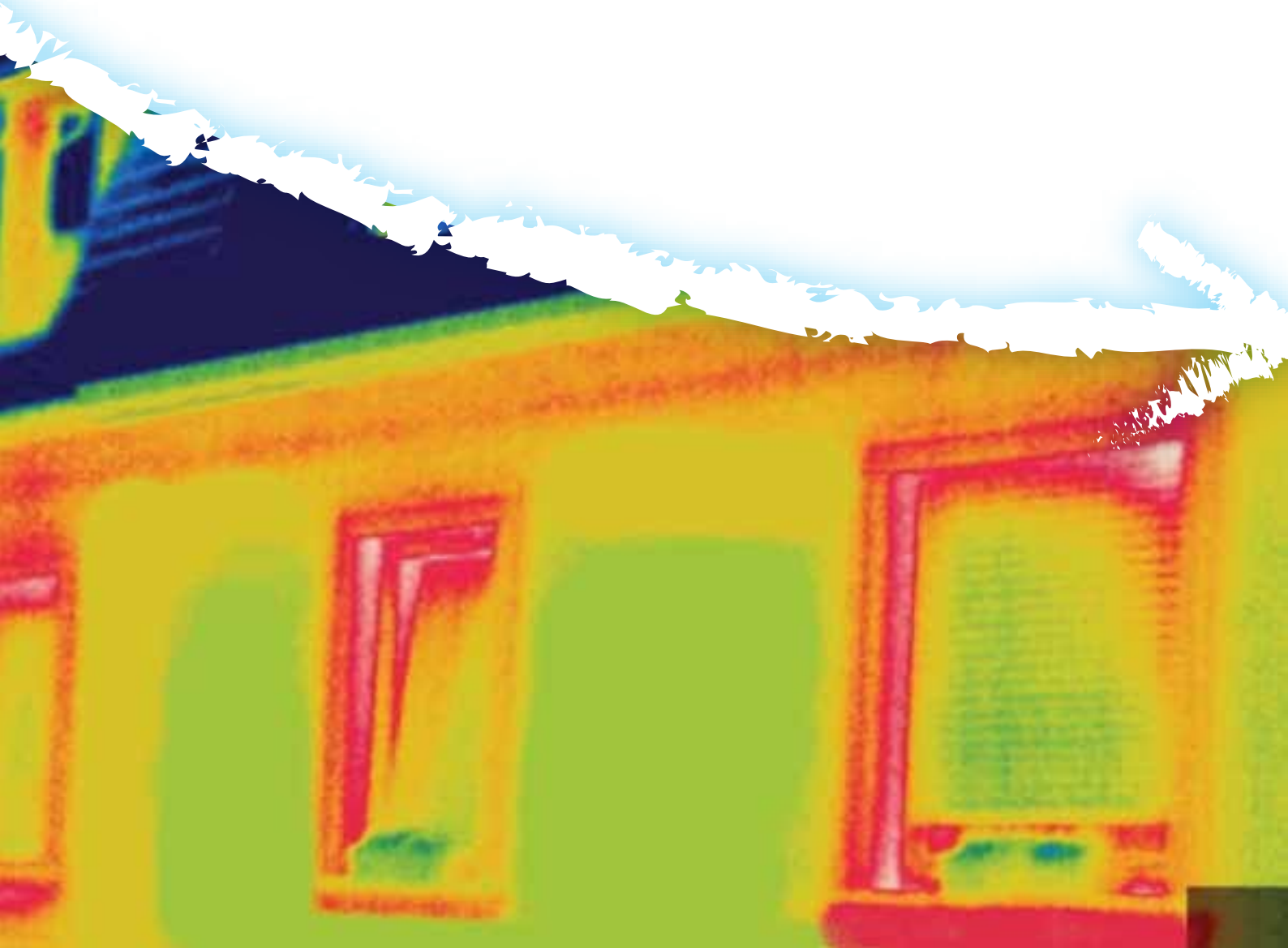
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This report looks at the current status and future potential of building retrofit for energy performance and carbon saving in the UK.

A brief review of current policy and building stock is followed by a discussion of ways forward. This is divided broadly into six key themes, though there is considerable overlap and connectivity between themes: a fact which illustrates well the nature of the retrofit problem. The discussion is informed by insights drawn from recent and current research in the field.

CONTENTS

INTRODUCTION

The spotlight is firmly on the UK this year and not just because of the Olympics. The UK Coalition Government is tackling the huge issue of the 45% of UK Carbon Emissions created by our built environment. This year they will roll out a portfolio of 'game changing' policies including Green Deal, ECO, Renewable Heat Incentive and the Localisim Act to further enable householders, industry and Cities to reduce energy consumption and carbon emissions.

The outcomes are potentially very promising with these policies collectively having the potential to draw in £bn's of pounds of investment and deliver wider local economic benefits in terms of GDP and jobs. However there is a great risk that the planned energy and carbon savings are not achieved unless there are significant changes in both our implementation and behavioural use of energy efficency in the built environment.

The Centre for Low Carbon Futures commissioned this report as part of a programme of translational research insights on energy efficiency. Our broader research agenda on Low Carbon Cities includes a "Mini Stern" review of a number of cities, and the development of a new Centre to provide independent ongoing measurement, reporting and verification of energy efficiency in the built environment. Our recent study on the Economics of Low Carbon Cities[1] was launched at the UNFCCC in Durban, and to date we have received enquires from Beijing, Tokyo and Mexico City, demonstrating the current global need for more useful research insights and tools to enable more effective energy efficiency deployment.

We are grateful to Dr A. Stafford, Professor C. Gorse and Professor M. Bell at Leeds Metropolitan University and Professor L. Shao at De Montfort University and contributions from EST and others for their work on this report

Jon Price

Director, The Centre for Low Carbon Futures

[1] Gouldson, A., Kerr, N., Topi, C., Dawkins, E., Kuylenstierna, J., Pearce, R. (2012) The Economics of Low Carbon Cities: A Mini-Stern Review for the Leeds City Region.

FOREWORD

If we are to hit our national carbon reduction target of 80% by 2050, almost every building in the country will need a low energy makeover. That means we have to improve nearly one building every minute, and we have to get the interventions right, first time. That is a challenge.

Each house is different, so there is no 'one size fits all' solution; householders and building users have different attitudes to, and understanding of, energy efficiency. Installers and tradesmen do not all have the necessary skills to fit more advanced energy efficiency and renewable energy measures. The solution is to test the real, in home performance of energy efficiency and renewable energy measures, and to make sure that everyone involved in specifying, fitting and using those measures are sufficiently informed to make sure that they work properly. We need to make sure that standards are set and followed, taking into account national, regional and local variations. In this way we will deliver low carbon, low energy homes and commercial buildings, which cost less for occupiers to heat.

There are expert, experienced and dedicated individuals and organisations who are offering practical solutions to this challenge. The recommendations of this report provide a roadmap for achieving a much better understanding of the issues. Energy Saving Trust field trials already provide insight into the performance of technologies, and our consumer awareness-raising helps to drive demand for retrofit measures. The Centre for Low Carbon Futures is building on some of the best academic research into building energy performance in the country to take the next steps towards a comprehensive low carbon building stock for 2050. I am very pleased that the Energy Saving Trust is working with the Centre for Low Carbon Futures on this essential work.

Philip Sellwood

CEO, Energy Saving Trust

PREFACE

The potential for reductions in carbon emissions in the built environment is considerable. However, unlocking the potential presents a multifaceted and intrinsically difficult problem. Not only is the building stock extremely diverse and numerous but ownership is equally diverse and complex. Addressing the technical, legal, economic and social issues will require considerable effort from all sectors of society. In this report the authors deal mainly with the technical and user issues but, as they are acutely aware, addressing these issues will form only part of the solution.

Perhaps the most critical of the questions raised by this report is the relationship between theoretical and as-built performance. Traditionally this discrepancy has been attributed to user variation but field test evidence suggests that a considerable element can be attributed to the underperformance of fabric and services, as-constructed. Moreover, a number of case studies have identified a clear link between the processes used in design and construction and the under-performance observed.

In addition to improving industry processes that deliver sound as-built performance, it will be crucial to adopt a range of measures that are well designed and tailored to individual buildings and building groups. This will require a considerable degree of coordination so that measures are not applied piecemeal but in a coherent and effective way.

Almost all the issues identified in this report expose a lack of fundamental understanding about the relationships involved and identify the need for a considerable research effort. However, time is very short and a great deal of learning will have to take place as action is taken. This points to the need for research to be embedded in the very actions and relationships that are being investigated. In short there must be a system of continual feedback, which will need to be amplified by the coordinated use of information technology.

If we are to ensure that the building stock in 2050 and beyond is truly sustainable it is essential that the issues identified in this report are tackled immediately but in such a way that enables us to learn as we go. There is no time to do it any other way.

Malcolm Bell

Emeritus Professor of Surveying and Sustainable Housing, Leeds Metropolitan University

EXECUTIVE SUMMARY

In order to achieve mandatory carbon reduction targets, a rapid, policy-driven transition to a low carbon economy is urgently required.

Around 45% of emissions in the UK derive from buildings. Although the Government is attempting to address the low carbon agenda with respect to new build, via progressive regulation towards a low carbon standard, the fact remains that around 70% of buildings existing today will still be in use by 2050. For this reason, low carbon retrofitting of existing buildings is a vitally important factor in the transition.

Extensive retrofit programmes, though necessary, are likely to be costly and therefore need to be properly researched and understood in order to 'get it right first time'. This is not a simple matter given the diversity of UK building stock and the fact that the real performance of buildings and retrofit interventions is as yet poorly understood.

It is now widely recognised, thanks in part to extensive research undertaken at Leeds Metropolitan University, that a 'performance gap' exists between predicted and real energy performance, both in new build and in retrofit. This points to a clear need for improved understanding of fabric, systems and build processes.

The primary gains will be achieved via improved fabric performance and this should be the initial focus of retrofit strategies. Once fabric performance is optimised further gains are available through the judicious use of micro-generation and low carbon technologies. However, there is a danger in approaching retrofit in a piecemeal fashion, as a series of disconnected project stages. Such an approach is unlikely to optimise the potential of either fabric or low carbon technologies. It also fails to take advantage of potential cost savings. The solution is to develop an integrated strategy from the beginning, even if the works themselves are staged.

Finally, a further set of gains will result from an improved understanding of behaviour and how people interact with buildings and technologies. Interdisciplinary research in this field is beginning to identify important factors, not least the complexity of influencing behaviour in ways that are both acceptable and durable.

Underpinning all the issues discussed is the potential of ICT to facilitate both research and delivery phases.

WHERE ARE WE NOW? A REVIEW OF CURRENT POLICY AND EXISTING STOCK

POLICY LANDSCAPE

Drivers

It is often stated that around 45% of the UK's total carbon emissions derive from buildings. Government aspires to achieve zero-carbon standards for new buildings from 2016 (domestic) and 2019 (non-domestic). However, since it is estimated that by 2050 around 70% of the 2010 building stock will still be in use, it is very clear that low carbon retrofit will have a huge role to play in achieving carbon emission targets.

In February 2011, ARUP published a UK Legislation Timeline poster in an attempt to summarise the overall policy landscape on carbon reduction, from 2005 Kyoto Protocol to 2020, and beyond to 2050 (ARUP, 2011). Taking into account the global, European and UK targets, it divides policy drivers into three main sections: Emissions, Energy and Efficiency. While the Emissions section applies mainly to large-scale industry processes, all of the policy drivers listed in the other two sections (Energy and Efficiency) are highly relevant to the question of building retrofit. These policy drivers are summarised briefly in Box 1.

ENERGY: RENEWABLES OBLIGATION, FEED-IN TARIFFS (FiTS), RENEWABLE HEAT INCENTIVE (RHI)

EFFICIENCY: CLIMATE CHANGE LEVY (CCL), CARBON REDUCTION COMMITMENT (CRC), CARBON EMISSIONS REDUCTION TARGET (CERT) , COMMUNITY ENERGY SAVINGS PROGRAMME (CESP), BUILDING REGULATIONS, CODE FOR SUSTAINABLE HOMES (CSH)

Box 1: Current policy drivers relevant to building retrofit

These policy drivers may vary to some extent between the constituent countries of the UK. For example, eligibility for FiTs and RHI is at present limited to England, Scotland and Wales, while the Renewables Obligation applies to England, Scotland, Wales and Northern Ireland. Similarly, Building Standards in Scotland and regulations in Northern Ireland differ from those in force in England and Wales.

Beyond these principal measures in the ARUP list, a range of further policy measures also impact on retrofit and energy use in buildings.

To raise awareness among building owners of their options for retrofit, the Government has supported impartial advice services from the Energy Saving Trust and Carbon Trust. Energy Performance Certificates – introduced as a requirement of the European level Energy Performance of Buildings Directive – are required by law to be provided by owners when they sell or rent out a home. The certificates inform the new buyer or user about energy use and retrofit options.

Government supported product labelling initiatives also play a part in raising awareness of the most energy efficient products on the market.

The Government has made use of fiscal incentives to drive energy and carbon saving. An Enhanced Capital Allowance incentivises the installation of energy saving measures in business premises and the Landlord's Energy Saving Allowance provides tax rebates for installation of insulation for private residential landlords. A reduced rate of VAT is available on many energy saving retrofit installations in homes.

Finally, driving installation of energy saving measures in homes are policies focused principally on fuel poverty. The Warm Front programme in England, or the Energy Assistance Package in Scotland, work alongside the CERT programme to help poor and vulnerable customers who cannot afford to heat their homes adequately because of poor energy efficiency. Some of the energy and carbon savings resulting from installing insulation or more efficient heating systems in fuel-poor homes are lost in 'comfort taking'. While the primary aim of these programmes is to enable people to heat their homes (see Theme 5), the overall net effect of fuel poverty programmes is also to reduce carbon emissions.

Beyond these existing programmes new policy measures are on the horizon. The Green Deal provides for upfront financing of energy saving measures on buildings, which are paid back through a long-term charge linked to the property's energy bills.

WHY ARE INTERVENTIONS NEEDED?

Investment in low carbon technologies and systems naturally becomes increasingly attractive as fossil fuel prices rise, and also as other issues such as security of supply and future-proofing become more important. Nevertheless, if the market was left to itself, the transition to a low carbon economy would happen too slowly to enable mandatory carbon reduction targets to be met in the short and medium term. Therefore government must kick-start the process by introducing policies which encourage early investment by various strategies, such as regulation and mandation, reducing risk, increasing the cost of inaction and supporting the spreading of initial capital investment over a period of time.

WHAT ARE THE COSTS OF INTERVENTIONS?

Policy interventions, such as those listed above, carry an intrinsic cost. However, many are aimed at not only decarbonising building energy use, but also at reducing overall consumption, which has the effect of mitigating or in some cases even completely compensating for any extra costs which are passed on to the end-user or building occupier.

The DECC report 'Estimated Impacts of Energy and Climate Change Policies on Energy Prices and Bills' (DECC, 2010a) looks at the effect of policies on both domestic and commercial energy costs. It takes into account the costs of the policies listed in Box 1, together with the additional costs of Smart Metering, security measures, Carbon Capture and Storage (CCS) demonstration and other initiatives. Figure 1 summarises the projected effects by 2020.

Clearly, individual decisions about uptake of energy efficiency measures will have a significant effect on actual fuel bills by 2020. In the domestic case, average projected uptake almost negates the effect of policy costs. It should also be noted that the costs of energy and climate change policies will be less if fossil fuel prices are higher than expected, since under these circumstances low carbon investment is incentivised more rapidly, irrespective of policy measures. The projected figures given in Figure 1 are based on oil prices of 80 $/bbl in 2020. Current prices (May 2010) are around 100 $/bbl, and significant long-term reductions seem unlikely (Oil-Price.net, 2011). For higher oil price scenarios, the overall domestic bill in 2020 with energy efficiency take-up is expected to be actually reduced by policy measures.

Percentage cost increase by 2020

Legend:
- Assuming no take-up of energy efficiency measures or renewables
- With projected take-up of energy efficiency measures or renewables
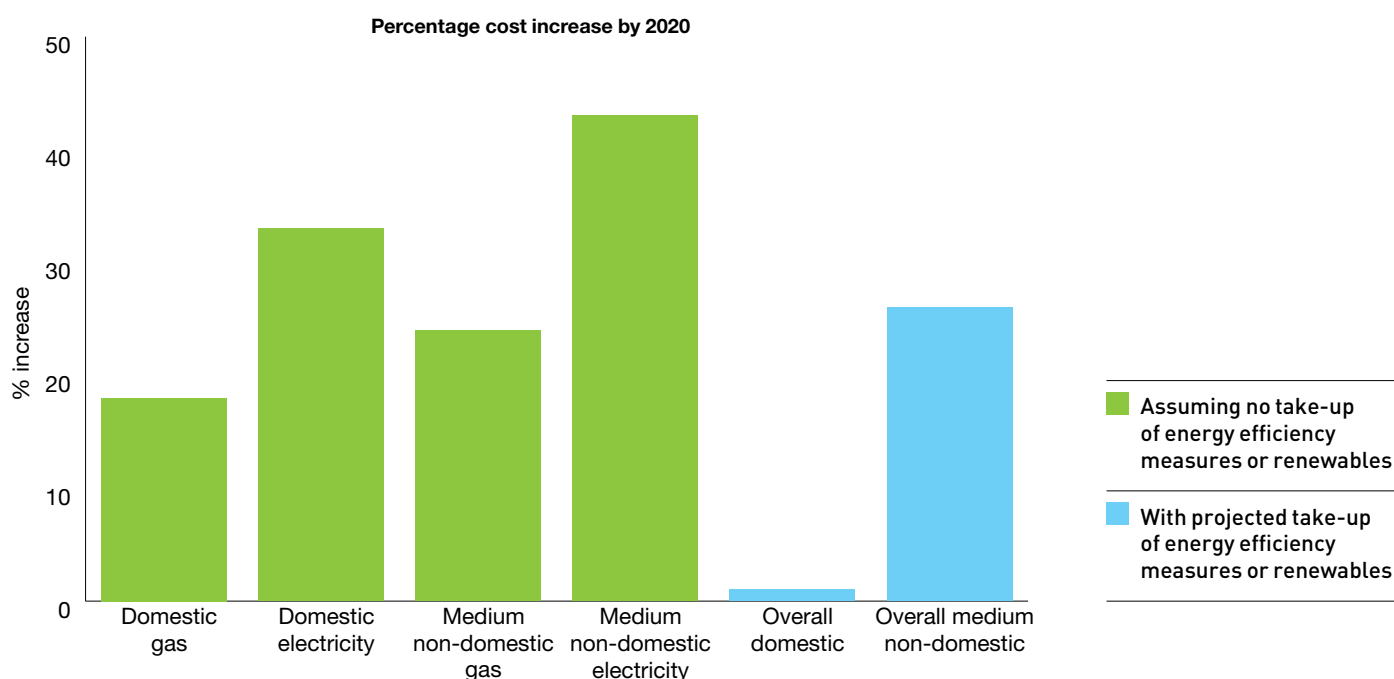
Fig 1: Projected effects of policies on fuel costs [after DECC 2010]

CURRENT BUILDING STOCK

Of the 70% of the total 2010 building stock still in use in 2050, 40% will be pre-1985, i.e. will pre-date the introduction of Part L of the Building Regulations for England and Wales (Better Buildings Partnership, 2010). The ENPER-TEBUC project final report (Hartless, 2004) offers an estimate of new build, replacement and renovation rates in a number of European member states. While annual replacement rates in the UK are thought to be low at around 0.1% of existing stock, since demolition rates are low renovation and refurbishment rates are likely to be much higher at around 2.9%–5% of existing stock for domestic buildings, and between 2% and 8% for commercial stock, depending upon the sector.

Domestic

The Domestic Energy Fact File (Utley and Shorrock, 2008a) classifies UK dwellings by age, type and tenure. The diagram below shows the age-distribution of domestic stock in 2006.

Figure 2 refers to the UK in general, but there are significant differences between the constituent countries, as described in detail in the Domestic Energy Fact File 2007: England, Scotland, Wales and Northern Ireland (Utley and Shorrock, 2008b). For example, Northern Ireland has the newest stock, with 61% of dwellings built since 1959, whereas Wales has the oldest, with 61% built prior to 1960. However, some 84% of households are located in England, with Scotland representing 9%, Wales 5% and Northern Ireland only 2%.
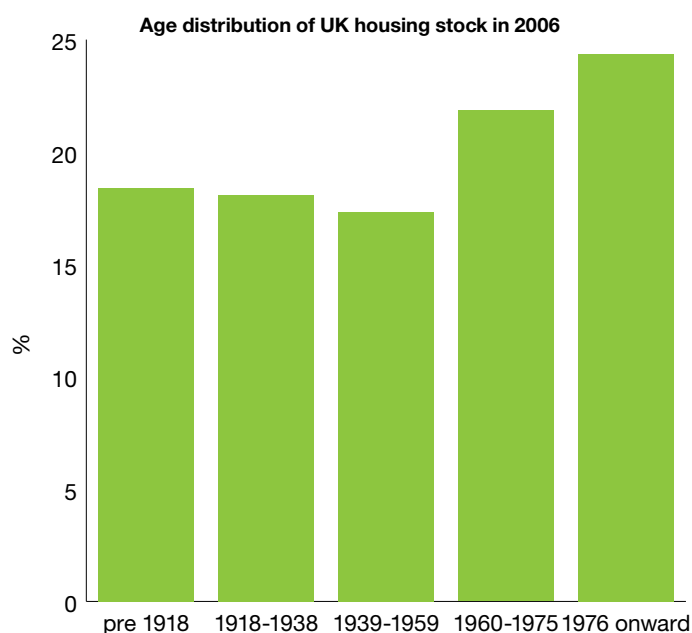
Basic insulation interventions are not sufficient in themselves to achieve required thermal performances. Nevertheless, such measures form a necessary starting point and also illustrate the complexity of the issues. For example, it is estimated from the age distribution and other data that about 30% of current stock is unlikely to have cavity walls and would therefore require internal or external wall insulation to improve thermal performance. This is not necessarily a major disadvantage, since external insulation can perform as well as, or better than, cavity wall insulation. However, by 2004 in England, Scotland and Wales less than 50% of existing cavity walls were thought to be insulated, though the figure for Northern Ireland was much higher at 78%. In 2009, some 30% of English homes failed the Decent Homes standard (down from 33% in 2008), with around 7% being specifically for reasons of poor thermal performance (DCLG, 2010). In Scotland, over 60% of homes failed the Scottish Housing Quality Standard (2009 figures), the majority of these for reasons of poor energy efficiency (Scottish Government, 2010).

Non-domestic

54% of the existing commercial building stock (representing 29% of floor-space area) was completed prior to 1939 (DCLG, 2000). It has been estimated that 80% of all current commercial stock would be rated below C on the Energy Performance Certificate (EPC) scale (Caleb Management Services, 2009).

Low carbon retrofit of commercial property has not been widely adopted so far. This has partly been due to 'split-incentive' issues, where upfront costs may fall disproportionately on short-term tenants while most of the benefits accrue to longer-term tenants and building owners. Only around a third of the commercial property market is owner-occupied. For these properties or for single-tenant/long-lease situations, some retrofit measures may have been adopted, provided they could be justified by simple economic payback perhaps combined with corporate social responsibility drivers.

Policy incentives such as CRC, FiTs and RHI may prove successful in supporting more rapid growth in this area.

Fig 2: Age distribution of UK Housing Stock in 2006 (after Domestic Energy Fact File, 2008)

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THE WAY FORWARD:
SIX KEY THEMES IN BUILDING RETROFIT

The following six key themes will be discussed in the following sections.

1. Retrofit isn't simple

2. Building energy performance is not well understood

3. Building fabric

4. Micro-generation and low carbon technologies

5. People use energy

6. The importance of IT and monitoring

Note that there will be considerable overlap between themes in the following sections, with some issues feeding into two or more themes. This is an illustration of the reality of the interconnectedness of various aspects of the retrofit problem, and hence the complexity of finding workable and robust solutions.

THEME 1:
RETROFIT ISN'T SIMPLE

ONE SIZE DOESN'T FIT ALL

A conclusion of the Gentoo Retrofit Reality project (Gentoo Group, 2010) encapsulates the complexity of performance-effective and cost-effective retrofit interventions in the following statement: "Retrofitting is not simple, each house is different and every person behaves differently within their home."

In an ideal world, it might be possible to identify a 'one size fits all' solution to effective building retrofit. However, the diversity of UK building stock in terms of age, use, materials, build type and quality, thermal mass, location, orientation and occupancy, means that solutions need to be specifically tailored to the building or group of buildings in question.

MEASURES MAY NOT PERFORM AS EXPECTED

Even if appropriate interventions can be identified, it is a mistake simply to assume that measures will perform according to expectations. This may be due to either intrinsic performance issues or installation and process issues. For example, researchers have frequently observed nominally enhanced loft insulation, which has been assumed to be performing up to Building Regulations 2006 standards but where in fact poor installation has resulted in missing areas and underperformance (Stafford & Bell, 2009; Miles-Shenton, 2011). Similarly, cavity wall insulation has been observed which has been installed correctly according to procedure, but nevertheless has resulted in an uneven cavity fill, producing density variations and leaving some areas unfilled. These examples demonstrate the necessity for increased understanding of the real performance of even very widely used measures under different conditions and circumstances. Such understanding can only be achieved by a combination of improved training and routine monitoring of at least a significant sample of cases. Performance predictions in general tend to be based upon an assumption of ideal behaviour of materials and products under standard conditions, combined with perfect installation. It is therefore perhaps not surprising that in reality performance rarely matches expectations.

BALANCING BENEFITS AND COSTS

Retrofitting for energy performance is always a balance between benefits and costs. The TARBASE project (Banfill, 2009) suggested that it is feasible to reduce CO_2 emissions from existing buildings by at least 50% and in some cases up to 80%, though this conclusion was based on projections, not on measured performance. It is undoubtedly technically possible to refurbish existing buildings to a level of thermal performance close to that of low-carbon new-build, (Miles-Shenton, 2010), but in some cases this can be prohibitively expensive and may even approach the cost of demolition and rebuilding. The question then becomes "How much benefit can be gained for a reasonable cost?" where the definition of 'reasonable cost' depends in part on mandatory targets, energy costs, policy drivers, and economies of scale. Technical advances and the maturation of low carbon industries will also tend to drive down costs over time.

It will be clear from many of the following sections that interdisciplinary learning is important for progress in a successful UK retrofit programme. Technical and social disciplines both have a clear role to play, but economic and financial disciplines must also be included. This type of expertise is necessary for researching innovative and effective ways of financing the necessary initiatives.

THINKING ABOUT FUTURE NEEDS

Finally, it should be remembered that some degree of progressive change in the UK climate is inevitable over the next few decades and there is value in ensuring that current retrofit projects are not incompatible with energy efficiency under future conditions. Particularly in commercial buildings, retrofit strategies may need to ensure that some adaptation flexibility is retained so that present carbon savings as a result of reduced heating or lighting are not wiped out by increased future needs for air conditioning or other carbon intensive technologies (TSB, 2010). It must be stressed that this consideration does not adversely affect the value of insulation measures, but may nevertheless affect other design considerations. For example, planning for increased solar gain may need to be balanced with optional shading strategies, or especially careful consideration given to the control of ventilation.

RECOMMENDATION: THAT A KEY POLICY PRIORITY FOR FUTURE RESEARCH SHOULD BE TO ADDRESS THE URGENT NEED FOR IMPROVED UNDERSTANDING OF THE REAL, IN-SITU PERFORMANCE AND PERFORMANCE DISTRIBUTION OF RETROFIT MEASURES, TOGETHER WITH IMPROVED UNDERSTANDING OF INSTALLATION PROCESSES AND THEIR IMPACT ON PERFORMANCE.

THEME 2: BUILDING ENERGY PERFORMANCE IS NOT WELL UNDERSTOOD

A TWO-FOLD PROBLEM: PREDICTION AND DELIVERY

In applying regulatory or other performance standards (such as the Code for Sustainable Homes or Passivhaus), the usual procedure at present is to evaluate design performance based on a theoretical model.

However, the problem with this approach is two-fold: firstly the difficulty of ensuring that the performance prediction in a particular case is accurate, and secondly the difficulty of ensuring that what is specified is actually built.

Predictions are often based largely on performance values for different elements – windows, doors, insulation etc. – which have been achieved in laboratory testing, under standard conditions. However, little may be known about their actual performance in-situ under widely varying conditions. Predictions also assume that the design will be built without error and exactly to specifications.

In some cases techniques for predicting performance may be inaccurate or may fail to include significant factors. A good example is the issue of the party wall bypass. A considerable body of work undertaken at Leeds Metropolitan University has demonstrated that a bypass mechanism operating in cavity party walls does in fact result in heat loss. This is contrary to the previously accepted view that the effective U-value (thermal transmittance) could be assumed to be zero, since equal temperatures on both sides of the party wall meant that there would be no simple conductive heat transmission (Wingfield 2010; Wingfield, Miles-Shenton and Bell 2009; Wingfield et. al. 2008). As a consequence of this work an amendment was made to Building Regulations Part L 2010 to take account of the newly-understood loss mechanism. The new regulations now allow a U-value of zero to be assumed only if the party wall cavity is fully filled and edge-sealed, specifying nominal U-values of 0.2 W/m²K for those which are edge-sealed only, and 0.5 W/m²K for untreated cavities.

Other amendments to Part L 2010 are also aimed at addressing the performance gap, e.g. the application of 'confidence factors' to thermal bridging or pressurisation test values, in circumstances where detailed calculation or measurement is not undertaken, or the requirement for energy performance calculations to be submitted at the design stage as well as at completion. This trend is expected to continue in the next iteration of the review in 2013.

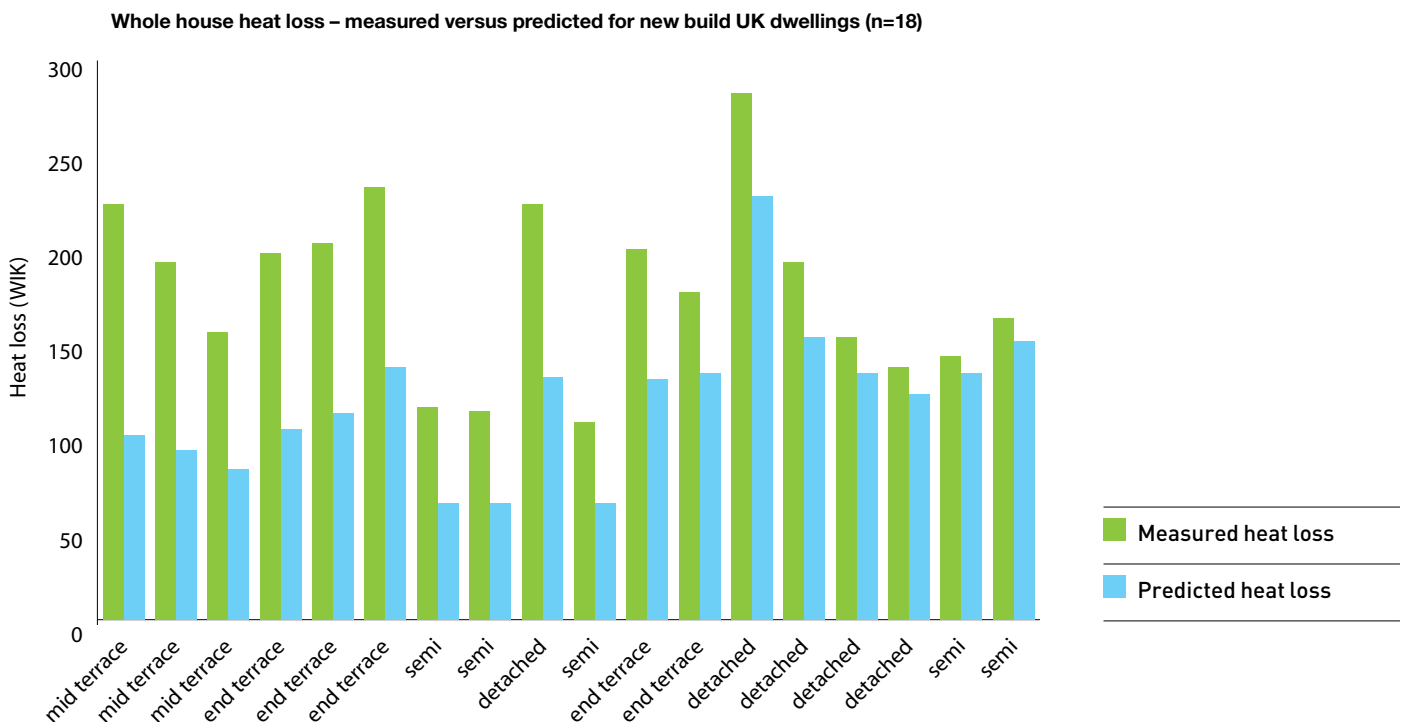**Whole house heat loss – measured versus predicted for new build UK dwellings (n=18)**

Fig.3a: Differences between predicted and measured whole house heat loss [Wingfield et. al., 2008], [Wingfield et. al., 2011], [Miles-Shenton et. al., in press, a], [Wingfield, Miles-Shenton and Bell, 2009], [Wingfield, Bell and Miles-Shenton, 2010]

However, even assuming that predictions are reasonably accurate, the problem of delivery remains. For new build in practice on-site, supply chain issues and time pressure often mean that materials and products are substituted for those specified at the last minute (Wingfield et. al. 2011). This may have knock-on effects, for example on detailing, which then may also be changed on-site. Finally there is the element of human error, and even that of experienced operatives ignoring design drawings and substituting a preferred construction that they have used in the past. All of these issues are likely to apply also to substantial retrofit projects.

At present, even contractors who are seriously engaged with learning and developing good practice find it difficult to transfer knowledge and experience between projects, because of the nature of workforce deployment in the industry.

All of the above factors mean that performance in practice tends to lag behind as-designed performance and furthermore varies from compliance in an unpredictable way.

THE PERFORMANCE GAP

Wingfield, Miles-Shenton and others have performed many detailed co-heating tests (Wingfield et. al. 2010) to measure whole-building heat loss coefficients on a variety of new build dwellings. Measured heat loss coefficients are almost always higher than predicted, sometimes by as much as 100% or more. This is likely to be attributable to a combination of incompletely understood prediction techniques, together with a failure to achieve the specified performance in practice. Figure 3a compares predicted whole-dwelling heat loss with the measured value in a total of 18 cases. Figure 3b ranks the same cases in order of discrepancy between predicted and measured mean U-values.

The cases in Figure 3 refer to new build dwellings, but similar performance gaps are observed for retrofit projects.

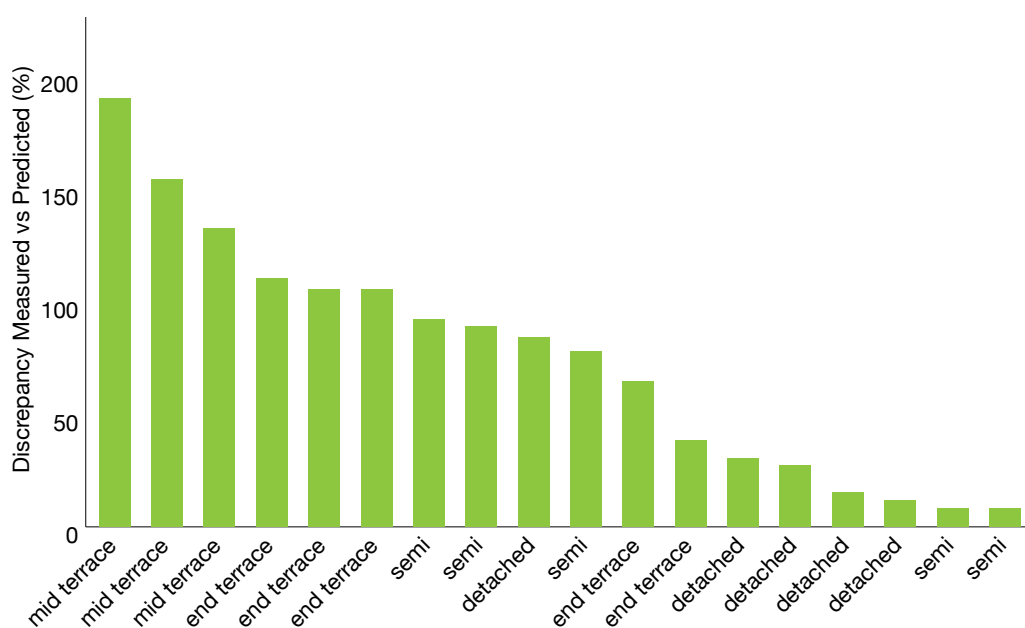**Discrepancy in measured versus predicted mean U-value for new UK housing (n=18)**

Fig 3b: Discrepancy in measured vs predicted mean U-values (references as for Fig 3a)

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Figure 4 shows reductions in heat loss coefficients for the case of a staged refurbishment project, where co-heating tests were performed after each stage. It is clear that real and significant improvements in performance were observed at each stage, but nevertheless these were not as great as the predicted improvements.

Underlying the performance gap problem is a set of fundamental questions about design and construction processes. Design processes rarely make allowances for in-situ performance tolerances, modelling often contains input errors (Trinick et. al., 2009) and, as observed above, construction often contains deviations from design that are not well controlled. Although there is case evidence of the existence of a performance gap, very little is known about the links between process and performance. Some have argued that underperformance can be reduced by including a significant element of off-site production, but there is as yet very little data to support this view. Indeed data from the Elm Tree Mews project, one of the few off-site production dwellings that have been tested (Bell et. al., 2010) suggest that off-site production can exhibit a performance gap of the same order as traditional on-site approaches. It is likely that different construction forms and techniques will have different process control requirements and that as more is learned about in-situ performance, processes will need to be continually improved to ensure that not only is the gap closed but it is kept closed.

The first step will be to establish the links between process and performance. The introduction of government accredited installation standards for key energy efficiency measures as part of the Green Deal will be an important step forward in up-skilling. However, much retrofit work – particularly in the domestic sector – will continue to be delivered through sub-contractors and small builders outside government programmes. Against this background, internal dissemination and progressive learning and improvement within organisations in the construction industry will require considerable improvement from its present relatively poor level.

RECOMMENDATIONS: THAT SYSTEMATIC WORK SHOULD BE UNDERTAKEN TO CLOSE THE PERFORMANCE GAP BY IMPROVING UNDERSTANDING OF THE LINKS BETWEEN PROCESS AND BUILDING PERFORMANCE.

THAT METHODS OF ON-SITE TRAINING AND OF SHARING GOOD PRACTICE WITHIN THE INDUSTRY SHOULD BE REVIEWED, AND FURTHER RESEARCH UNDERTAKEN INTO EFFECTIVE ROUTES TOWARDS PROCESS IMPROVEMENT.
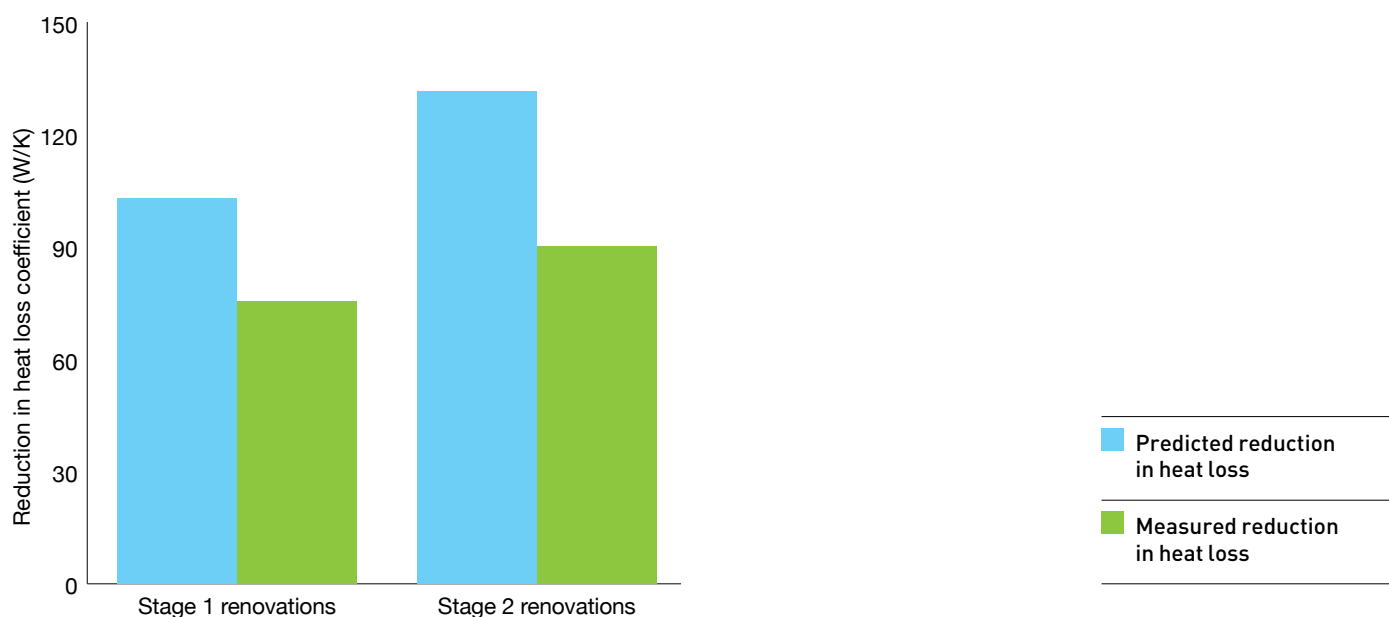

Fig 4: Predicted and measured reduction in heat loss coefficient for a two-stage refurbishment project [Miles-Shenton et. al., in press, b]

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THEME 3:
BUILDING FABRIC

Fabric performance is fundamental to achieving significantly reduced energy consumption while maintaining acceptable levels of thermal comfort. Only when fabric performance is clearly understood and optimised will further gains from behaviour change, on-site generation and other technologies become efficiently attainable. In the non-domestic sector there is currently a reluctance to invest in fabric performance and insulation. Organisations prefer to concentrate on non-fabric measures such as energy efficient lighting. However, policy interventions, such as the Carbon Reduction Commitment (CRC), may help to enhance the attractiveness of insulation measures in this sector in the future.

Many basic insulation measures, such as loft insulation and cavity wall insulation (CWI) are relatively inexpensive and offer payback periods which make them economically viable. Frequently these simple measures do not go far enough and policy interventions such as Green Deal (DECC, 2010b) will be required to achieve the enhanced standards which will support targets. It is estimated that around 40% of dwellings with cavity walls have cavity insulation (2006 figures). Also in 2006 almost 95% of accessible lofts reported having some insulation, though in the majority of cases this was considerably less than the currently recommended minimum thickness of 270mm (Utley & Shorrock, 2008).

Fabric performance generally is a complex web of interactions, including thermal transmission of elements (walls, floors, roofs, windows etc), air-tightness, thermal bridging and bypass mechanisms. It is therefore vital to regard refurbishment projects holistically, rather than as a series of disconnected measures, and to understand that the performance of measures in-situ can be affected by many factors, including process issues.

FABRIC PERFORMANCE TESTING

The measurement of whole-building heat loss via co-heating testing (Wingfield et. al. 2010) offers a method of assessing overall fabric performance. Performing a co-heating test before and after a refurbishment programme gives an excellent indication of performance gains. Unfortunately the technique is rather costly in terms of time, resources and expertise and, in its present form, is not likely to be practical as a standard or routine assessment tool for every retrofit project. However, as a research technique it is invaluable and could form part of a series of large-scale investigations, for example into the statistical distribution of gains achieved for different measures in different building types.

For measures intended to reduce heat loss due to air leakage, air-tightness testing (pressurisation testing) is a simpler, quicker and less intrusive method of assessment (ATTMA, 2006). However, it cannot provide an assessment of overall heat loss.

There is still much important methodological work to be done in developing robust whole-house testing methods, which can be routinely applied as part of the production process to verify quality and reproducibility.

CAVITY WALLS

As previously mentioned in Section 1, around 30% of current dwellings do not have cavity walls. For commercial stock, the figure is probably even higher. A significant proportion of the remainder have walls with un-insulated cavities. The ECI 40% House Scenario (ECI, 2005) assumes that 100% of cavity walls and 15% of solid walls would be insulated by 2050.

Following large-scale energy supplier funded programmes over several years, the percentage of cavity wall homes that presently remain unfilled is subject to debate, but in England is estimated to be around 43%, or almost eight million (DECC, 2011a). It is increasingly recognised that a significant proportion of cavity walls are unsuitable for cavity wall insulation for a variety of reasons. These homes will generally require solid wall insulation as for non-cavity wall homes.

Conventional retrofit filling of external cavity walls with mineral wool, glass wool or polyurethane foam is generally considered to be an effective and relatively low cost intervention, recommended for most buildings where cavities exist (EST, 2009).

Nevertheless, the gap between expected and real performance can exist even where accredited installers are following standard procedure. Investigations performed by the Centre for the Built Environment Research Group at Leeds Metropolitan University using thermal imaging and/or borescopy have shown a number of potential problems including areas of missing insulation, insulation material slippage, variations in density or incomplete filling of cavities (Miles-Shenton et. al., in press, b). The performance of many insulation materials is also affected by moisture.

Air movement in the cavities of internal party walls can also have a detrimental effect by allowing heat loss via a thermal bypass mechanism as described in theme 2.

It is clear from all of the above that the real gains made by current large scale programmes for insulating cavity walls are not yet fully and quantitatively understood.

SOLID WALLS

For solid walls, the choice is between insulating externally or internally. External insulation cladding is regarded as the better option, especially if windows and doors can be replaced and/or relocated at the same time so that the external insulation layer can be of uniform thickness. Room sizes are not reduced and the works need not be particularly disruptive to occupants. In larger buildings, external insulation can also have the added benefit of eliminating thermal bridges especially those at intermediate floor level. However, in some areas it is not currently acceptable to alter the external appearance of buildings.

A major drawback of internal insulation is the reduction in the size of the internal space. A more subtle consideration is the fact that internal wall insulation effectively reduces the apparent thermal mass of the building in question. This may or may not be desirable. For example, research evidence shows that low thermal mass can improve the controllability of heat pump systems, allowing greater reactivity and some planned variations in temperature to be achieved without incurring energy penalties associated with reduced heat pump efficiency (Boait, Fan and Stafford, 2011). Whilst this consideration is only one factor amongst many, it is a further example of the need to plan retrofit programmes in an integrated way from the outset.

LOFT INSULATION

Loft insulation to at least current Building Regulations standards is a clear necessity as a simple and effective measure. However, in view of frequent observations by researchers, it is vital that both installers and occupants understand the need for full coverage of the whole roof area – especially near eaves and in hard to access areas – in order to eliminate cold areas which could give rise to condensation and mould, as well as compromising thermal performance. Installers should also understand the need for the insulation to be in contact with the primary air barrier to prevent thermal bypassing.

AIR TIGHTNESS

Air tightness in new build has a maximum allowable value controlled by Building Regulations (currently 10 m³/h.m² at 50Pa), but this aspect of performance is particularly vulnerable to subsequent modifications to the building structure, including significant retrofitting interventions as well as a host of more trivial activities that may breach the primary air barrier.

Air tightness can be measured via pressurisation testing and forensic investigations can be made via thermal imaging and smoke-testing. Such investigations at Leeds Metropolitan University have identified many common sites of unintended air infiltration, such as service penetrations, around trickle vents around and through loft hatches, around poorly-fitting windows and doors and into intermediate floor voids (Johnston and Miles-Shenton 2011). However, in addition to these direct leakage paths there can be many indirect paths which impact significantly on performance, and which are often less well understood (Wingfield et. al., 2008).

In retrofit projects, good air tightness is likely to be related to increased awareness and improved training procedures. Air tightness targets and the processes necessary to achieve them should be fully understood by all concerned from project design through every stage of implementation. The relationship between improved air tightness and ventilation requirements is an example of the necessity for a complete design strategy from the outset.

THERMAL BRIDGING AND BYPASSES

Again, process issues and more widespread understanding of the principles involved are key to improved performance. There is therefore a need for better training at all levels within the industry.

Thermal bypassing is complex and is often confused with air tightness. A thermal bypass occurs where air is allowed to move through, around and between the insulation – in effect bypassing the benefit of the insulation. Therefore, it is possible to have a very air tight house but still have thermal bypassing resulting in lower thermal performance. The air barrier and the thermal insulation should always be in the same plane and be in contact with one another in order to prevent bypassing, but this fact is not always appreciated by designers or on-site operatives.

RECOMMENDATIONS: THAT METHODOLOGICAL RESEARCH SHOULD BE UNDERTAKEN TO DEVELOP IN-SITU TESTING METHODS FOR ROUTINE USE IN PRODUCTION.

THAT THE REAL IN-SITU PERFORMANCE OF SIMPLE FABRIC MEASURES SHOULD BE BETTER UNDERSTOOD.

THAT TRAINING SHOULD BE IMPROVED ACROSS THE INDUSTRY TO ENSURE IMPROVED UNDERSTANDING OF THE PRINCIPLES OF HEAT LOSS MECHANISMS.

THEME 4: MICRO-GENERATION AND LOW-CARBON TECHNOLOGIES

In this category we include all those technologies with eligibility for Feed-in Tariffs (FiTs) or the planned Renewable Heat Incentive (RHI) payments. Those eligible at present are listed below:

ELIGIBILITY FOR FEED-IN TARIFFS

Feed-in Tariff eligibility (below 5 MW)

- Solar electric photovoltaics (PV)
- Wind power
- Hydro-electric power
- Anaerobic digestion (biogas for electricity generation)
- Micro gas powered combined heat and power (up to 2 kW)

Possible future eligibility

- Fuel cells

ELIGIBILITY FOR RENEWABLE HEAT INCENTIVE PAYMENTS

Renewable Heat Incentive eligibility (installations after 15/7/2009)

- Biomass boilers
- Biogas combustion (up to 200 kW)
- Deep geothermal
- Ground source heat pumps
- Solar thermal (up to 200 kW)
- Water source heat pumps

Possible future eligibility

- Air source heat pumps
- Hot air heating (e.g. kilns)
- Bio-liquids
- Landfill gas

The RHI scheme for domestic renewable heat installations will not come into full operation until October 2012. However, a fund of around £15m has been provided to enable interim, one-off payments to support installation of some technologies (air source and ground source heat pumps, biomass boilers and solar thermal) between 1 August 2011 and 31 March 2012. This is the Renewable Heat Premium Payment (RHPP) and single payments will be made on a first-come first-served basis. The value of the payment depends upon the technology chosen and ranges from £300 for solar thermal to £1,250 for ground source heat pumps. Only off gas-grid households are eligible for payments, except in the case of solar thermal (all households eligible). Other conditions of participation include micro generation certification (MCS) of both products and installers and the willingness to participate in monitoring if selected at random to do so. The element of monitoring will be an important factor in building up evidence about the real in-situ performance of the technologies in different circumstances, and may be used to inform tariff levels at the official start of the RHI scheme.

FABRIC FIRST – BUT ESTABLISH AN INTEGRATED STRATEGY FROM THE OUTSET

It is clear that RHI technologies should only be installed after appropriate energy efficiency interventions have already been undertaken, and indeed this is a requirement of eligibility for payments under the scheme.

What can sometimes be less well understood are the advantages to be gained from approaching refurbishment strategically as a whole rather than in a piecemeal fashion. This can save costs and ensure that conditions for the performance of the technologies are optimised. One obvious example is where roof replacement can be combined with PV installation, to save costs on building materials by specifying BIPV (building integrated PV), or on access arrangements by undertaking the work as one package. Another example is where floor works could be combined with installation of under floor heating pipes in order to improve the performance of a proposed heat pump system. The relationships between fabric and technologies can often be quite complex, as in the issue of heat pump controllability discussed in Key Theme 3.

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ECONOMIES OF SCALE

Social housing providers (e.g. local authorities) can be influential in installing large numbers of renewable and low carbon technologies, taking advantage of the ability to reduce costs via economies of scale. However, this can result in a tendency for a single technology type to be championed and hence installed in both optimal and sub-optimal circumstances. Examples of this would be installation of PV on roofs with non-ideal orientations or tilt angles, or installation of heat pumps as replacement heating systems in properties which are on the gas grid (Stafford and Bell, 2009).

MORE CLARITY REQUIRED

Owners and adopters of renewable technologies are currently not always well served by their energy suppliers in terms of easy access to advice and appropriate tariffs. The need for more clarity with regard to information dissemination and also the need to improve and simplify the MCS and to review training, have all been acknowledged by government in the recent Microgeneration Strategy report (DECC, 2011b).

A number of issues around RHI payments and the assessment of outputs are still to be resolved. It is not yet clear whether domestic or small-scale RHI payments should be made on the basis of routinely metered output or 'deemed' output, whereby a level of generation is assumed based on the size of the system installed. Metering might potentially give rise to conflicts of interest in landlord/tenant relationships, giving the owner (as recipient of RHI payments) less incentive to adopt energy saving measures. Similarly, metering raises issues of protocols, equity and system boundaries. It is not always a simple matter to determine heat output accurately. For example, in the case of heat pumps, the location of meters can significantly affect the measured output in ways that are not easily standardised between different installations (Stafford, 2011). While these are both good arguments for using 'deemed' output, this approach is potentially problematic in terms of accuracy and assessing the output of individual systems.

RECOMMENDATION: CONSIDERATION SHOULD BE GIVEN TO ESTABLISHING SETS OF INTEGRATED DESIGN SOLUTIONS FOR WHOLE HOUSE IMPROVEMENTS COVERING ENERGY EFFICIENCY AND RENEWABLE ENERGY. SUCH INTEGRATED SOLUTIONS SHOULD BE FIRMLY UNDERPINNED BY MONITORED IN-SITU PERFORMANCE DATA, WHICH SHOULD BE READILY AVAILABLE, FOR EXAMPLE BY FORMING PART OF A UK DATABASE OF SYSTEM PERFORMANCES.

THEME 5: PEOPLE USE ENERGY

No matter how well performing the building fabric, or how suitable and effective the micro-generation technology, it is an inescapable fact that overall energy use depends to some extent upon occupant behaviour. In fact, the ECI 40% House report (ECI, 2005) states that: "if UK society continues to develop along current trends, no carbon reductions are expected by 2050. Only societies where environmental concern and awareness are much stronger than today will produce significantly reduced carbon emissions." This is a complex area of study, encompassing issues of occupancy and employment patterns, day-to-day behaviour and attitudes, and user experiences of interaction with services and technologies. Many of these issues are explored in some detail in the Joseph Rowntree Foundation low carbon housing study 'Lessons from Elm Tree Mews' (Bell et. al., 2010).

FEEDBACK

It has been suggested that appropriate feedback can be helpful in encouraging people to reduce energy use and much has been made of the future role of smart meters in providing this feedback. However, the long-term role of feedback is complex and uncertain. The recent Energy Demand Research Project (AECOM, 2011) found that interventions without the use of smart meters generally did not result in energy savings, whereas the use of smart meters combined with Real Time Displays could achieve savings of around 3%. However, the evidence was somewhat difficult to interpret since the trials were not standardised between the different suppliers and a range of additional interventions were used simultaneously, leading to variable results. The simplest and most user-focussed form of feedback at present is probably that provided by simple pre-payment meters – the Gentoo group (2010) found that customers who use pre-payment meters were generally more conscious of their energy usage than those who paid monthly or quarterly bills though this is almost certainly related to income levels.

Between 2014 and 2020, every British home will be fitted with a smart meter, including an in-home display of energy use. To be of significant benefit to consumers, an EST study concluded that smart meters should be located appropriately within the dwelling, be easy to read and interpret, and include real-time information in the form of costs (£/day) as well as power consumption (watts) (EST, 2009). This EST study found that there were also strong preferences for graphical displays in addition to digital information, and for historical data and data on cumulative daily spend to be accessible. Comparisons of usage against a local average or norm may also help to encourage and sustain desirable behaviours. Work still remains to be done on maximising and quantifying the effectiveness of such comparisons, and on understanding how engagement can best be encouraged to persist rather than decline over time with exposure.

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TAKE-BACK EFFECTS

In dwellings where fuel poverty is a factor in restricting energy use, the effect of retrofit interventions may not be to reduce consumption, but instead to allow occupants to increase their levels of comfort. This is the so-called 'take-back' effect. For example, in their social housing study the Gentoo group (2010) found that homes with the lowest energy use before retrofitting interventions achieved the lowest savings afterwards, and they attribute this to the fact that these customers preferred additional comfort and warmth over money savings. Clearly then, in the worst cases it is possible that retrofitting interventions may neither reduce energy usage nor be sufficient to lift occupants out of fuel poverty, even though the interventions are effective.

UNDERSTANDING REAL BEHAVIOUR

It is also vital to ensure that there is a robust understanding of real practices, preferences and behaviours within the population. For example, the fact that improvements in energy efficiency have failed to result in expected energy savings has sometimes been attributed to assumed increases in internal demand temperatures over recent years. However, a repeated cross-sectional social survey of owners of centrally heated English houses found no evidence of change in reported thermostat settings between 1984 and 2007 (Shipworth, 2011). The lack of expected savings has instead been attributed to factors such as energy efficiency interventions failing to deliver expected performance, increased penetration of central heating (so that mean daily temperatures are increased but not maximum temperatures), increases in the dwelling area heated or the duration of heating, or changes in behaviours such as window opening.

POST OCCUPANCY EVALUATION

It is becoming increasingly common to assess the performance of larger commercial buildings and some others via Post Occupancy Evaluation (POE), which consists of a detailed study based on questionnaires, walk-through surveys, interviews and other techniques. This type of research focuses on the experience of the actual building user and can be an invaluable source of learning, provided the prevailing culture is tolerant of freely available information relating to failures as well as successes (Leaman, Stevenson and Bordass, 2010). POE may have an increasing role to play in the domestic sector also, either in new build or after significant retrofit interventions. It has the capability of generating rich data about the actual practices of building users, as well as the performance of technical interventions. It is vital that this growing knowledge is systematised and properly analysed if it is to be useful in informing retrofit strategic design in the future.

In commercial buildings it has long been assumed that thermal comfort is best provided by a neutral and unchanging environment. However, recent research strongly suggests that people prefer an environment that includes some variation, especially if they have a degree of personal control or at least opportunities for adaptive behaviours, such as additional clothing or access to windows and thermostats.

As well as deliberate behaviours based upon occupant preferences, practices arising from poor functioning or commissioning of services can also affect energy consumption. For example, in the Stamford Brook large-scale energy monitoring project (Sutton et. al. 2011), a particular dwelling was identified where the electricity consumption was well in excess of that expected, given a detailed understanding of the fabric and occupancy patterns (although still within the normal range for UK dwellings as a whole). Upon further investigation the problem was found to be caused by a commissioning failure. Incorrect installation of the heating system had resulted in all hot water being supplied by an immersion heater instead of the gas boiler, without the occupants being aware of this fact. Without the detailed knowledge of the monitoring team this error may not have come to light. Similarly, researchers at Leeds Metropolitan University have frequently observed MVHR systems that have passed commissioning checks but have not, in fact, been operating within parameters.

RECOMMENDATION: THAT THE CURRENT TREND TOWARDS REAL-WORLD SOCIO-TECHNICAL RESEARCH, INCLUDING RESEARCH INTO THE DRIVERS AND BARRIERS ASSOCIATED WITH BEHAVIOUR CHANGE, AND THE UNDERSTANDING OF REAL PRACTICES SHOULD CONTINUE TO BE WELL-SUPPORTED, AND SHOULD INFORM POLICY WHERE APPROPRIATE.

THEME 6: THE IMPORTANCE OF ICT AND MONITORING

ICT has a vital role to play in providing the tools needed to achieve the goals identified in the previous themes. ICT can support the collecting and organising of data, dissemination of knowledge, improvement of design processes, appropriate feedback and understanding of routes to durable behaviour change. Without ICT none of this activity would be possible on a sufficiently ambitious scale to meet proposed targets.

Because of the almost universal nature of its applicability, we confine ourselves in this report to highlighting a few illustrative examples of current ICT research, demonstrating how they feed in to the previous themes.

ICT AND THE DISSEMINATION OF KNOWLEDGE IN DESIGN AND CONSTRUCTION

In Theme 2 we discussed issues of understanding the thermal consequences of designs and the difficulties of learning efficiently from past experience. A large proportion of design and construction is undertaken by small organisations that may find it particularly difficult to access practical knowledge from intensive studies undertaken by larger and better resourced organisations. Even within larger organisations, communication of lessons learned may be poor, or may be hampered by significant outsourcing. Therefore there is a clear need for readily accessible information on 'what works and what doesn't work' and assistance with designing for improved thermal performance.

Similarly, as discussed in Theme 5, the lessons learned from POE studies are also often difficult to disseminate widely and effectively and ICT tools could help to facilitate dissemination of techniques and data.

De Montford University is currently undertaking research within the LESSONS project (Wright, n.d.) with the aim of establishing an accessible database of case studies on building performance, together with designer-centred tools which will enable rapid formulation and evaluation of proposed designs, including retrofit and new build. The success of this approach will depend very much on the open contribution of experience from research and practitioner organisations to inform best practice design and evaluation.

ICT AND BUILDING PERFORMANCE VISIBILITY

Theme 3 emphasised the importance of building performance, especially in terms of the building fabric. In the non-domestic sector building energy performance is characterised by the Energy Performance Certificate (EPC) and by the Display Energy Certificate (DEC), which has to be displayed in the building itself. However, access to the latter information is limited and often only visible to visitors to the building. Using ICT appropriately, there is no reason why this information should not be freely and openly available online, and consequently fully in the public domain. Indeed, this could go further, to include detailed monitoring data relating to real energy consumption. This approach would also help to identify areas where the EPC model might be failing to match the real performance.

ICT AND BEHAVIOUR

ICT need not be seen as a 'top-down' solution, precluding user engagement. It has the capacity to focus on energy users, both as individuals and as groups, providing valuable information on practices and preferences, and hence enabling acceptable and durable behaviour changes.

The factors that influence and entrench behaviour change are not yet well understood, but it is clear that feedback in appropriate user-responsive forms is a necessary pre-condition. The current EPSRC project 'Reduction of Energy Demand in Buildings through Optional Use of Wireless Behaviour Information (Wi-be) Systems' (Li Shao, 2010), explores the use of wireless systems for monitoring personal energy use and feeding back information in a form that is preferred by the user (e.g. to mobile phones or personal computers). The system is low cost and low power, and is applicable in principle to both workplace and domestic use, but does require both in-building and on-body sensors. There may be considerable scope here for acquiring a better understanding of the practices and motivations of different groups, with different initial attitudes to energy saving.

ICT AND MICRO-GENERATION

As the penetration of renewable energy sources increases, grid management and supply management issues become more and more important. ICT will be vital in tracking, monitoring and optimising micro-generation installations, and in identifying opportunities for demand management and the use of multiple systems to maximise local renewable energy use.

Again the users should be placed at the centre of technology development. An example of user-centred design is the Wattbox, developed at De Montfort University. This device learns behaviour patterns from users and controls multiple micro-generation devices based on this insight. By doing so, the ICT technology returns the control of novel, sometimes complicated and off putting technologies to users of all levels of technical competency. As a result, not only are energy efficiency and indoor comfort maximised, the acceptability and uptake of novel energy technologies are also greatly enhanced, thanks to user involvement in control.

RECOMMENDATIONS: THAT FURTHER RESEARCH SHOULD BE UNDERTAKEN WHICH EFFECTIVELY COMBINES INNOVATIVE ICT INTERVENTIONS WITH REAL ENERGY MONITORING AND SOCIAL INVESTIGATIONS IN ORDER TO INCREASE UNDERSTANDING OF THE TYPES OF BEHAVIOURAL ISSUES THAT CAN BE ADDRESSED USING ICT.

THAT ICT SHOULD ROUTINELY BE USED AS A TOOL FOR THE DISSEMINATION OF TECHNICAL AND DESIGN INFORMATION, FOR USE BY SMES AS WELL AS LARGER ORGANISATIONS.

THAT ICT FOR BUILDING ENERGY CONTROL SHOULD ADOPT A USER-CENTRIC APPROACH; AUTOMATIC CONTROLS SHOULD BE BASED ON USER BEHAVIOUR INFORMATION AND MANUAL CONTROLS SHOULD BE INFORMED BY SMART INFORMATION TECHNOLOGIES.

CONCLUSIONS

Retrofitting of existing buildings for improved energy performance will play a vital role in achieving the UK's carbon reduction targets, but the problem is complex and the route to optimum effectiveness is not yet clear.

Investment in research is required to ensure real and progressive savings. This research must be interdisciplinary in nature, bringing together technical, social and economic expertise.

Ways must be found of enabling fundamental changes to be made in the industry, including better training at all levels as well as improved dissemination of knowledge and best practice.

ICT can support and enhance the process of identifying and delivering necessary change in all areas, including user-centred learning.

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