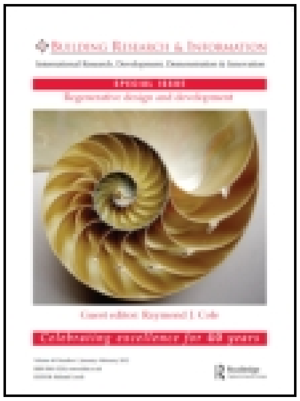

Building Research & Information
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rbri20

Retrofitting existing housing: how far, how much?

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Published online: 12 Jul 2013.

BRI Building Research & Information, 2013
Vol. 41, No. 5, 532–550, http://dx.doi.org/10.1080/09613218.2013.807064

Routledge
Taylor & Francis Group

RESEARCH PAPER

Retrofitting existing housing: how far, how much?

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The significance of retrofitting the existing housing stock is considered for the policy commitment of delivering an 80% CO_2 emission reduction by 2050. Background issues of energy, legislation, potential and actual CO_2 savings, socio-economics (payback, fuel poverty, health impacts, employment stimulus, etc.) are discussed. Different potential retrofit strategies for the housing stock are presented. Three large-scale housing retrofit programmes in Wales, UK, are analysed for energy savings (using the Energy and Environmental Prediction Model), CO_2 reduction and costs. Two 'whole house' retrofit projects in Wales are also assessed, one of which has been the subject of long-term monitoring. Data are compared on a range of retrofit options: different strategies (elemental, multiple and whole-house measures), costs, actual CO_2 reductions and associated benefits. The findings indicate that as the cost of measures rise in relation to the predicted savings, reasonable paybacks will be difficult to achieve, particularly for finance packages such as the 'Green Deal'. There are funding opportunities for installing 'shallow' elemental measures to reduce CO_2 emissions by 10–30%. However, the large-scale financing of 'deep' (60–80% reductions) whole-house packages of measures is not currently available and does not pay back.

Keywords: building stock, energy, housing, low carbon, public policy, refurbishment, retrofit

L'importance de la rénovation du parc de logements existants est examinée dans la perspective d'assurer l'engagement politique d'une réduction de 80 % des émissions de CO_2 d'ici 2050. Les questions contextuelles touchant à l'énergie, à la législation, aux économies de CO_2 potentielles et réelles, aux aspects socioéconomiques (retour sur investissement, pauvreté énergétique, incidences sur la santé, incitation à l'emploi, etc.) sont traitées. Différentes stratégies possibles de rénovation du parc de logements sont présentées. Trois programmes de rénovation à grande échelle de logements au Pays de Galles, Royaume-Uni, sont analysés en termes d'économies d'énergie (en utilisant le Modèle de prévision énergétique et environnementale), de réduction du CO_2 et de coûts. Deux projets de rénovation « complète » de logements au Pays de Galles sont également évalués, dont l'un a fait l'objet d'un suivi à long terme. Les données sont comparées en fonction d'un éventail d'options de rénovation : stratégies différentes (mesures élémentaires, multiples et concernant l'ensemble de la maison), coûts, réductions réelles de CO_2 et avantages connexes. Les résultats indiquent qu'au fur et à mesure que le coût des mesures augmente par rapport aux économies prévues, il devient difficile d'obtenir des retours sur investissement d'un niveau raisonnable, s'agissant en particulier de modalités de financement telles que le « Green Deal ». Il existe des possibilités de financement pour la mise en place de mesures élémentaires « légères » visant à réduire les émissions de CO_2 de 10–30 %. Cependant, le financement à grande échelle de trains de mesures « lourdes » concernant l'ensemble de la maison (réductions de 60–80 %) n'est pas actuellement disponible et ne permet pas le retour sur investissement.

Mots clés: parc bâti, énergie, logement, bas carbone, politique publique, réhabilitation, rénovation

Introduction

The topic of retrofitting existing houses to reduce energy demand and CO_2 emissions is currently attracting much attention in the UK. This paper first reviews the major issues associated with housing retrofit for reducing CO_2 emissions. These cover a range of aspects, associated not only with energy use, but also with the wider socio-economic factors that add to the context of housing retrofit. The paper then provides analyses of results from three large-scale retrofit case studies, carried out in Wales, UK, over a period of around 12 years, which involved the application of basic energy-efficiency measures. Also considered are two cases of building-scale retrofit, which are based on a 'whole house' approach, involving a broader range of low carbon measures. The main focus of the work described here relates to predicted reductions in CO_2 emissions and costs, taken from retrofit programmes. The Welsh government is particularly concerned with reducing CO_2 emissions in housing, with Wales having a relatively high number of older properties and a high incidence of fuel poverty. It has sustainability in its government constitution and is currently, for the first time, developing its own energy-related Building Regulations. Although the focus of the work is on Wales, the results are applicable to the UK and other countries where large-scale housing retrofit is of interest.

Energy use, CO_2 emissions and housing

The UK's CO_2 emissions associated with all energy use are 460 million tonnes (Office National Statistics (ONS), 2011). In 2008, the European Union Climate and Energy Package committed to transform Europe into a highly energy-efficient, low carbon economy, agreeing that greenhouse gas emissions would be cut by at least 20% of 1990 levels by 2020 (Commission of the European Communities Impact Assessment, 2008). In May 2010, the European Commission presented its analysis of options to move beyond 20% emission reductions and to explore options for moving towards a 30% reduction (European Commission, 2012). The UK government's Climate Change Act (HM Government, 2008) has a commitment to reduce CO_2 emissions by 80% by 2050 from 1990 levels with interim targets of 26% by 2020.

Around 50% of the UK's energy use and CO_2 emissions are associated with energy use in buildings, of which 28% is attributed to housing (Palmer & Cooper, 2011), and, as shown in Figure 1, some 61% of this is associated with space heating (Department of Energy and Climate Change (DECC), 2011a). A recent analysis of the UK's energy demand (DECC, 2012) has shown that energy for heating of buildings is considerably larger than their use of electrical power, typically up to five times during the heating season, indicating that this is an area where major energy and CO_2 emission reductions are needed. So, reducing space heating in existing houses has to be a priority in reaching CO_2 emission reduction targets.

It is important to differentiate between energy use and CO_2 emissions. Reducing the heat loss from a building, for example, through increased levels of thermal insulation, and providing more efficient heating systems can reduce energy use. CO_2 emissions, associated with burning fossil fuels, are also reduced through energy-saving measures, but further reductions can be made by fuel switching to a less carbon-intensive fuel, for example, from oil to gas, or using low or zero carbon energy supply systems, such as solar and biomass. A 'fabric first' approach is often favoured to reduce heat loss, before offsetting CO_2 emissions through the use of low carbon energy supply systems.

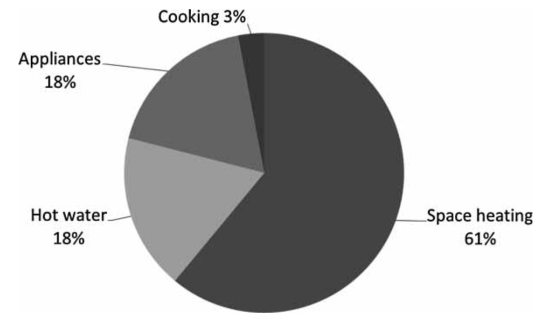

Figure 1 Percentage breakdown of household energy use
Source: Department of Energy and Climate Change (DECC) (2011c)

UK housing stock

There are now approximately 26 million homes in the UK (Utley & Shorrock, 2008, 2012), having grown from 18 million in 1976 to an expected 27 million by 2020, representing what is projected to be a 50% a growth in fewer than 50 years (Construction Products Association, 2010, p. 8). The current annual rate of new build is less than 0.5% per year at around 110 000 completions (HM Government, 2011) and the demolition rate is typically less than 0.1% (Boardman, 2006). Forecasts suggest that as much as 80% of the dwellings that will exist in 2050 have already been built (Wright, 2008). Therefore, the UK's target of 80% reduction in CO_2 emissions will not be achieved without a significant retrofit of existing houses.

The total number of dwellings in Wales is 1.31 million, with just over 60% of the housing stock constructed before 1959 (Housing and Neighbourhoods Monitor, n.d.), which, as shown in Figure 2, is older than other parts of the UK. Older houses can prove harder to treat, for example, due to their solid-wall construction. It is also worth noting that there are currently an estimated 22 000 voids or unoccupied houses in Wales (Welsh Government, 2012), most of which are in the private sector and in need of refurbishment. Therefore, with the rate of new build at around 0.5%, reusing and retrofitting voids would equate to about three years of new build, and would provide a sustainable approach

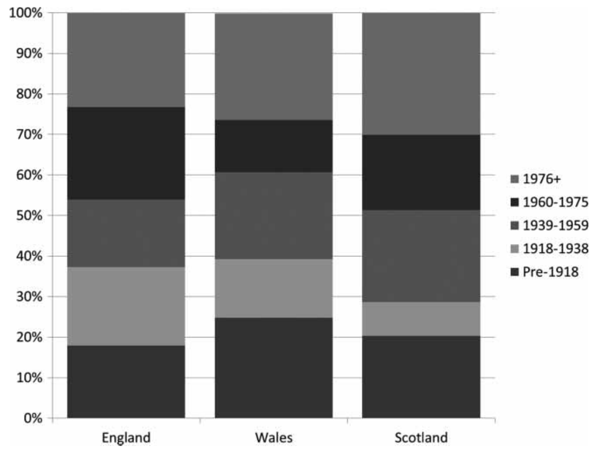

Figure 2 Distribution of housing stock by age in the UK, 2005

to delivering houses into the market with the potential for 'deep' CO_2 emission reductions.

Factors affecting energy use

Despite measures to improve the energy efficiency of dwellings, CO_2 emissions in the housing sector continue to rise. Over the last 40 years the overall household energy consumption has increased by about 12.5%. Heating is still the dominant energy use in housing; however, as illustrated in Figure 3, in recent years there is an indication of a reduction in heating energy demand but a considerable increase in electrical demand for lighting and appliances (DECC, 2011a). This reflects the significant increase in 'unregulated energy use' through the increasing number of electrical appliances in homes. Similar house types can have widely different levels of energy consumption, for example, due to the number and use of electrical appliances, varying number of inhabitants, patterns of use, comfort preference and temperature control. Improvements in heating energy efficiency over the last 40 years have been offset by increases in indoor air temperatures, by an average of 6 °C, with a shift to whole-house heating (DECC, 2012a). Home energy use is also significantly affected by external temperatures; for example, there was an annual 13% increase in domestic energy use resulting from the cold winter of 2010 (DECC, 2011c), followed by a 22% decrease in the relatively warmer winter of 2011. Older houses generally use more energy for heating as they are built to relatively lower thermal standards. They therefore have the potential for higher levels of energy saving and CO_2 emission reduction. For example, insulating a solid wall in an older property should yield greater energy savings than insulating a more modern cavity wall construction, although older properties are generally harder to treat.

Building Regulations and existing housing

Building Regulations have had an impact on energy-efficiency standards since the 1965, although until the mid-1970s the concern was to minimize condensation risk. All new buildings will be expected to be 'nearly zero energy' by 2020 (European Commission, 2010). The definition of 'near zero energy', although not yet fully established, relates to a low-energy consumption for heating (space and hot water), with the

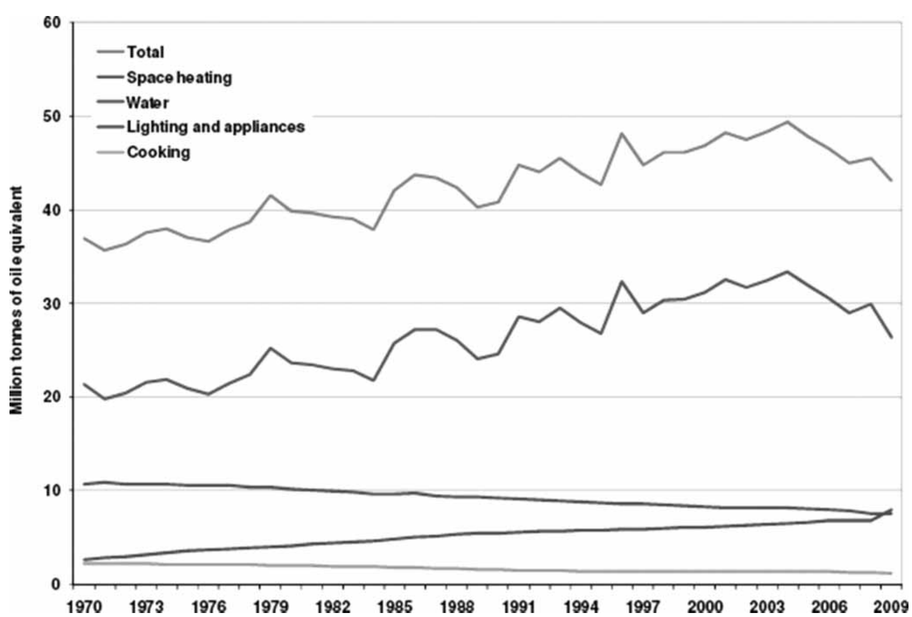

Figure 3 Domestic final energy consumption by end use in the UK, 1970–2009
Source: Department of Energy and Climate Change (DECC) (2011a)

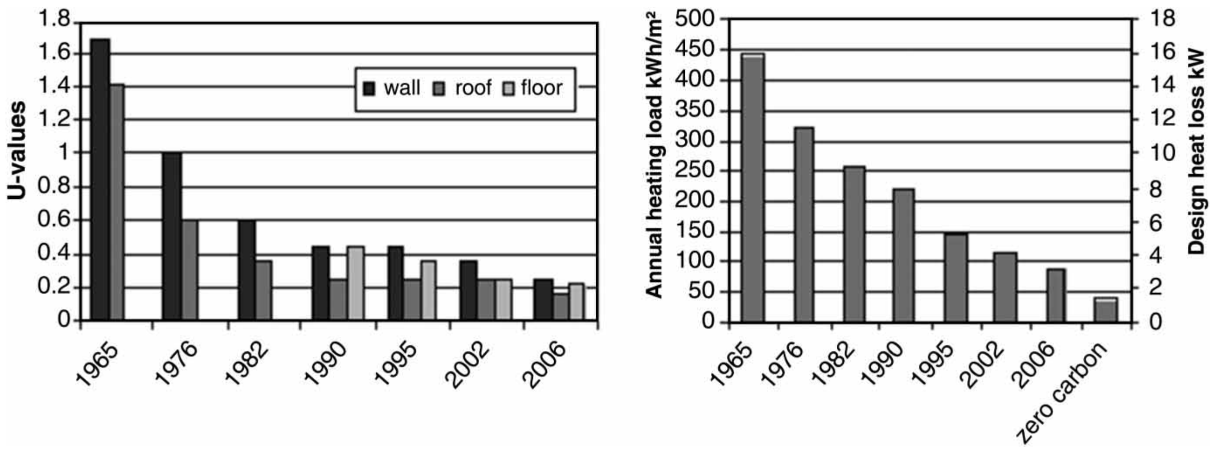

Figure 4 Improvement to *U*-values for walls, roof and floors since 1965, and reduction in average heating load and design heat loss
Source: Jones (2005)

majority of this consumption sourced from renewable energy supply. This renewable energy supply could be integrated into the building design or located nearby, provided specifically for the building in question. It does not include 'green' renewable energy from the grid, although in the UK so-called 'allowable' solutions may include this in future (Zero Carbon Hub, 2011).

For new housing, UK Building Regulations have focused on improving thermal insulation standards, reducing air leakage and selecting efficient heating systems. Figure 4 summarizes the improvement to *U*-values for walls, roof and floors since 1965 (Jones, 2005), with lower *U*-values indicating higher levels of thermal insulation. This has considerably reduced annual heating demand.

The refurbishment of existing housing is currently covered by the UK Building Regulations, in relation to extension work, and replacement of elements and controlled fittings and services (Approved Document L1B, 2010). This can yield considerable national energy savings, and in the revision of the UK Building Regulations in 2002, it was estimated that over 40% of the energy savings were predicted to come from improvements in the existing housing stock, mainly through boiler and window replacement (Office of the Deputy Prime Minister (ODPM), 2004). For buildings over 1000 m^2, 'consequential improvements' are required by the European Energy Performance of Buildings Directive (EPBD) (European Commission, 2002), *e.g.* if a building is to be extended, then a percentage of the total building costs should be allocated to improving overall energy efficiency. For non-domestic buildings, consequential improvements are implemented through the UK Building regulations (Approved Document L2B, 2010). Future regulations may require consequential improvements for existing housing.

Retrofitting existing buildings

It has been estimated that if the savings through insulation and heating efficiency improvements from 1970 onwards had not been made, then energy consumption in UK homes would be around twice the current levels (ONS, 2011). In general, measures have included loft insulation, double-glazing and more efficient boilers, measures that can be regarded as easy tasks (often colloquially referred to as 'low hanging fruit') and natural replacement. These are measures where occupants can generally see cost-effective real benefits, not only in greater energy efficiency, but also in increased thermal comfort.

The cost of retrofitting existing UK housing to meet the targeted 80% CO_2 reductions by 2050 is estimated to be between £200 billion and £400 billion (Sustainable Development Commission, 2010, p. 7). Although there is likely be some government-directed financial support, the majority of costs will likely fall on individual householders. The cost of applying measures can be high and they tend to increase exponentially as the 80% emission reduction target is approached. Measures can be implemented at an 'elemental' approach applying individual measures, such as cavity-wall insulation, or a 'whole house' approach, which integrates a number of measures tailored to the specific property. Figure 5 illustrates the potential trend in cost increase associated with going from relatively simple elemental 'shallow retrofit' measures to a multifaceted whole-house 'deep retrofit' approach. Some combinations of measures can give additional cost savings, *e.g.* increased insulation can reduce the size of the heating system required. However, multiple measures tend to follow the law of diminishing returns, where energy saving from a combination of measures is not necessarily the sum of savings from individual measures. As discussed below, most retrofitting programmes to date have

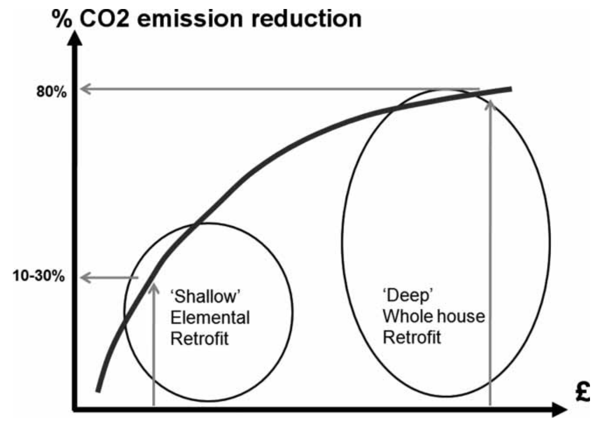

Figure 5 How the cost and complexity of refurbishment varies with percentage CO_2 emission reductions

been based on an elemental approach and a whole-house approach can prove costly and disruptive to the household.

Fuel poverty

Up to 25% of UK households, and an estimated 41% in Wales, live in fuel poverty (BBC News, 2011), where affordable warmth is probably of greater concern to them than global warming. Any wide-scale application of energy-efficiency measures should accept that some of the benefits will be realized as increased warmth and not just energy savings. It is estimated that this 'take back' through improved comfort may account for up 50% of the energy-saving measures, estimated from relatively shallow retrofitting energy savings of around 12% (Lomas, 2010). Substandard housing, which is often hard to heat, is already estimated to cost the National Health Service (NHS) £2.5 billion a year through building-associated health-related issues (National Housing Federation/ECOTEC, 2010). The built environment has a considerable impact on health and quality of life, with housing impacting on major health issues such as cardiovascular disease, accidents and mental health (Jones, Patterson, & Lannon, 2007). Energy savings and CO_2 emission reductions should therefore not be seen as the sole benefit from improving home energy efficiency.

Funding opportunities

Recent initiatives in the UK have made some inroads to improving the existing housing stock, *e.g.* the Energy Efficiency Commitment (EEC), Carbon Emission Reduction Target (CERT) and Community Energy Savings Programme (CESP) schemes require energy supply companies to meet targets to reduce the amount of CO_2 emissions from households. Programmes involving these schemes have resourced the installation of over 5 million energy-saving measures in existing houses between 2008 and 2011 (DECC, 2011b). In Wales, the ARBED regeneration programme (Welsh Government, 2013) has provided finance for local authorities and registered social landlords (RSLs) to upgrade the energy performance of their existing housing stock. Although the impact of such programmes has served to some extent to 'kick start' the industry; whether this has been enough to provide a stable industry that can reduce its future costs and provide quality remains to be seen. The forthcoming 'Green Deal' (DECC, 2010), and the expected transfer of CERT and CESP funding to the new Energy Company Obligation (ECO) scheme, and possible future developments in Building Regulations to include more attention to existing buildings, will play a major role in reducing the future carbon footprint of the existing UK housing stock. The 'Golden Rule' associated with the Green Deal requires that the expected financial savings from reduced energy use must be equal to or greater than the cost of carrying out the measures, the cost of which will be attached to the household energy bill. However, it has been recognized that the predicted savings are not always achieved in practice. A set of 'in use' factors has been produced by the UK government in relation to 'Green Deal' calculations, *e.g.* applying a performance reduction of 15% for double-glazing, and 33% and 35% for external solid-wall insulation and cavity-wall insulation, respectively (DECC, 2012b).

Benefits of energy efficiency retrofit

In summary, the benefits of energy-efficiency retrofit for existing buildings are attractive. They reduce CO_2 emissions and increase home comfort. But costs, and to some extent the uncertainty of outcomes from installing energy-saving measures, together with disruption factors, can be a major barrier to wide-scale take-up by existing householders. The following sections present results from large- and small-scale retrofit programmes, which will inform this debate.

Large-scale retrofit projects

Three retrofit studies are presented here that were carried out in Wales over the past 12 years:

- The first study formed part of a research programme to develop the Energy and Environmental Prediction (EEP) model, and was carried out between 1998 and 2002 – funded by the UK Engineering and Physical Sciences Research Council (EPSRC) and Medical Research Council (MRC). The study demonstrated how the EEP model could be used to assess energy-saving retrofitting measures for the housing stock in Neath Port Talbot, South Wales.

- The second study analysed the potential energy savings and costs associated with a large-scale retrofit programme. The programme was carried out by the community interest company Warm Wales Ltd in Neath Port Talbot, and it took place from 2004 to 2007.

- The third study analysed the potential energy savings and costs associated the recent 12-month 'ARBED' regeneration programme, involving the retrofit of housing across Wales, between 2010 and 2011.

Retrofit of existing housing using the Energy and Environmental Prediction (EEP) model

This study presents an analysis of the energy consumption and CO_2 emissions for housing in Neath Port Talbot. An important factor, in relation to reducing CO_2 emissions for existing housing, is the ability to predict at a large-scale the impact of retrofitting with energy-saving measures. Of particular concern is identifying the most appropriate package of measures to be applied to specific house types, what is their cost, and what are the energy savings and CO_2 emission reductions associated with them. In order to assess the impact of upgrading the performance of existing housing, an Energy and Environmental Prediction (EEP) model was developed by the Welsh School of Architecture (Jones, Williams, & Lannon, 2000). The EEP model was used in Neath Port Talbot as a test-bed for its application. EEP is based around a 'geographical information system' (GIS), which contains information on all the housing within a local authority area. It uses an embedded sub-model for predicting domestic energy use, based on the UK Standard Assessment Procedure (SAP) tool (SAP, 2005). SAP is the UK government's approved method for assessing a building's energy performance, providing a score between 1 and 100 relating to energy performance, with the higher number indicating a dwelling with lower energy running costs. EEP uses the SAP approach to estimate the house energy performance and CO_2 emissions, and to assess the impact of carrying out energy-conservation measures. Figure 6 shows an example of EEP output in the form of a 'before and

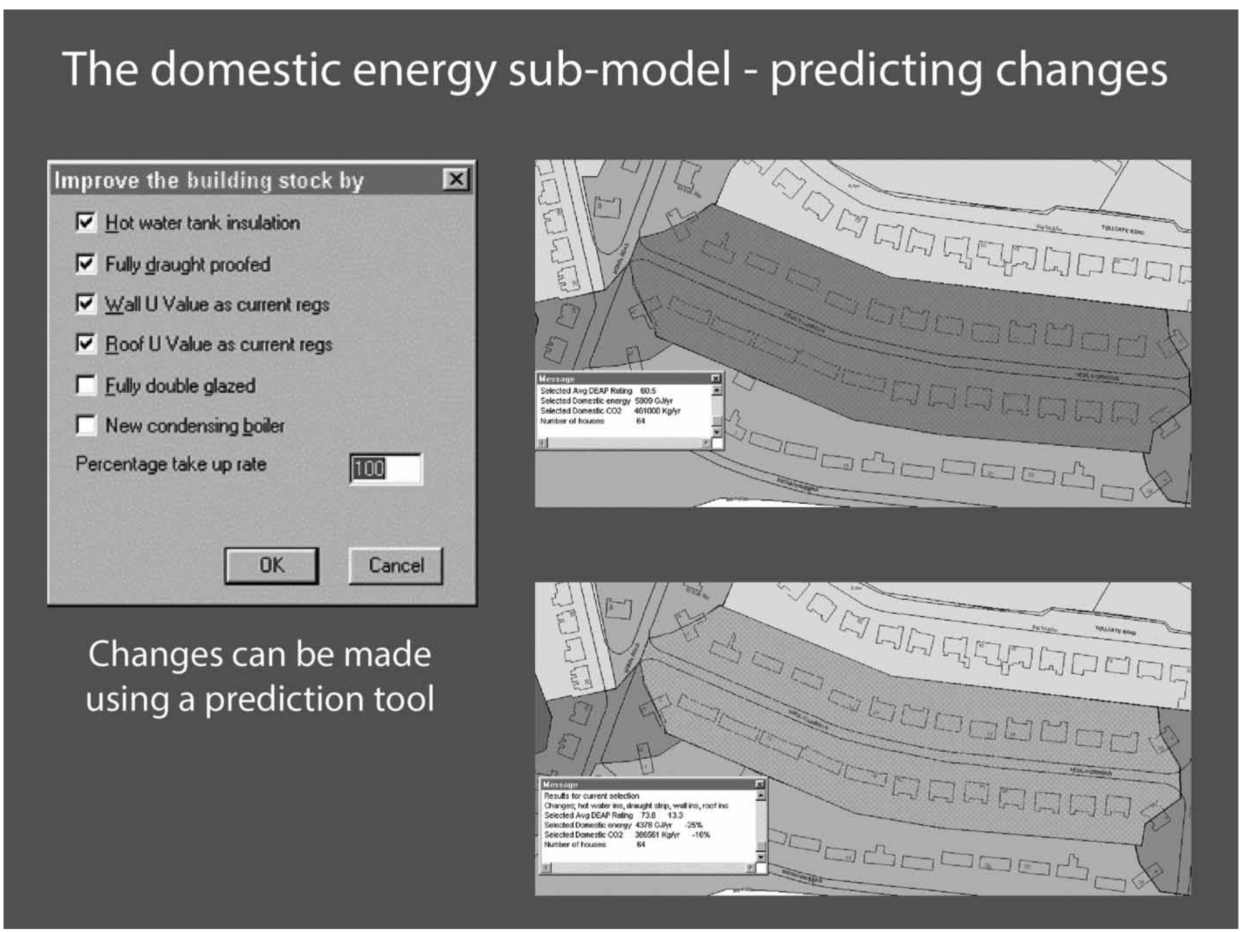

Figure 6 Output of the Energy and Environmental Prediction (EEP) model as a thematic map indicated energy demand at 'postcode' level for before (top) and after (bottom) energy demand condition, and the menu for applying energy conservation measures

after' thematic map of annual energy use and CO_2 emissions at postcode level (taken from a larger sample of all the housing in the local authority). It identifies a postcode that has a relatively high level of energy use (a relatively darker shade in the upper thematic map). A combination of energy-saving measures was selected from a standard menu and the energy and CO_2 emission reductions predicted (now a relatively lighter shade in the lower thematic map). EEP also has sub-models to predict non-domestic energy use, traffic flow and health impacts, and has also been used to relate health impacts to housing (Jones *et al.*, 2000).

In 2002, EEP was used to assess the potential for wide-scale energy savings for housing in Neath Port Talbot in relation to space heating and domestic hot water (Jones & Lannon, 2007). The EEP model included data for around 55 000 houses, of which 9852 were local authority properties. The houses were surveyed over the period 1999–2001. Based on their main design features in relation to built form and age, the properties were allocated to specific groups, such that the 55 000 houses were represented by standard house types. In general, for local authorities fewer than 100 standard house types for the purpose of annual energy use analysis can represent the majority of its housing stock. These standard house types were then tested against a range of energy-saving measures using the SAP tool, as illustrated in the menu in Figure 6. The distribution of the SAP ratings for local authority properties is shown in Figure 7a, in comparison with private sector housing in the area. The average SAP rating for local authority housing was estimated to be 46.9, from a minimum of 28.2 to a maximum of 70.6. The EEP model was used to simulate various energy-saving interventions for the local authority properties. Figure 7a presents the situation before any measures were applied. Figure 7b presents the distribution of the SAP ratings if the Welsh Housing Quality Standard (WHQS) improvements, described in Table 1, were undertaken. The WHQS provides guidance for local authorities on the assessment process using the SAP method, setting minimum SAP targets for each property based upon floor area, ranging from 58 for small dwellings (35 m^2) to 70 for larger dwellings (120 m^2). For an appropriate package of measures applied to each house type, the average SAP rating for the local authority properties was 68.9, from a minimum of 57.1 to a maximum of 80.1. If a 'blanket' approach was applied installing the Home Energy Efficiency Scheme (HEES) measures to all local authority properties (Figure 7c), the average rating would rise to 74.7, from a minimum of 57.1 to a maximum 93.1. The SAP ratings in Figure 7b used the data shown in table 1 to identify the most cost-efficient combination of measures to bring properties up to the required WHQS SAP standard. The application of improved

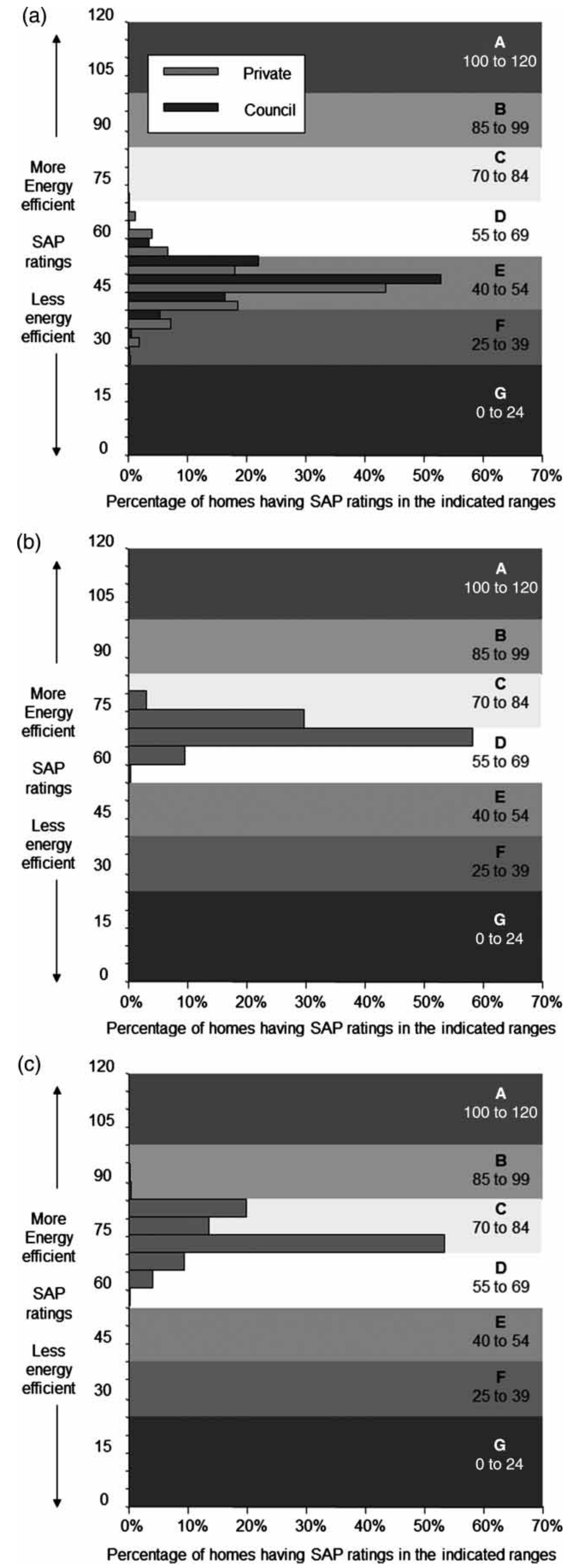

Figure 7 Distribution of Standard Assessment Procedure (SAP) values for (a) council and private sector housing, (b) council housing at Welsh Housing Quality Standard (WHQS) standard, and (c) Home Energy Efficiency Scheme (HEES) standard

Table 1 Energy-efficiency measures and costs to achieve the Welsh Housing Quality Standard (WHQS) standard

Energy-efficiency measure	Number of properties	Percentage of properties	Measure cost (£)	Total cost (£)
Cavity-wall insulation installation	253	2.6	240	60 720
Non-cavity-wall insulation installation	14	0.1	4000	56 000
Loft insulation, double-glazing and draught-proofing	20	0.2	3215	64 300
Double-glazing and draught-proofing	2	0.0	3075	6150
New boiler	898	9.1	2000	1 796 000
New boiler and loft insulation	407	4.1	2140	870 980
New boiler and cavity-wall insulation	6665	67.6	2240	14 929 600
New boiler and non-cavity-wall insulation improvements	392	4.0	6000	2 352 000
All measures (cavity wall)	875	8.9	5755	5 035 625
All measures (non-cavity wall)	22	0.2	9515	209 330
Unable to reach the standard	304	3.1	2755	837 520
Standard achieved	1	0.0	0	0
Total	9853			26 218 225

Source: Home Energy Conservation ACT report to the Neath Port Talbot County Borough Council (NPTCBC) for the Home Energy Efficiency Scheme (HEES) grant scheme over the period 1 April 2000 to 31 March 2001.

wall insulation was predicted to raise 267 properties to the standard. The vast majority of houses, some 6665, would meet the standard with an improvement in cavity-wall insulation levels and a new boiler; 392 of these would require solid-wall insulation; with the remainder requiring cavity-wall insulation. Some 897 properties would require a complete set of measures (*i.e.* cavity-wall but not solid-wall insulation, loft insulation, double-glazing, and a new boiler) to meet the standard. The survey accounted for measures already installed from local authority HEES data. The total cost of such a programme was estimated to be around £26 million. However, if the complete set of measures were applied to all properties (corresponding to Figure 7c), the costs would rise to an estimated £53 million. So taking the SAP rating from 46.9 to 68.9, and meeting WHQS standards, would be roughly half the cost of taking it from 46.9 to 74.7, by applying blanket non-selective measures.

If the local authority were to improve its domestic sector's energy efficiency to the WHQS standard, according to the EEP/SAP analysis, there would be an estimated reduction in energy use of 34% or 390 306 GJ/year and the CO_2 emissions would drop by 29% or 22 800 tonnes per year. So, for an estimated average cost of £2653 per property, emission reductions of 29% could be achieved. Figure 8 presents the costs versus emission reductions for different dwelling age. The range of savings for similar cost of measures in Figure 8 reflects the different house types, and around 90 house types were used to describe the sample. The relative high-cost packages reflect the use of solid-wall insulation, of which there were relatively few (Table 1). In general, older properties achieve higher reductions per unit cost, although in some cases they may be harder to treat, *e.g.* those requiring external wall insulation (EWI). Also, the low to mid-cost items such as loft top-up insulation and double-glazing are relatively low in savings, although they potentially increase household comfort levels. The study demonstrates the importance of selecting the most appropriate package of measures for specific house types to achieve maximum savings in relation to costs.

Large-scale retrofit programme in Neath Port Talbot

A large programme of energy-efficiency retrofitting of existing housing was carried out in Neath Port Talbot between 2004 and 2007. The programme was carried out by Warm Wales Ltd, a 'not for profit' community-interest company that delivers home energy-saving measures, particularly targeting the poorer sectors of the community, and in many cases providing help for those who would otherwise not be eligible for financial support. A report on the programme was carried out for Warm Wales (Patterson, 2008). The programme specifically targeted households that were in fuel poverty, as defined by when more than 10% of their income is spent on energy, although the scheme was available to all households regardless of tenure. The main funding was obtained through the utility company National Grid under the terms of the Energy

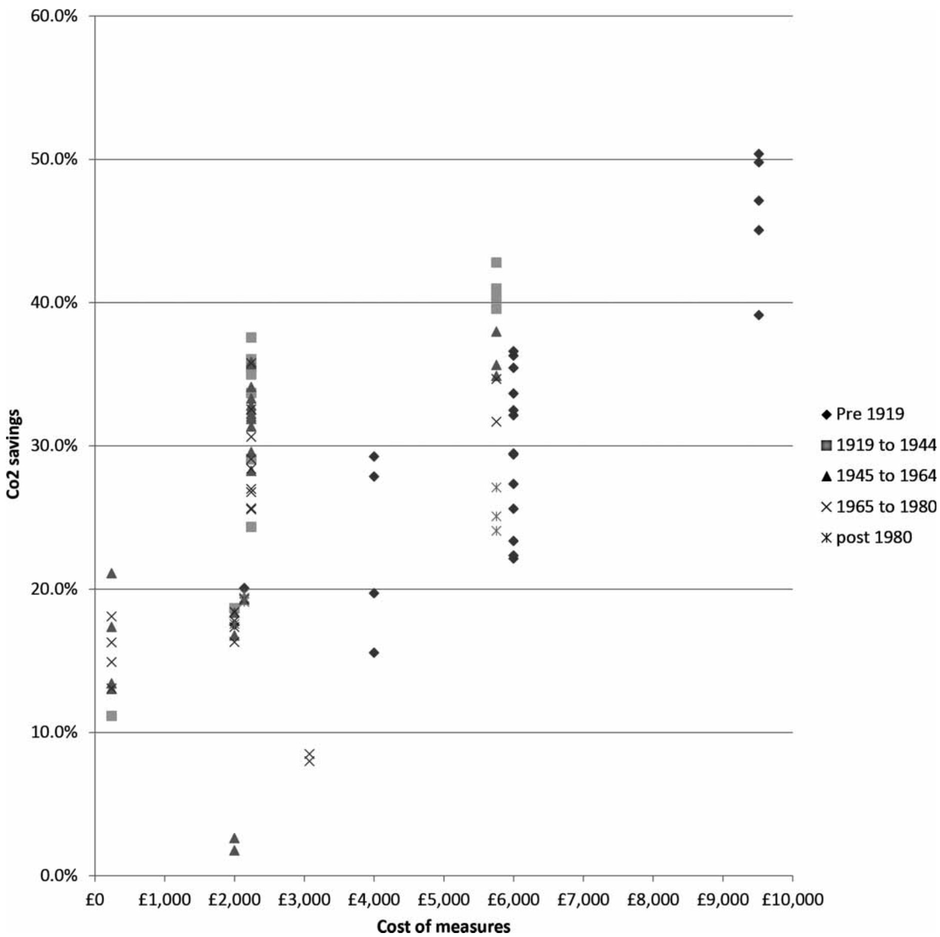

Figure 8 Percentage CO_2 emission reductions versus cost, using the Energy and Environment Prediction (EEP) model

Efficiency Commitment (EEC), where electricity and gas suppliers were obligated by government to achieve targets for the promotion of improvements in domestic energy efficiency. Other funding sources included the local authority. All householders participating in the scheme were also eligible to request free benefits advice, relating to government financial support, and where new or additional benefits were identified for the qualifying households they were offered a home visit and help with the application process.

The total dwelling stock in the local authority in 2004 was 61 698 households. The Warm Wales programme of work included the installation of cavity-wall insulation, EWI, loft insulation (and loft 'top-ups') and hot water cylinder insulation jackets. It also included a replacement boiler or full central heating system if the programme identified owner occupied householders who were in need of a new boiler or central heating system but did not qualify under the HEES Wales. Extensions to the gas supply network were provided in several areas of the borough where the lack of access to mains gas contributed to high instances of fuel poverty.

A total of 49 831 households were assessed and 28 799 energy-efficiency measures installed to 18 832 properties. A total of £10.3 million was invested in the scheme, of which just over £8 million went to energy-saving measures; the remaining £2.3 million was used to fund new gas supplies. Table 2 summarizes the details of the breakdown of measures installed with costs and estimated savings. The majority of measures were loft insulation and cavity-wall insulation, with the largest benefits arising from installing new heating systems, especially in the older properties. Figure 9 summarizes the costs versus predicted CO_2 emission reductions for different ages of property. As with the previous study, older properties have the potential to achieve greater savings in relation to cost of measures. The total energy savings arising from the programme were estimated using the EEP model, and the actual costs of the programme were provided from Warm Wales. An estimated 28 799 tonnes of CO_2 emissions were saved, with the average savings per house being 9.2%. This saving may be considered relatively low; however, many of the measures were low cost, with the average cost across the sample being just £450.

Table 2 Summary of measures carried out (house type)

Energy-efficiency measure	Number of properties	Percentage of properties	Average saving (%)	Measure cost (£)	Total cost (£)
Cavity wall insulation	3946	21.4	13.5	330	1 301 308
Hot water tank jacket and cavity wall insulation	72	0.4	13.4	344	24 799
Loft insulation	6447	35.0	1.0	228	1 470 307
Hot water tank jacket and loft insulation	945	5.1	0.9	243	229 363
Cavity wall insulation and loft insulation	5400	29.3	14.7	558	3 012 335
Hot water tank jacket, cavity wall insulation and loft insulation	893	4.8	14.8	572	511 235
Heating system	166	0.9	15.7	2224	369 248
Cavity wall insulation and heating system	73	0.4	25.1	2554	186 454
Hot water tank jacket, cavity wall insulation and heating system	3	0.0	24.7	2569	7 706
Loft insulation and heating system	223	1.2	16.5	2452	546 896
Hot water tank jacket, loft insulation and heating system	32	0.2	16.3	2467	78 947
Cavity wall insulation, loft insulation and heating system	172	0.9	26.1	2782	478 543
Hot water tank jacket, cavity wall insulation, loft insulation and heating system	34	0.2	26.8	2797	95 094
Total	18 428				8 312 235

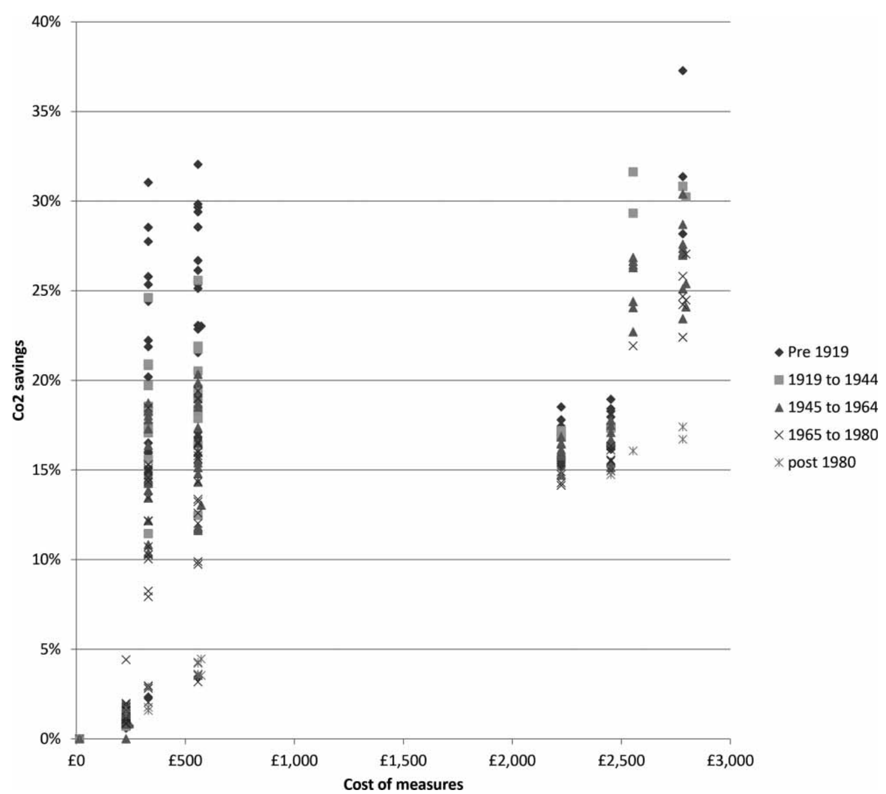

Figure 9 Percentage CO_2 emission reductions versus costs for Neath Port Talbot

The approach was mainly targeted at 'easy to treat' elemental measures rather than a whole building approach. There were a number of additional positive outcomes from the programme, with some 2305 households removed from fuel poverty. There were also other benefits, which are summarized in Table 3. The greatest perceived benefit was increased comfort and warmth, so it is likely that the measures resulted in some level of 'take back' through improved comfort and this may detract from the estimated 9.2% CO_2 emission reduction stated above. Other reported benefits included reduced fuel bills and improved well-being. The programme created 54 new jobs, and 127 workers received training. The programme also involved providing benefit advice to householders, which resulted in an extra £2.1 million per year being injected into the local economy. This demonstrates the importance of including other socio-economic activities within such large-scale retrofit programmes making use of the opportunities provided through large-scale interventions.

Welsh Housing Retrofit programme: ARBED

ARBED is a regeneration programme developed by the Welsh government to target improving the energy performance of housing in Wales, particularly the most energy-inefficient homes, and to reduce the impact of fuel poverty on households in Wales. It also aimed to generate employment opportunities for Welsh residents and economic opportunities for Welsh businesses. The ARBED scheme was initially set up to take a 'whole house' approach to install energy-efficiency measures and building integrated renewable energy supply systems across Wales. Around £60 million of funding was invested in ARBED from a range of sources, including the Welsh government, CERT and CESP, and direct funding from RSLs and local authorities whose housing schemes were retrofitted. Twenty-eight projects took place across Wales with work on site starting in April 2010 and continuing for 12 months. More than 6000 homes were included in the ARBED scheme in total.

Warm Wales was commissioned by seven separate RSLs and local authorities located across South and West Wales to implement their ARBED projects. The total number of properties included within the Warm Wales programme was 1147. A total of 40% of properties were built before 1919, therefore having solid wall construction; 25% of the properties were built between 1919 and 1964; 18% from 1965 to 1980; and 18% after 1980. A total of almost £7.5 million was invested in the Warm Wales programme. The measures implemented included: EWI, solar photovoltaic panels (PV), solar thermal and fuel switching. A total of 905 properties received one measure, 240 received two measures and two received three measures. Although the ARBED scheme initially aimed to take a whole-house approach, the projects within the Warm Wales programme took more of an elemental approach, improving many properties with fewer measures (Table 4), with the dominant measure being EWI. A total of 502 properties received fuel switching

Table 3 Summary of benefits from the programme

Statement	Loft Insulation (*n*=51) (%)	Cavity-wall Insulation (*n*=40) (%)	New heating system (*n*=9) (%)
My house feels warmer since the measures were installed	72.3	84.6	66.7
My house feels drier since the measures were installed	41.3	50.0	55.6
My house feels more comfortable during the winter since the measures were installed	63.8	76.9	66.7
My house feels more comfortable during the summer since the measures were installed	44.6	51.3	55.5
I use more rooms in the house since the measures were installed	20.0	21.1	25.0
The quality of air in my house has worsened since the measures were installed	10.9	7.7	12.5
I use the heating more often since the measures were installed	19.6	18.9	33.3
I heat more rooms since the measures were installed	14.9	18.0	11.1
I feel that my heating bills are more affordable now since the measures were installed.	32.0	41.0	33.3
I feel better since the measures were installed	27.7	30.8	33.3
I feel healthier since the measures were installed	19.2	23.1	33.3

Table 4 Summary of measures undertaken

Energy-efficiency measure	Number of properties	Percentage of properties	Average Saving (%)	Measure cost (£)	Total cost (£)
pre 1919 semi solar thermal	2	0.3	6.0	4 393	8 786
pre 1919 semi solar PV	6	0.9	11.0	4 988	29 928
pre 1919 semi EWI	69	10.7	25.0	7 730	533 370
pre 1919 semi EWI and solar thermal	4	0.6	31.0	12 123	48 492
pre 1919 semi EWI and solar PV	22	3.4	36.0	12 718	279 796
pre 1919 semi EWI, solar PV and solar thermal	1	0.2	42.0	17 111	17 111
pre 1919 mid terrace EWI and solar PV	62	9.6	41.0	12 718	788 516
pre 1919 mid terrace solar thermal	2	0.3	5.0	4 393	8 786
pre 1919 mid terrace solar PV	23	3.6	11.0	4 988	114 724
pre 1919 mid terrace EWI	190	29.5	30.0	7 730	1 468 700
pre 1919 mid terrace EWI and solar thermal	10	1.6	35.0	12 123	121 230
1945-1964 semi solar thermal	10	1.6	8.0	4 400	44 000
1945-1964 semi solar PV	40	6.2	12.0	5 000	200 000
1945-1964 semi EWI	22	3.4	24.0	7 730	170 060
1945-1964 semi Solar thermal and solar PV	7	1.1	20.0	9 380	65 660
1945-1964 semi EWI and solar PV	2	0.3	36.0	12 718	25 436
1965-1980 semi EWI	33	5.1	14.0	7 730	255 090
1965-1980 semi solar PV	31	4.8	14.0	4 988	154 628
1965-1980 mid ter EWI	4	0.6	15.0	7 730	30 920
1965-1980 mid ter solar PV	4	0.6	14.0	4 988	19 952
1980 semi EWI	14	2.2	4.0	7 730	108 220
1980 semi solar PV	87	13.5	22.0	4 988	433 956
Total	645				4 927 361

(not included in Table 4), mainly from electric to gas. This provided about 55% energy savings for an average cost of just over £3000. For the 645 houses that did not involve fuel switching, their total cost of measures was £4 927 361, giving an average cost of measures per property of £7639. The average CO_2 saving was calculated by the EEP model as 24.7%. If only the heating-related measures are considered, *i.e.* EWI and solar thermal, the average cost would be £7771 and the average savings 25.3%.

The relation between the cost of measures and percentage reductions in CO_2 emissions for different age groups is shown in Figure 10, which does not include fuel switching. Figure 11 summarizes the cost per measure and average CO_2 emission reductions. Fuel switching (based on Economy 7 being the original fuel source) provides the most cost-effective savings, achieving about 50–60% emission reductions per year.

One of the key training opportunities provided through the scheme was the recruitment of 15 community energy wardens who worked with Warm Wales and the main contractor to support community engagement, installation of measures and a basic aftercare service to residents.

Whole-house approach: retrofit of individual houses

The government has a target for reducing CO_2 emissions from existing housing by 80% for over 1 million houses adopting a ‘whole house’ approach (Technology Strategy Board (TSB), 2009). There are currently a number of ‘whole house’ retrofit demonstration projects in the UK. The TSB government-funded ‘Retrofit for the Future’ programme has funded 86 whole-house schemes and aims to achieve 80% reductions in CO_2 emissions. There have also

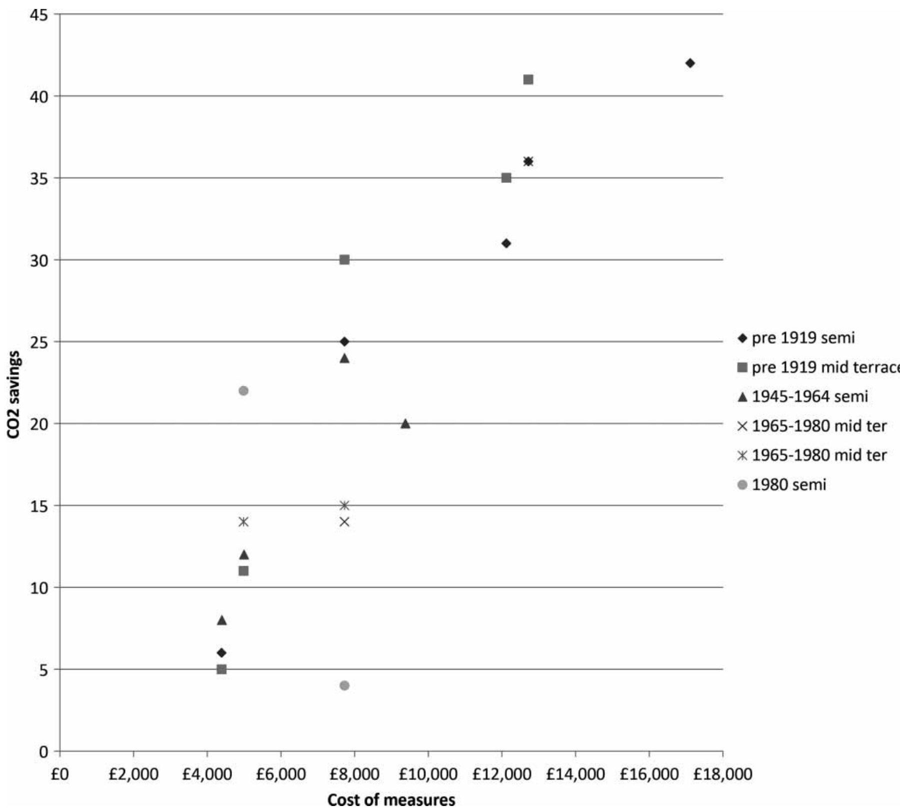

Figure 10 Percentage CO_2 emission reductions versus costs (ARBED)

been local schemes, such as the 'Target 2050' programme by Stroud District Council, where the retrofitting of ten houses was estimated to provide an average 58% reduction in CO_2 emissions for an average investment of £22 902 (Stroud District Council, 2011). Such schemes may currently be considered relatively high cost, but are essential to achieve an understanding of how to tackle the problem of existing building retrofit and eventually to reduce costs. Two Welsh whole house examples are presented below, one funded under the TSB programme and the other funded by a local authority.

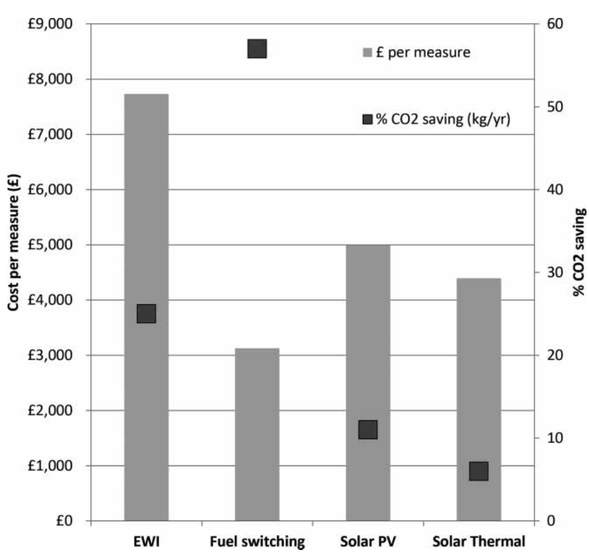

Figure 11 Comparison of CO_2 savings and pounds sterling per measure

End of terrace retrofit house: Turnstiles, Newport

The Turnstiles low carbon retrofit project, led by the Welsh School of Architecture, is located in Newport, Wales (Figure 12). The energy saving and CO_2 offset measures are listed in Table 5. The cost of the measures, together with spatial improvements to the property, including the cost of a small extension to the living space, was around £70 000. The property was occupied throughout the retrofit programme. The predicted reduction in CO_2 emissions was 83%, from the pre-retrofit 103 kg/m^2 per annum to a post-retrofit 17 kg/m^2 per annum. The initial monitoring of energy performance (undertaken by the Welsh School of Architecture) over the 2011–2012 heating season indicated that the measured CO_2 emission reductions were 74%. The initial breakdown of energy consumption is presented in Figure 13, which shows that the heating energy use is now only 43% of overall energy use, compared with the national average of some 61% (Figure 1). In order to evaluate

Figure 12 Low carbon retrofit project in Newport, Wales

Table 5 Measures applied to the Newport house

Dry lining insulation on internal walls: U-value = 0.19
Roof insulation: U-value = 0.19
Triple-glazed non-polyvinylchloride (PVC) windows: U-value = 0.90
Improved air tightness to 2 $m^2/(m^2h)$
Mechanical ventilation heat recovery (MVHR) ventilation system
Time and temperature zone controls
Ground-source heat pump
Solar thermal evacuated tube collectors (2.88 m^2)
2 kWp photovoltaic (PV) panels
Extended living spaces in roof and external annex

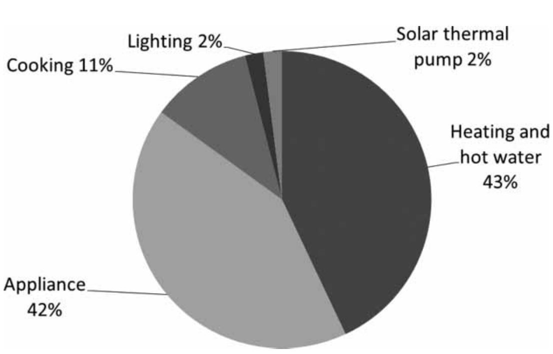

Figure 13 Post-retrofit annual breakdown of energy consumption

the real benefits of the retrofit measures, the house will be monitored for two years to conclude its performance against predicted targets. This demonstration project, and others like it, provides much needed information, not only on the performance of low carbon technologies, but also on issues associated with carrying out refurbishment and costs.

Penrhiwceiber

A second example of retrofitting existing houses in Wales has been led by the Building Research Establishment (BRE Wales) in Penrhiwceiber (Figure 14). This has involved the refurbishment of a terrace of five houses. Pre-works, the annual fuel bills ranged from £1000 to £1500 per annum and most of the residents were in fuel poverty. The dwellings were considered ‘hard to treat’ due to their solid stonewall construction, and in this case internal wall insulation was applied. A list of the measures undertaken is presented in Table 6. The project was predicted to achieve 60% reductions in CO_2 emissions for a cost of some £25 000, which included the complete refurbishment of the interior of the houses to a high standard.

Both the above examples demonstrate the benefits of combining whole-house retrofitting with improving the general aspects of the building to provide overall improvements to quality of life. However, costs are relatively high, from £25 000 for potentially 60% CO_2 emission reductions to £70 000 for approaching 80% reductions. As the first case study indicates the potential emission reductions in practice approach

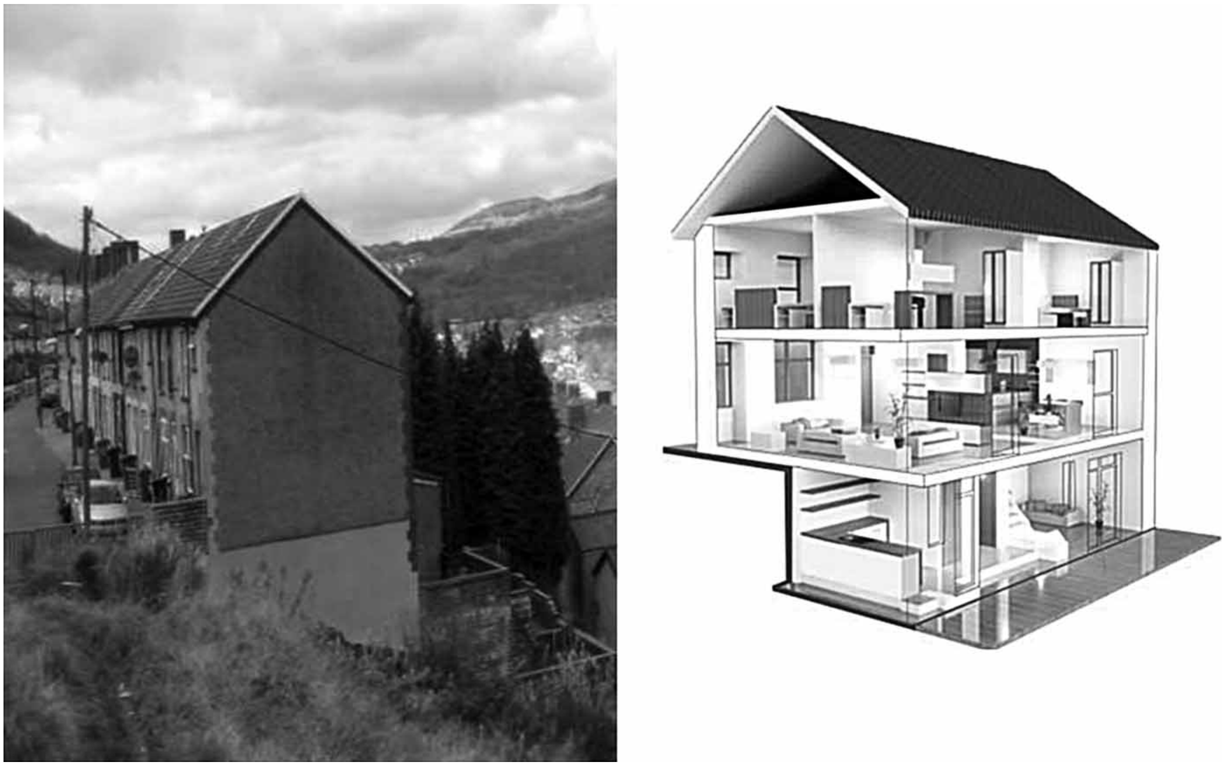

Figure 14 Low carbon retrofit project in Penrhiwceiber, Wales

Table 6 Measures applied to the Penrhiwceiber houses

New windows and doors: *U*-value = 1.2
Internal solid wall front and back insulation: *U*-value of walls reduced from 2.1 to 0.28
(30 mm of polyurethane)
Floor insulation: *U*-value = 0.23
Warm roof: *U*-value = 0.20
Increased air tightness: 5 $m^3/h/m^2$
New 90% efficient boiler
4 m^2 solar thermal hot water heating

the design predictions (74% compared with 83%), so any 'take back' in terms of improved comfort may have less of an impact on emission reductions for whole-house retrofit compared with an elemental approach. However, this is a single building case study and the results should be interpreted within this context.

Discussion of programme costs and CO_2 savings

From the above programmes, the cost versus CO_2 emission reductions are summarized in Figure 15, corrected for inflation over the period. They include results from the large-scale programmes, and the whole-house projects (including the results from the Stroud programme). The results might be considered in three groups:

- elemental 'shallow' retrofits, costing up to around £6000 (and in many cases much less) and producing potential CO_2 emission reductions in the range of 10–30%
- multiple measures, costing £8000–14 000 producing emission reductions up to 40%, usually combining EWI with improved energy systems
- whole-house measures with CO_2 emission reductions of up to 80%, but at higher costs of up to £70 000

Therefore, significant improvements are achievable at lower costs, but for savings above 30–40%, the costs rise steeply, although major cost increases seem to take effect beyond 60% emission reductions.

The results from the three large-scale retrofit programmes are summarized in Table 7. There is a large difference in the cost of measures between the first and third study for a similar percentage energy saving. This is largely due to the dominance of EWI in the third study. A simple analysis of repayment on

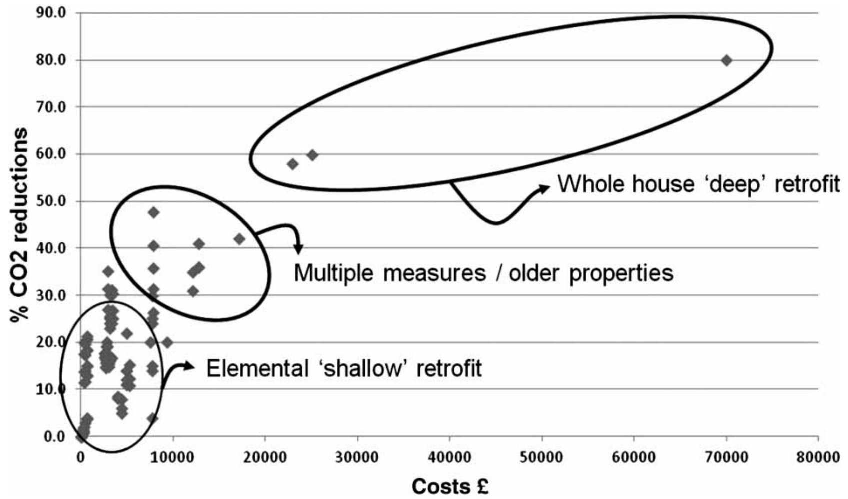

Figure 15 Summary of costs versus savings for all programmes. The date points are from Figures 8–10 and the two whole-house Welsh case studies. Data for the average Stroud results are also included. The costs are adjusted for inflation in relation to the data from Figures 8 and 9

a 'Green Deal'-type loan together with savings is presented in Figure 16. This presents the repayment costs for the three average costs of measures from Table 7 (adjusted for inflation) based on 0% and 7% interest over 10 and 20 years, and assumes an annual energy price increase of 5%. (Five per cent is a fairly arbitrary number chosen for illustrative purposes. It is roughly equivalent to a 50% increase over ten years, which follows some predictions. Alternatively, gas prices could fall dramatically with new supply scenarios.) In the third study, only the heating-related measures are used in the analysis. The general indication is that as the cost of measures rise in relation to predicted savings (partly due to the easy measures having already been applied), reasonable paybacks, assuming some sort of loan system, become difficult to achieve. This is unlikely to comply with the Green Deal 'Golden Rule'. These calculations do not reflect 'take back' due to higher temperatures, or 'in use' factors resulting in underperformance, both of which would reduce the energy savings in practice and make payback even more problematic.

Table 7 Summary of average cost of measures and average percentage savings for the three large-scale retrofit studies

Study	Average cost of measures (£)	Average percentage savings
Neath Port Talbot, EEP, 2001	2653 (3608)	29.0
Neath Port Talbot, Warm Wales, 2006–2007	450 (526)	9.2
ARBED, 2011	7771	25.3

Note: The numbers in parentheses are the costs adjusted for inflation.

Conclusions

Retrofit programmes such as the ones located in Wales discussed in this paper have the potential significantly to reduce CO_2 emissions whilst having other positive impacts such as improving health and quality of life. The case studies described indicate that most retrofit programmes have focused on the elemental approach, aiming to include large numbers of properties with the most cost-effective measures. Costs associated with installing measures range from a few hundred pounds for shallow elemental retrofits up to £70 000 for a deep whole-house retrofit. The cost of whole-house retrofits, together with disruption factors, is considered a major barrier to wide-scale take up by existing householders. Therefore, the UK government's target of 80% reduction in CO_2 emissions will be difficult to achieve in relation to housing retrofit within current financial schemes. Of course with the increase of retrofitting programmes, costs are expected to decrease, and indeed energy prices are likely to continue to rise, driving the need to retrofit to higher standards, and providing more of an incentive for householders to implement measures. However, a consequence of the 'low hanging fruit' approach, adopted by many of the large-scale retrofit programmes to date through their elemental approach, is that unless the cost–benefit balance changes significantly, subsequent retrofit programmes may prove prohibitively expensive. There will be a need for new finance models, probably combined with support from Building Regulations, to provide the incentive for large-scale whole-house retrofit.

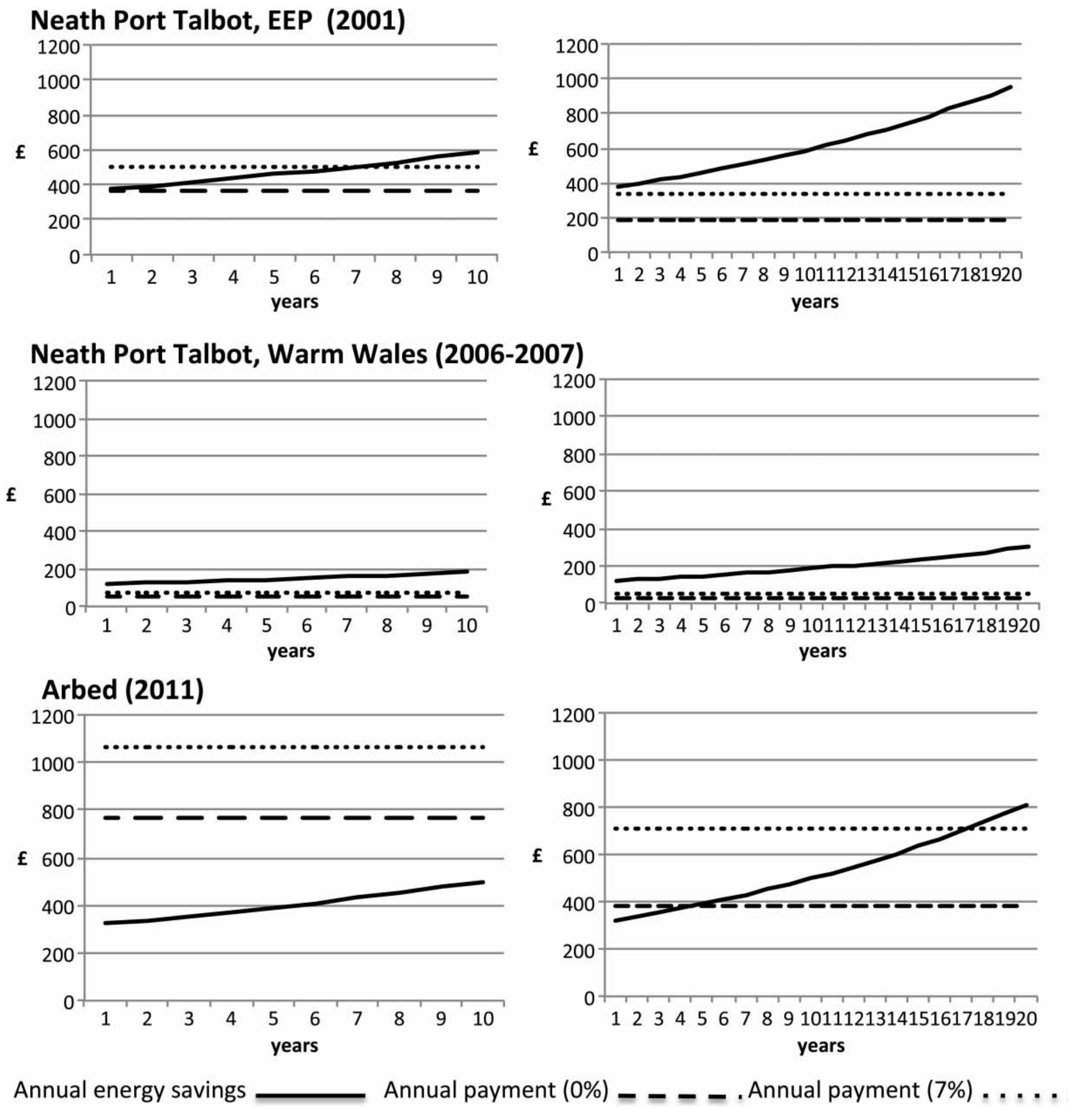

Figure 16 Comparison of energy savings (for an annual increase in energy cost of 5%) over a 10- and a 20-year period for annual payment of measures at interest rates of 0% and 7%, respectively, corresponding to the case study information shown in Table 7

A focus on older properties and on retrofitting empty properties should yield higher savings and provide opportunities for 'whole house' retrofits as part of improvements to general housing standards. The UK government has recently identified solid-wall insulation as a key retrofit measure. However, solid-wall insulation is still relatively expensive, and additional financial support is needed to achieve a payback, *e.g.* through a Green Deal-type loan.

It is important to be able to target the most beneficial combination of packages of energy-saving measures and renewable energy supply, for specific house types. The EEP model used in the above analysis of large-scale retrofit programmes provides a useful prediction framework where appropriate packages of measures can be targeted for specific house types to achieve maximum savings in relation to costs. However, the EEP model uses existing information on energy performance based on the UK government's SAP tool. There are 'in-use' factors now being applied to account for lack of predicted performance in practice, especially solid-wall insulation, where further research is needed to better assess performance in use.

There will be a degree of 'take-back', especially associated with the more elemental larger-scale retrofit programmes which have particularly targeted the fuel poor, where a proportion of the savings is realized as affordable warmth. This should be seen as an additional benefit of retrofit programmes. However, the degree of 'take back' in terms of improved comfort may have less of an impact for whole-house retrofits as in many cases they will be implemented by relatively affluent occupants who will already be able to afford warmth and are therefore more likely to realize the full energy-saving benefits.

There are additional benefits from whole-house retrofitting including improving the general aspects and quality of the building, which can provide an improved quality of life. The Warm Wales programmes demonstrate the importance of including other socio-economic activities, such as job creation, start-up companies, training and benefits advice, within large-scale retrofit programmes, taking advantage of the opportunities provided through large-scale interventions. The cost–benefits from these additional activities are not generally accounted for in retrofit programmes, and in future they might be used to better target government support funding.

The contribution of housing retrofit to achieving the UK's 2050 target for CO_2 emission reductions is unlikely to occur in a single step. The existing housing stock may undergo a series of retrofits as the cost of measures come down and energy prices increase. Although, there is still a need to focus on reducing energy demand, not only to reduce CO_2 emissions, but also to improve comfort, in future there will also probably be the need for a greater emphasis on decarbonizing the supply at both building and community scale (HM Government, 2011).

Acknowledgements

The authors would like to acknowledge support from the Engineering and Physical Science Research Council (EPSRC grants GR/K19181 and GR/L81536)) and the Medical Research Council (MRC grant G9900679), which contributed to the development of the EEP model. Also thanks to Neath Port Talbot County Borough Council and Warm Wales Ltd for their support in funding the analysis for the large-scale retrofit studies; and to the TSB for funding the Turnstiles project.

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