Cynon Taf Community Housing Group

New Ideas Social Research: Eco-refurbishment of Terraced Stock

What benefits are there to be achieved through the refurbishment of high-density terraced housing?

Grŵp Cartrefi Cymunedol Cynon Taf
CYNON TAF
Community Housing Group

*delivering **quality** housing services, **locally***
*darparu'n **lleol** gwasanaethau tai o **ansawdd** uchel*

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Primary Research Question

What benefits are there to be achieved through the refurbishment of high-density terraced housing?

Sub Questions

- What are the financial cost implications of completing a refurbishment of 'hard-to-treat', pre-1919 terraced housing?
- What are the costs and benefits that may be accrued through refurbishment of this stock type?

Research Objectives

- Research seeks to build upon the knowledge gained through completion of stage one of the Association's eco-terrace scheme in Penrhiwceiber.
- Determine a financial cost analysis of implementing different retrofit measures.
- Distinguish additional environmental and social costs/benefits that may be incurred through refurbishment.
- Highlight any limiting factors, which may impact upon the success of a project, and determine how best to address these issues

Executive Summary

- Given the inefficiency, quantity and the prevalence of fuel poverty in pre 1919, terraced housing, the need to retrofit this stock type is clear.
- Yet retrofitting a 'hard-to-treat' terraced house to a high environmental standard is an unavoidably expensive project.
- The cheap, simple measures tend to be the most cost efficient e.g. Loft Insulation and draught proofing
    - However, implementing these measures will only achieve a certain standard, which is certainly below an 80% CO_2 emissions reduction.
    - Therefore, assuming no decarbonization of the national grid, the use of renewable systems (Solar water heating or Ground Source heat pumps) will be necessary if we are to achieve these objectives.
    - Yet these are currently expensive, and a greater empirical evidence base is required in order to verify their benefits.
- Household and behavioural factors have the potential to mitigate or even offset physical improvements. This is known as the 'rebound effect'.
    - Addressing these 'human factors' of building misuse presents an equally large challenge as the physical upgrading of our stock.
- Despite these difficulties, refurbishment presents an opportunity to address a whole range of additional issues and may be viewed as a central element of a wider regeneration strategy.
- Prior to commencing a retrofit scheme, it is recommended that a thorough, coordinated planning process is conducted
    - This should include and examination of the costs and benefits to both the immediate tenants and the wider community.
    - This should ensure that all potential costs are accounted for and the maximum value is derived from both the refurbishment itself, and the process of construction.

CONTENTS

1. Introduction

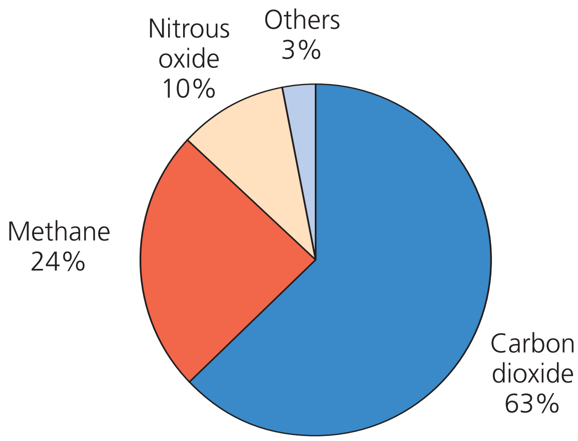
In analyzing the arguments that are made for and against the approaches of demolition and refurbishment, it is important to highlight the key challenges that are faced, which provide the very rationale for action. The primary grounds for improving our stock may be found in the twofold challenge of reducing domestic sector carbon emissions and tackling fuel poverty. These issues are regarded as principal symptoms of a housing stock that is said to be 'inefficient and requiring improvement' (Jenkins, 2010). Each of these challenges will now be described, and the potential for a refurbishment approach to address these issues will be discussed.

Following the presentation of these two central themes, an appraisal will be made with regards to the potential of different retrofit measures to achieve both economic and environmental objectives. This appraisal will also take account of the various behavioural factors, which impact on our CO_2 emissions, and will highlight some important empirical evidence in the form of three case studies. The paper culminates in the presentation of different models, which display the relationship between the capital costs of installing different measures and the potential benefits of their implementation. This study is chiefly concerned with the upgrade of Pre 1919 terraced housing and a specific focus on this stock type is provided.

1.1. Climate Change

Tackling climate change by reducing Greenhouse Gas [GHG] emissions is undoubtedly the foremost challenge underpinning the need to improve the performance of our housing stock. Carbon Dioxide (CO_2) forms the highest proportion of GHG emissions and it is estimated that the UK's domestic buildings account for 27% of total CO_2 emissions by end-user (DEFRA, 2006). The UK government has acknowledged the drastic need for action and has recently set an updated and increased target for an 80% reduction in CO_2 emissions by the year 2050, using 1990 levels as a baseline (Climate Change Act, 2008). This target is ambitious, going above and beyond the short-term Kyoto Protocol commitment of a 12.5% reduction in GHG emissions by 2010, which the UK is now widely expected to have achieved (DTI, 2003; DECC, 2010).

Figure 1: The relative contribution to global warming over the next 100 years of current emissions of greenhouse gases



Source: DEFRA (2006)

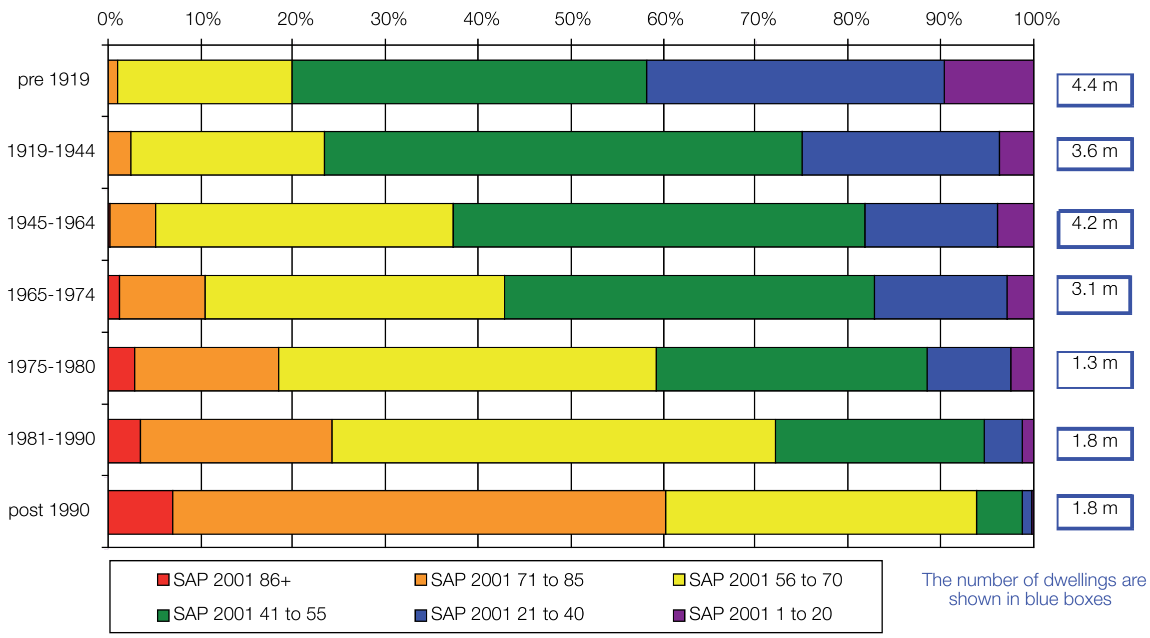
1.1.1. Residential Sector objectives

In the Residential sector the Government has implemented and proposed numerous policy measures in order to reduce CO_2 emissions from new-build housing. Stricter building regulations and energy standards, combined with the provision of financial incentives have culminated in grand targets being set to make all new homes 'zero carbon' in England by 2016 and in Wales by 2011 (DEFRA, 2007). However, it is evident that new housing will only make up a minority of the future housing stock against which these targets are set. Indeed, allowing for the current and projected rates of house building and demolition, it is estimated that 86% of our current housing will still be in use in 2050, making up two-thirds of the total stock (SDC, 2006; Boardman, et al. 2005). Thus, the National Assembly for Wales' Sustainability Committee (NAW, 2010) observe that the majority of Wales' residential carbon savings must be achieved through our existing housing stock. Furthermore, when we consider the current energy performance of our existing housing, the requirement for action is yet further apparent.

1.1.2. Performance of Existing Stock

The UK's current stock is estimated to contain some of the oldest and least efficient housing in Northern Europe (Lowe and Oreszczyn, 2008). Although Ravetz (2008) observes that the performance of this stock has improved in recent years, with overall average SAP ratings increasing from 42 in 1996 to 49 in 2006, there remains considerable scope for improvement. The performance of older stock is found to perform particularly badly, and figure 2 shows that pre 1919 housing achieves the lowest SAP ratings of all. This is particularly concerning, given that the DCLG (2009) estimates that over 4.7 million homes in England were built before 1919, making up around 22% of the total stock. Meanwhile, Wales faces a proportionately greater challenge with 33.7% of the total stock pre-dating 1919 and as many as 492,000 homes being designated 'hard to heat', and which are the greatest source of domestic carbon emissions (NAW, 2010).

Figure 2: Profile of Energy Performance in Existing Dwelling Stock (2004)



Source: DCLG (2006)

1.2. Fuel Poverty

As a concept 'fuel poverty' is described as occurring when a household needs to spend more than 10% of its income on fuel to maintain an 'adequate level of warmth' (DEFRA, 2008). Herein, an 'adequate level of warmth' is defined as 21 degrees for the main living area, and 18 degrees for other occupied rooms (DEFRA, 2008). Another factor, which must be considered in this equation, is the heating regime that is attributed to the household. This may be 'standard, 'full' or 'partial' depending on the nature of the house and its occupancy.

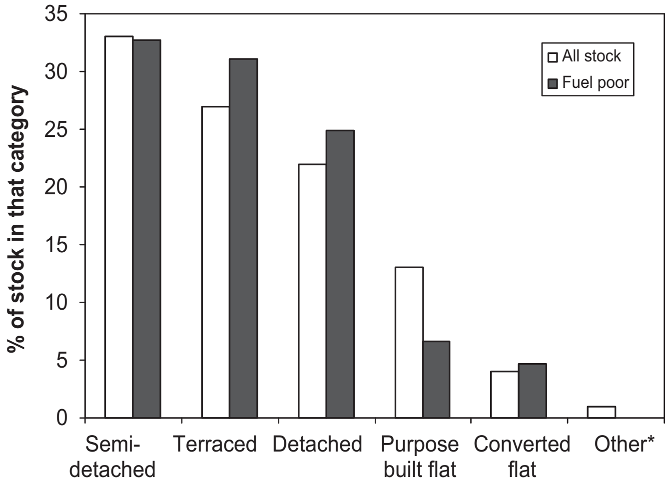
A 'standard' heating regime is applied to households where the residents leave the house during the day (for work, study etc.) and where the heating should only be used in evenings and weekends (DEFRA, 2008). A 'full' regime is applied when a household requires continuous heating throughout the day, as its residents do not leave the property due to disability, old age, sickness etc. Such residents are described as ‘vulnerable’. Finally, a ‘partial’ heating regime is applied to households where only parts of the house should be heated at any one time, as the property is larger than the resident’s needs. Fuel poverty may be calculated as follows:

$$\textit{fuel poverty ratio} = \frac{\textit{fuel costs (usage x price)}}{\textit{income}}$$

Fuel costs here are not simply based on actual expenditure but are calculated by multiplying the household’s fuel requirements with the corresponding fuel prices. Such fuel requirements are determined by modeling a wide range of factors, and importantly take account of the type of domestic energy usage and the energy efficiency of the household.

Because the condition of fuel poverty depends upon the variables of income, dependence, fuel prices and energy efficiency, levels of fuel poverty fluctuate considerably and can thus be difficult to accurately ascertain. Nevertheless, as of 2006, it was estimated that around 14% of all households in the UK (3.5 million households) were below the fuel poverty threshold (DEFRA, 2008). Broken down, these statistics reveal that fuel poverty is a particular problem for terraced properties (Jenkins, 2008). This is displayed in Graph 1, which shows that the percentage of fuel poor households in terraced homes is proportionately higher than that in any other stock type.

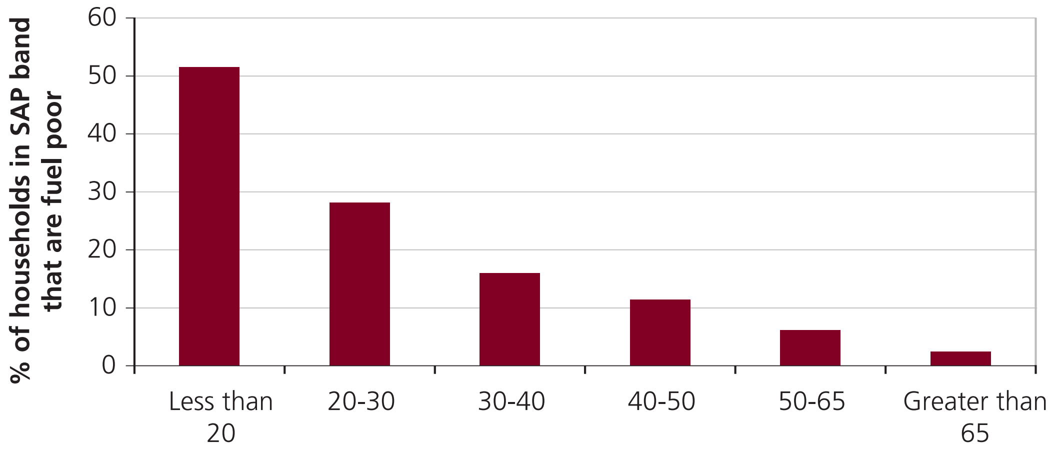
Graph 1: English fuel Poverty and Stock by housing Categories



Source: Jenkins (2010) citing DCLG (2008) AND DBERR (2005)

There is a strong link between fuel poverty and energy efficiency, which is displayed below in Graph 2. The graph shows that there is an inverse correlation between SAP rating and the prevalence of fuel poor households. Whilst over 50% of households with a SAP rating below 20 are in fuel poverty, only around 2.5% of households with a SAP greater than 65 are fuel poor.

Graph 2: Percentage of households in fuel poverty by income and energy efficiency



Source: DEFRA (2008)

1.3. Addressing our Pre-1919 Terraced Stock

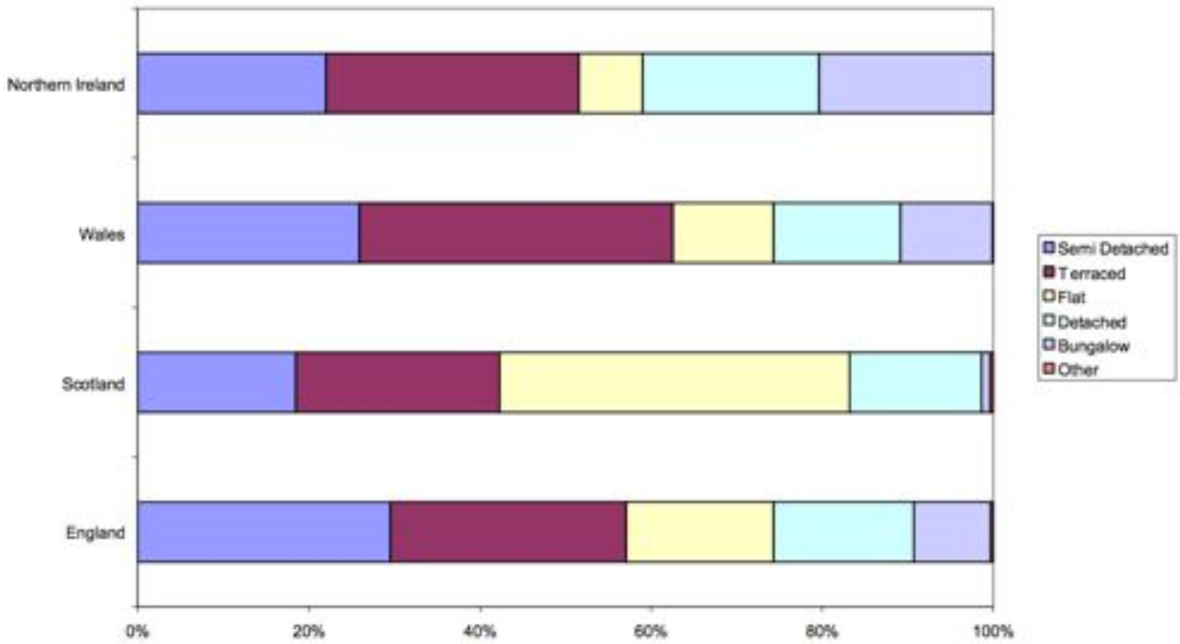
As observed, pre 1919 housing is the least efficient housing type by age in the UK with less than 60% of properties in this stock achieving a SAP rating above 40. Couple this observation with the fact that households in terraced properties suffer from the highest rates of fuel poverty, and the need to address our pre-1919 terraced housing is plain to see. What's more, the rationale for action is further strengthened when we consider the sheer amount of pre-1919 terraced housing that remains in the UK, and especially in Wales. Table 1 shows that pre-1919 housing makes up 30% of Wales' total housing stock, with terraced housing making up 59% of this stock type. Thus, in total there are an estimated 226,000 Pre-1919 terraced houses in Wales, accounting for 18% of the total housing stock. This is a considerable amount and it is reasonable to assume that a substantial proportion of these houses will have been built during the industrial revolution in order to house the many mining communities in Wales. Indeed, Shorrock and Utley (2008) observe that the ratio of terraced housing in Wales is higher than that in England, Scotland, and Northern Ireland (as displayed in figure 3). Hence, it is evident that addressing this stock type is a particular issue within Wales and will thus require a high level of attention.

Table 1: Pre-1919 homes in Wales

<table>
<tr><td colspan="3">Estimated no. of pre-1919 homes in Wales</td><td>383,000</td><td>30%</td></tr>
<tr><td colspan="3">Total no. of homes in Wales (2008)</td><td>1,268,000</td><td rowspan="8">Total Terraced
226,000</td></tr>
<tr><th>Pre-1919 homes - property type</th><th>Estimated no. in Wales</th><th>% pre1919 homes</th><th>% stock wide</th></tr>
<tr><td>Detached</td><td>83,200</td><td>22%</td><td>28%</td></tr>
<tr><td>Semi detached</td><td>56,000</td><td>15%</td><td>31%</td></tr>
<tr><td>End terrace</td><td>60,000</td><td>16%</td><td>11%</td></tr>
<tr><td>Mid terrace</td><td>166,000</td><td>43%</td><td>22%</td></tr>
<tr><td>Flat</td><td>18,400</td><td>5%</td><td>8%</td></tr>
<tr><td>Total</td><td>383,000</td><td>100%</td><td>100%</td></tr>
</table>

Source: WAG (2008) Living in Wales Survey – Data prepared by Welsh Assembly Government

Figure 3: Housing stock distribution by type of dwelling in 2005



Source: Shorrock and Utley (2007)

Thus, Considering:

a) The poor performance of our pre-1919 housing
b) The prevalence of fuel poverty in our terraced stock and
c) The sheer amount of this housing type that exists (and will continue to exist for the foreseeable future)

The need to urgently address this housing stock type is clear.

1.4. Additional Incentives

Asides from reducing fuel poverty and carbon emissions, sustainable refurbishment has the potential to address a range of additional factors, which further incentivize the approach. King and Wilkes (2010) identify wider sustainability gains that may be incurred through this approach and include:

- Reducing emissions besides CO^2
- Increasing the provision of natural light, thus maximizing solar gains and reducing the energy demand for electric lighting
- Reducing water consumption and demands on our water network
- Providing household recycling facilities
- Increasing the energy efficiency of lighting and household appliances

Besides these environmental sustainability factors, other benefits may exist for all stakeholders and for the wider neighbourhood in which the refurbishment occurs. Such benefits are aligned with the country's wider regeneration objectives and relate to the social and economic sustainability of implementing such an approach.

1.4.1. Beyond Environmental Sustainability

It is worth noting that in recent years the ideas associated with sustainable regeneration have moved beyond the simple desire to reduce energy consumption and there are now many other aspects, which must be accounted for (Yates, 2006). Indeed, Edwards (2000) outlines a general typology for sustainable housing, which incorporates a wide range of components at both the individual building and neighborhood level. Herein, sustainable housing at the neighborhood level should display the following features:

- High density, mixed use and diversified tenure
- Integration of land use and transport planning
- Urban layout that creates shelter and safety
- The exploitation of renewable energy supplies (wind, sun etc.)
- Capture of rainfall for certain water uses
- Use of open space to facilitate interaction and ecological well-being
- Pollution and Waste strategies
- Natural habitats integrated with housing

Thus, it is evident that in considering the potential of a refurbishment approach it is necessary to evaluate a wide range of features, beyond the scale of the individual building and the mere energy equation. In this respect it is worth considering the holistic analysis made by Power (2008), which suggests that a refurbishment approach is in fact preferential to demolition on the grounds of wider sustainability. Power (2008:4488) suggests that refurbishment should be favored:

'On the basis of time, cost, community impact, prevention of sprawl, reuse of existing infrastructure and protection of existing communities'.

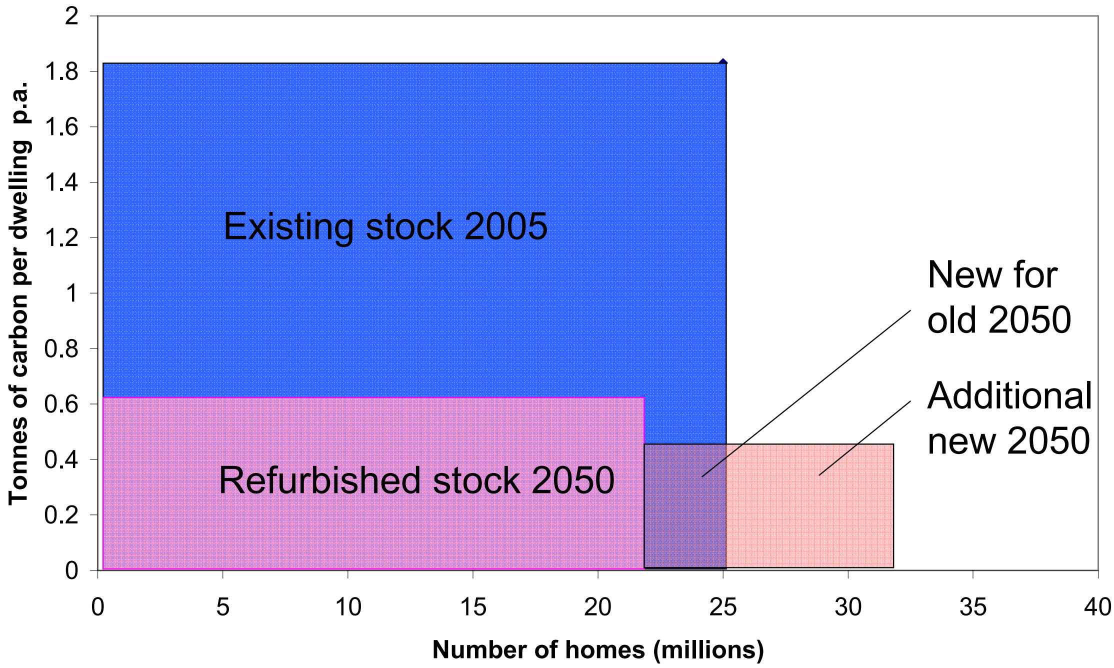
The debate about whether we should demolish or refurbish our most inefficient stock is a contentious one, and is discussed in more detail below.

2. Improving Performance

2.1. Demolition vs. Refurbishment

There is considerable discussion about how we might best improve the performance of our existing housing and a fundamental dispute exists as to whether we should demolish or refurbish our old and inefficient homes. In some divisions, demolition and new build is advocated as the most efficient and indeed necessary strategy if we are to meet our emissions targets. The ODPM's Sustainable Communities Plan (2003) and the Environmental Change Institute's (ECI) more recent publication of the *40% House* (2005) are amongst the most significant proponents of this approach. The ODPM (2003) has proposed 'large-scale clearance' of many houses within Housing Market Renewal Areas, whilst the *40% House* expresses a similar judgment in arguing that a 60% reduction in domestic CO_2 emissions would require the demolition of as many as 3 million homes by the year 2050. The housing stock implications for the *40% House* scenario are displayed below in graph 4.

Graph 4: Emissions required from refurbished and new build homes to achieve a 60% CO2 reduction



Source: ECI (2006)

However, the matter of such large-scale demolition is a complicated and contentious issue and many argue that a refurbishment approach would be preferential for a wide range of reasons.

Irrespective of the wider social and economic issues relating to demolition, the justification for large-scale clearance and rebuild on energy efficiency and environmental grounds has been found questionable. Indeed, whilst the EHA (2007) acknowledges that newly built properties may perform better than those built in the past, their report, entitled '*New tricks with old bricks*' highlights an important distinction between 'embodied' and 'operational' CO2 emissions. Here, 'embodied' emissions relate to the CO2 given off as a result of the materials used in the house building process, and 'operational' emissions relate to the CO2 given off from the house's normal energy use once occupied. Considering this distinction, it is apparent that refurbished homes have a clear head start over prospective new build properties due to the simple reason that they have already been built and thus do not generate the same level of 'embodied' emissions than would result from building new properties (EHA, 2007). Moreover, due to these initial savings made through removing the need for new build materials and construction, the EHA (2007) has found there to be almost no difference in the average emissions of new compared with refurbished housing over a 50-year period.

Such a holistic approach to monitoring building performance is similarly encouraged by Sodagar et al. (2009), who stress the need to establish the 'Whole Life Emissions' (WLE) of buildings in order to determine their total environmental impact. Sodagar et al. (2009) observe that the start and end of a building's life greatly contribute to their overall CO2 emissions and thus recommend that the life of all buildings should be extended as far as possible to minimize their environmental impact.

However, Power (2008) observes that such a comprehensive account of CO_2 emissions is not always made and is indeed absent from the ECI's *40% house* report. Consequently, Power (2008) argues that such research has oversimplified estimations of CO_2 emissions and that subsequently the arguments for large-scale demolition are considerably weakened.

Beyond the environmental equation, Power (2008) argues that there are wider benefits to be captured through implementing a refurbishment approach. Moreover, it is suggested that refurbishment may play an important role within a wider regeneration strategy and in helping to renew poorer neighbourhoods. To this effect, four reasons are cited (Power, 2008:4496):

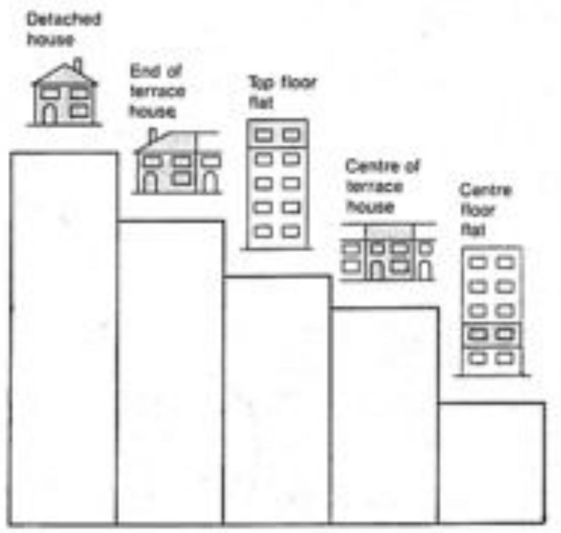
1. Renovation may spark a 'virtuous cycle of reinvestment, revaluing unused buildings and land while encouraging upgrading of all property to a much higher quality and energy efficiency standards'.
2. Renewal adds value to 'infill spaces' (small gaps created by change of use, earlier demolition and poor land-use planning), which have the potential to provide extra land we need for additional building.
3. Refurbishment has the potential to sustain urban density and support the critical mass of people that are required to support local services.
4. The reinvestment in declining communities that occurs through renovation assists the local economic development of a neighbourhood. Additionally, the work is said to be well suited to small, local contractors who often hire local workers, thus generating new employment opportunities and skills within the community.

The validity of this final claim will be studied later in this paper through a study of the training and employment opportunities created as part of the refurbishment and regeneration works that are ongoing in Ty'r Felin Street in Penrhiwceiber. Whilst these arguments do serve to strengthen the argument for refurbishment, it is worth noting that they are somewhat disputable, and perhaps a more evidence-based approach is required to substantiate such claims and reliably inform debate. Indeed, Bramley and Power (2008:30) argue that 'many of the claims made for such compact forms in terms of the sustainability benefits are contested, and few have been rigorously researched'.

2.2. Pre 1919 Terrace Refurbishment

As stated, sustainable or eco refurbishment stands in opposition to demolition and the main arguments for this approach are that it presents a comparatively cheap, quick and reliable way of reducing CO_2 emissions within a relatively short time frame (Power, 2008). However, by any standards, the task of upgrading our vast amount of pre-1919 terraced housing stock is both a large and complicated one. Yet encouragingly, Power (2008) argues that this building type may be relatively easy to upgrade, and can achieve as high environmental energy efficiency standards as current new build. Furthermore, whilst this stock is frequently identified as 'inefficient', figure 4 reveals that 'centre terrace' housing actually uses a proportionately low amount of energy by comparison with other forms and thus provides a good starting point for this approach.

Figure 4: Average energy use by dwelling type (assuming equal floor area and orientation)



Source: Edwards (2000)

In addition to the energy benefits of refurbishing terraced housing, the socio-economic rationale for refurbishing this stock type must also be considered. Regarding the aforementioned issue of density, the CPRE (2004) describe how 'Pre-1919 terraces are typically built at a density of 80-100 dwellings per hectare (dph) and with street patterns that were designed for pedestrian access to shops and services'. This matter of pedestrian access is doubtful in the context of the South Wales valleys, as much of this stock type is built across steep terrain. However, density is indeed seen as a key component of sustainable housing for a range of reasons, outline by Jabareen (2006). Overall, higher densities are said to be more likely to allow the interactions needed to make urban functions, infrastructure or activities viable (Jabareen, 2006:41).

The average density of the Victorian terraced stock type within Rhondda Cynon Taf's 'Northern Strategy' area (which encompasses the town of Penrhiwceiber, the location of CTCHG's eco-terrace scheme) is specified as being 70 dph (RCT, 2006:78). Although, in theory, this density is certainly high enough to allow for the aforementioned sustainability benefits, a number of other factors must be considered in order for such benefits to be realised. The main difficulties are listed below and have been ascertained through consultation with the Local Authority's Housing Strategy department:

- Firstly, the density here is probably too high given the absence of sufficient land values and the apparent lack of demand, leaving a significant number of properties vacant.
- Secondly, there appears to be an oversupply of a single stock type (2 bedroom terrace), making the area unsuitable for a wide range of households E.g. larger families and elderly or disabled people who cannot use the stairs. The

consequence of this problem is that the area becomes inflexible for people with changing household circumstances who may hence be forced out of the area to find suitable accommodation

- Lastly, this housing is in many ways unsuitable for modern living standards and is unable to provide certain features that are required for today's living standards e.g. Space for wheelie bins, flexible living spaces etc.

However, refurbishment does evidently have the potential to address these issues, as has already been demonstrated through CTCHG's eco-terrace scheme. The BRE explain how the scheme has aimed to provide 'open/flexible living spaces conducive to modern family life' and provide 'meaningful storage space, accommodate spaces for recycling and create areas for drying clothes inside'. Furthermore, in an attempt to reduce the density and provide the option of larger housing in the street, two properties were knocked together to form a single dwelling. A range of energy-efficiency and water saving measures were also incorporated, but perhaps more importantly, this example serves to demonstrate how refurbishment may also be used to tackle wider housing problems such as those outlined above.

2.3. Retrofitting Approaches

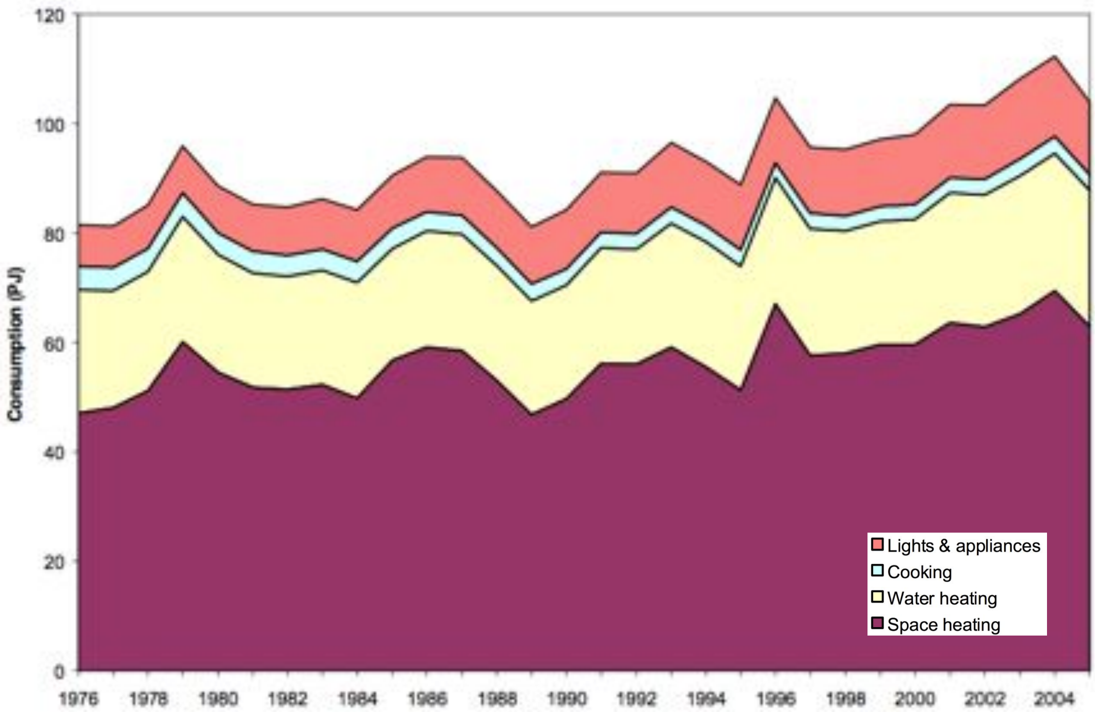
'Sustainable' or 'Eco' refurbishment approaches invariably involve the utilization of a range of retrofit measures. Retrofit may be defined as 'improvement in the efficiency of energy-using equipment or the thermal characteristics of an existing building' (Percival, 2010). However, the price of installing these measures, and the levels of carbon and fuel cost savings offered by each of them varies significantly. Therefore, it is possible to rank each measure into a 'retrofit hierarchy', according to how cost-efficient they are. Within this hierarchy we are able to split the types of measures into two distinct categories:

1. Energy Efficiency measures
2. Utilizing Renewable Energy Sources (Percival, 2010)

The first of these categories aims to reduce the consumption and need for energy, predominantly through upgrading the building's thermal efficiency and optimizing the efficiency of its appliances. Importantly, the majority of these methods, such as loft and cavity wall insulation, and draft proofing of windows and doors can be implemented relatively easily and cheaply (as displayed in Table 2). Furthermore, it is estimated that approximately a third of our current household CO^2 emissions could be saved through adopting such simple energy efficiency measures (EHA, 2007).

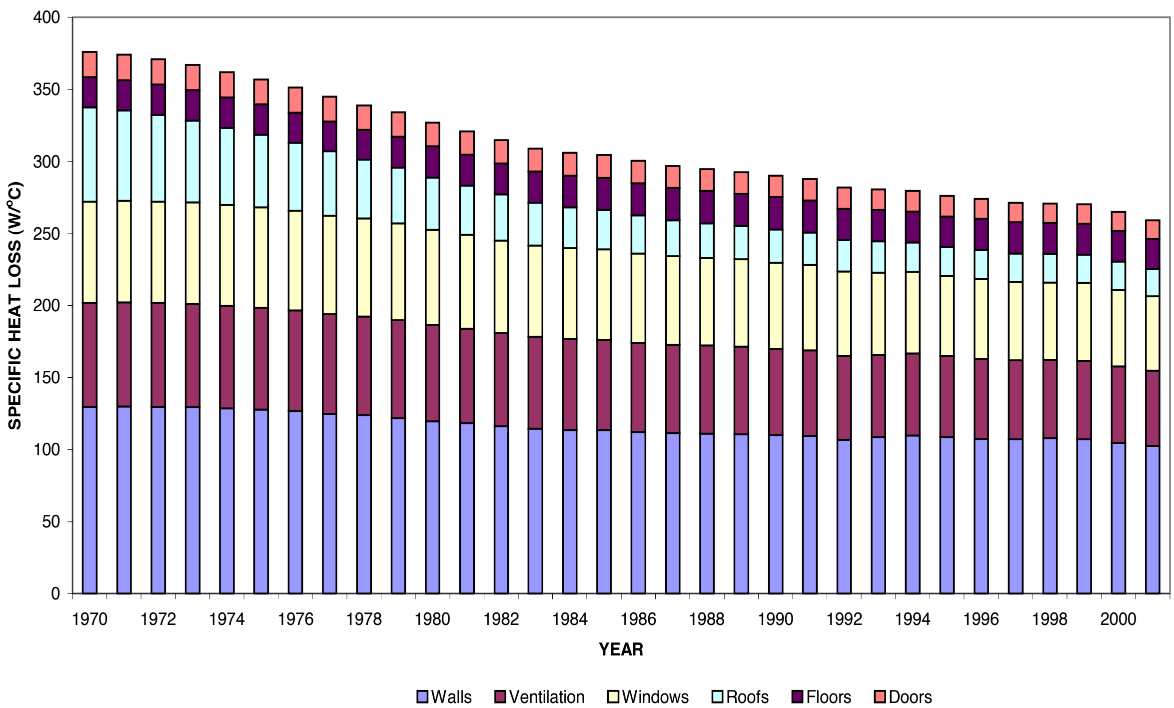
Graph 5 shows the proportion of domestic energy that is used by Space Heating, Water Heating, Lights and Appliances, and cooking. Additionally, Graph 6 reveals the different sources of heat loss from the average dwelling. Whilst Jenkins (2008) observes that these percentages will vary depending on location, house type and occupancy type, it is clear that in general, heating space uses by far the most energy and that significant heat loss may occur through all components of the building envelope.

Graph 5: Domestic energy consumption by end use



Source: Shorrock and Utley (2008)

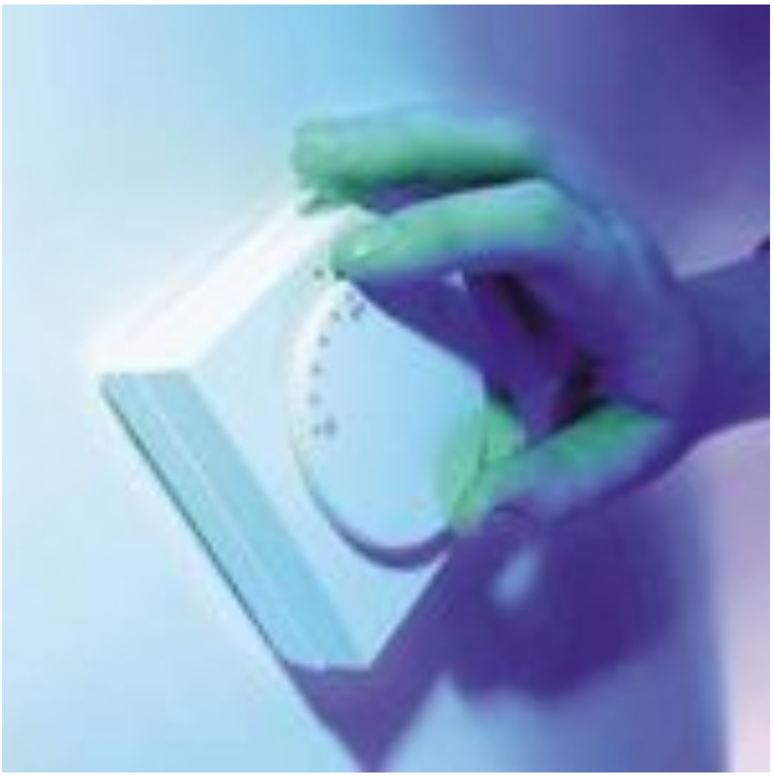
Graph 6: Source of Heat loss of the Average Dwelling



Source: Shorrock and Utley (2003)

Considering that the majority of our energy is used for heating space and that such a large proportion of this heat is lost through walls, ventilation and windows, it is somewhat unsurprising that significant efficiency gains may be made through implementing such thermal efficiency retrofit measures. Additionally, table 2 reveals that a proportionately high number of SAP rating points may be gained through these measures and at a relatively low cost by comparison with the use of more complex technologies, that are required for a shift to renewable energy sources. Indeed, DEFRA (2008) observe that a SAP 65 house will typically have loft insulation of 100mm or more, the majority of those with cavity walls will be filled and most will have double glazing in at least some rooms. Consequently, it would appear sensible to adopt such measures on the grounds of both cost and energy efficiency, allowing them to be ranked at the top the retrofit hierarchy.

3. Challenges to Improved Performance



Whilst in principle, retrofit offers the potential to decrease our CO^2 emissions and reduce fuel bills, there are a number of barriers that limit the uptake of such schemes and prevent the realization of the potential benefits. The following factors are cited as significant obstacles in the uptake and implementation of refurbishment schemes:

- Economic and financial problems
- A lack of knowledge and desire to deliver
- Policy and regulatory confusion
- Technological issues
- A skills gap in the construction industry
- Behavioural and occupancy factors

These difficulties are often interlinked with one another, and are thus difficult to address in isolation. Nevertheless, these will be discussed in more detail in the following chapter. The chapter will also examine the key issues, which impact upon performance and savings once a refurbishment has been completed.

3.1. Economic challenges

Summarizing the fundamental economic problem, Holmes and Mabey (2009:1) of the 'climate change capital' think tank, state that:

'Residential energy efficiency is the most complex climate intervention to deliver because the market failures are many and transaction costs high.'

Largely underpinning these market failures is the apparent confusion surrounding the costs and benefits incurred through refurbishment approaches. Without a clear understanding of these costs and benefits, the market becomes distorted and the presentation of a verifiable financial argument is made very difficult. Indeed, the lack of a strong, clear economic argument for the implementation of different measures is oft cited as the primary obstacle to improved performance. The main causes of this economic problem lie in:

a) Identifying the correct prices and funding sources
b) The impact of retrofitting on operating and maintenance costs
c) Measuring the benefits in terms of occupancy rates and satisfaction

(Rhoads, 2010)

In the rented sector, this uncertainty is compounded by the problem of split incentives, which is a thorny and somewhat unavoidable matter. Reduced energy consumption and the associated reduction in running costs are undoubtedly the most tangible benefits of completing a residential retrofit. However, the primary beneficiary of these is the bill payer (who is customarily the occupier) and therefore, there is reduced incentive for owners to invest in retrofitting unless their property is owner-occupied (Rhoads 2010). Thus, for properties in the rented sector, which make up 29% of Wales' total stock, alternative incentives/ requirements are needed to encourage landlords to invest (WAG, 2010). Thus, market intervention is often required in order to facilitate and promote the development of retrofit schemes.

This may be done through the provision of various financial incentives and through policy intervention. The Government's 'Green Deal', VAT reductions, the Feed In Tariff (FIT) and the impending Renewable Heat Incentive (RHI) are all examples of attempts to increase the appeal and financial viability of implementing retrofit technologies. Furthermore, in policy terms, grand objectives have been established, particularly with regards to the building of new housing and the standard of the social housing stock.

Indeed, energy efficiency forms a significant component of both the *Decent Homes Standard* in England and the *WHQS* in Wales. In England, a 2010 deadline was set for all social housing to meet Standard, but was been criticized as being unachievable, whilst in Wales, social landlords are required to meet the *WHQS* by 2012 (which is still largely viewed as unattainable). Nevertheless, the focus on the Social Housing Sector is important as it has the potential to spearhead the increased take-up of retrofit measures across all housing tenures. The reasons for this will now be discussed, and the role of Social Housing in facilitating the so-called 'Great British Refurb' will be outlined.

3.1.1. The role of Social Housing

Due to its share of housing stock and potential for impacting on CO^2 emissions, the Social Housing sector represents a platform for more widespread and rapid penetration of low-carbon interventions (Greenwood et al. 2009). Indeed, social landlords have been hailed as 'refurbishment pioneers', due to their potential to kick-start the market into delivering the larger scale refurbishment solutions that are required (Price, 2009). Given the shear amount of stock that is owned by social landlords, it is clear that a great deal of investment will be required in order to meet the aforementioned targets on improved energy performance. Whilst this is proving to be a very challenging task, it is of a greater significance for two main reasons.

Firstly, through widespread investment in different forms of retrofit schemes and technologies, it is hoped that a significant contribution to the industry's knowledge base will be made. That is to say, that through increasing the number of 'exemplar' refurbishment projects, we will expand the breadth of empirical evidence that we have on the actual costs, processes, and outcomes of completing such schemes (Lowe and Oreszczyn, 2008:4479, Jenkins, 2010:836). Moreover, such 'high-quality', practical evidence is cited as being 'largely absent' from the debate on low-energy housing, which is currently dominated on the whole by theoretical modeling and predictions. Thus, increased empirical data is vital if we are to bridge the gap between theory and practice and may be achieved through the refurbishment of our Social Housing stock. As such, Social Housing has the potential to act as something of a shop window for wider refurbishment in the owner-occupied and private-rented sectors as working examples of relatively new technologies (such as mechanical ventilation heat recovery, micro-generation and even, external wall insulation) may be observed and valued accordingly (Jenkins, 2010:836).

Secondly, the refurbishment of our social housing stock has the potential to act as financial lever in bringing down initial capital transaction costs of different retrofit measures (Jenkins, 2010). Although the refurbishment of our existing stock is vital if we are to meet our emission reduction targets, Peacock (2009:841), observes that the capital investment currently needed to deliver the required CO reductions is 'substantial and as a consequence is probably out of reach for most householders'. Whilst some measures are currently recognized as cost-effective to install due to the potential fuel bill savings that may be made, these alone are likely to be insufficient in achieving our 80% CO^2e reduction (Peacock, 2009). Therefore, it is proposed that through a largely subsidized social housing sector, increased sales of presently inefficient technologies will eventually reduce the capital cost of such measures to a level at which they become viable and attractive to the private sector (Jenkins, 2010:836). Such an approach is described as 'product diffusion theory', and is based on the principle that developing a mass market in a certain populace (Social Housing) will allow the development of technology, product delivery mechanisms and supply chains to evolve, and also begin to frame societal norms that eventually lead to new patterns of consumption in the wider population (Peacock, 2009:840). The fundamental premise of this strategy is that it has the potential to stimulate both the private housing sector and the manufacturers, thus encouraging long-term technology growth and market evolution (Jenkins, 2010:836).

In addition to, and in causation of these economic challenges, there are other factors, which compound the quality and deliverability of retrofit schemes taking place.

3.2. Skills, Knowledge and Understanding

It appears that there is presently a general lack of understanding as to the scale of the challenge that is faced, and the way in which solutions should be delivered. The confusion around the costs and benefits of different retrofit measures, and the economic problems that this causes has already been discussed. However the lack of knowledge in this field is also at the root of a range of other challenges involved in reducing our domestic CO^2 emissions. In fact, Lowe and Oreszczyn (2008:4475) argue that the 'main barriers to improved performance are located in policy process and availability of human resources rather than in technology as narrowly defined'. The following problems are all symptoms of this incomprehension and of the lack of know-how and skills that are required to deliver effective solutions:

Unclarity on climate change policy and regulatory confusion in the housing industry appear to be amongst the principal demonstrations of this incomprehension (Lowe and Oreszczyn, 2008:4475). For example, an insistence on 'zero-carbon' objectives and the use of on-site renewables are likely to push up the costs of delivery beyond what is financially feasible in current market conditions (Lowe and Oreszczyn, 2008:4475). Compounding this issue of costs, a lack of preparedness within the UK's construction industry is also cited as a major barrier to improved performance. Lowe and Oreszczyn (2008:4478) argue that the industry neither has the technology to deliver solutions nor knows what would be required to do so.

In addition to the technical challenges, a lack of desire is frequently cited as one of the main barriers to tackling the so-called 'retrofit challenge' (Doggart, 2009). Whilst the lack of a clear financial incentive is undoubtedly fundamental to this problem, Jenkins (2010:837) suggests that this lack of desire may also result from the perceived lack of an immediate threat from Climate Change in the UK.

Lastly, the challenges concerned with changing people's attitudes and behaviour go somewhat unmentioned in much of the literature on sustainable refurbishment, which draws heavily upon the theoretical modeling of different technologies. Yet Greenwood et al. (2009) observe that despite the more widespread application of energy saving technologies, behaviour is now recognized as a crucial factor in yielding the highest energy savings. The importance of these 'human factors' cannot be understated and are discussed in more detail below.

3.3. Realizing the Benefits: Human factors

At this point it is worth re-emphasizing the point that the potential reductions in CO^2 emissions and fuel costs have been 'commonly estimated using basic physical principles and engineering models' (Sorrell, 2007:V). That is to say, that in modeling the prospective performance of a refurbished property, many assumptions are made about how the building will be used. In particular, Standard Assessment Procedure (SAP), the default calculation tool for dwellings in the UK, makes a number of assumptions with regards to how modeled dwellings will be used by their occupants (Griffiths, 2010).

Yet in reality, once a retrofit project has been completed, a range of factors exist, which will influence the actual effectiveness of these measures, and the true benefits that are accrued. In fact, Sorrell (2007:V) argues that the energy savings that are realised in practice generally fall short of the estimates made using these modeling techniques. The issues here are largely related to the human factors of occupancy composition and behaviour.

In stressing the importance of these factors, Midden et al (2007:169) argue that technological and behavioural factors are so closely interwoven that it is in fact inappropriate to study them in isolation. Thus, in this respect, this paper will now engage an integrated approach in examining this relationship between humans and retrofit technologies interact, and identify how this relationship should shape the formulation of an effective domestic energy strategy.

The 'Rebound' Effect

The phenomenon known as the 'rebound' or 'take-back' effect occurs when 'Improvements in energy efficiency make energy services cheaper, and therefore encourage increased consumption of those services' (Sorrell et al. 2008:1356). It has the potential to decrease the energy savings that may otherwise be achieved through refurbishment, and in extreme cases offset these altogether. This latter outcome is termed 'backfire' (Sorrell et al. 2008:1356).

The rebound effect may occur in two distinct forms as households use energy in both direct and indirect ways. The direct rebound relates to the increased consumption of electricity, natural gas and other fossil fuels, while indirect rebound occurs as decreased energy costs enable greater consumption of other goods and services (Steg, 2008). The sum of direct and indirect rebound effects represents the *economy-wide* rebound effect. This paper will restrict its focus to direct domestic energy usage and will examine how and why actual household energy use may differ from the forecasted potential energy savings of different retrofit technologies.

Highlighting the fundamental problem and its historical context, Sorrell (2007:62, citing Jevons, 1865) notes that it is 'a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption'. This is certainly true within the residential sector, where Shipworth (2009:2) observes that despite significant improvements in insulation and efficiency since 1970, emissions have been broadly flat, as people have chosen to heat their homes to a higher standard. Indeed, Walker (2009) explains how actual domestic energy use is in fact, the outcome of a complex interaction between the built form, the location, energy-using equipment installed, affordability of fuel, and occupant factors. With regards to such occupant factors, Steg (2008) highlights how the main issues influencing individuals' household energy use are:

- An awareness of the need for energy conservation
- An awareness of possible ways to conserve energy
- The motivation to do it
- An ability to adapt their behaviour

Outlining the extent of building 'misuse' or 'take-back', Shipworth (2008) highlights how we only achieve roughly half the savings that we predict from our interventions. Whilst this may lead us to believe that households are simply using too much energy for the reasons outlined above, Shipworth (2008) believes that it is in fact wrong to blame this solely on occupant factors. Instead, it is argued that this disparity between our actual and predicted savings is the consequences of a range of factors relating to:

- Inaccurate models
- An incomplete understanding of:
    - How buildings work (building physics)
    - How heating, lighting & hot water systems work
    - How people use buildings to create comfort
- An inability to build/renovate buildings as designed/modeled
- Fabric, technology, control systems and occupant interactions

(Shipworth, 2008:3)

Therefore, the requirement for more, detailed empirical data is again expressed, as is the need to treat all interventions as hypotheses until robust direct empirically testing shows energy savings (Shipworth, 2008:15). To this end, and to highlight the true importance of the 'human factor' some sample case studies will now be presented. These have been chosen as they display how the actual savings attained through energy-saving measures vary, and highlight the importance of considering occupant's lifestyle factors. They also show how difficult it can be to actually obtain such data, as the methods of assessment are problematic and the time period required to make fair comparisons is a necessarily long one.

CASE STUDY 1: Gentoo Housing Association - 'Retrofit reality' project

retrofit reality

Aims of the project

The project aimed to gain an understanding of how hard it really is to make homes more environmentally friendly. Four key questions were outlined, namely:

1. How difficult are these products to put into a house?
2. How easy are they to use?
3. What are the benefits to people living in the homes? This included the fuel and water savings, levels of comfort and lifestyle benefits.
4. What type of maintenance do they require (for example, how often would they need to be fixed)?

Products Installed

- Total of 139 homes addressed – with an average spend of £5,250 per house
- Different measures were fitted according to the suitability of the dwelling e.g. Some homes did not have enough roof space to fit Solar Panels
- The measures installed were as follows;
    - Solar hot water systems (44 houses), A-rated condensing boilers (108 houses) Energy efficient showers (up to 88 houses), Double-glazing (72 homes)
    - Different insulation measures (not fully specified) were also installed in 28 of the properties.

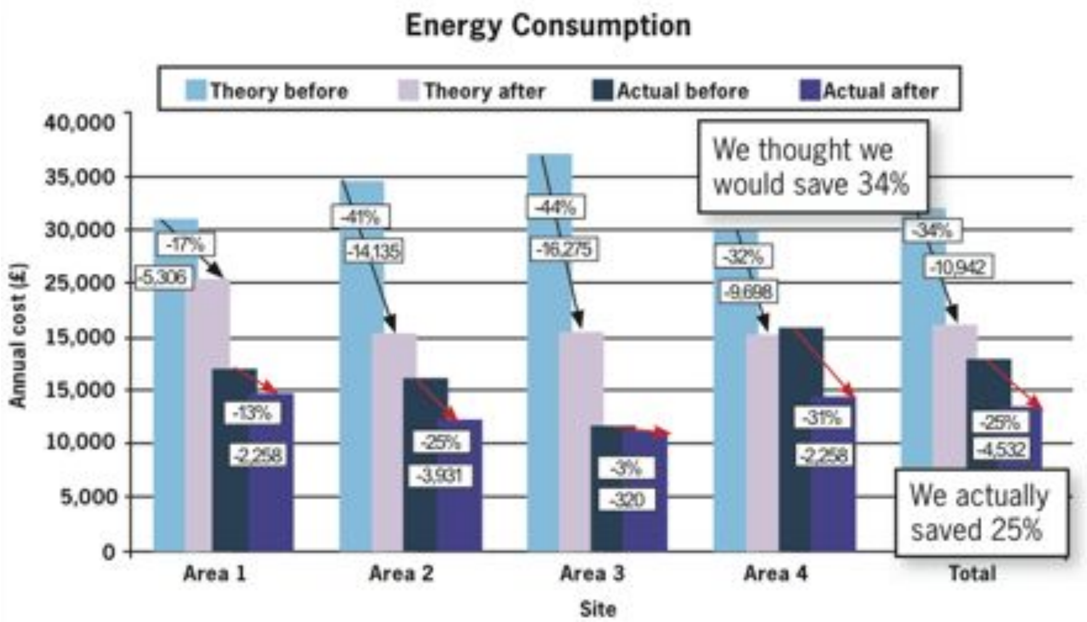
Method of Assessment

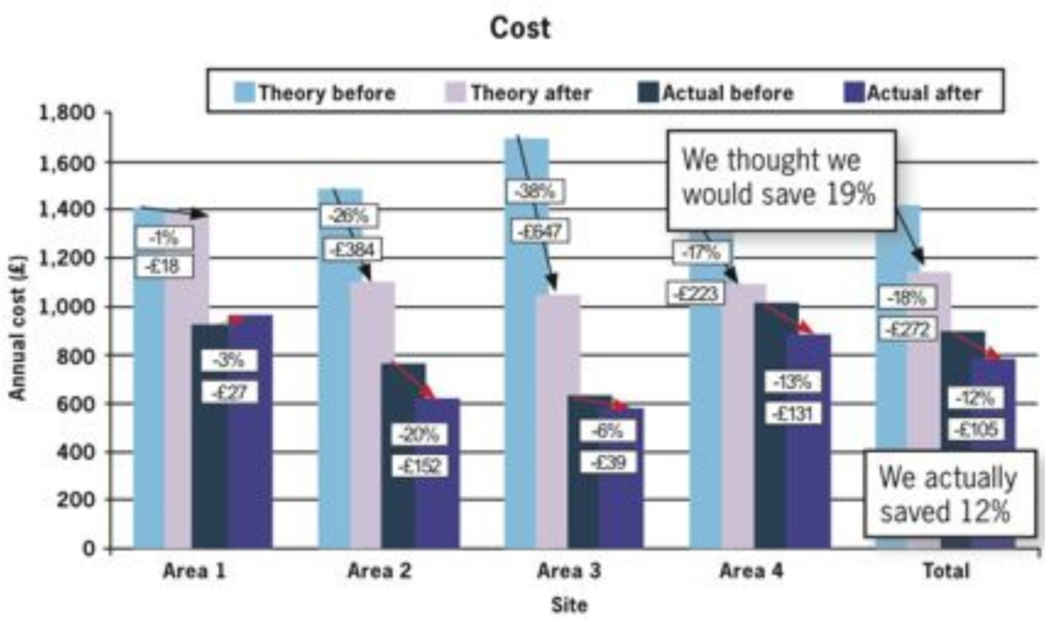
To establish a baseline, it was necessary to determine each household's income and fuel bills, and the performance of the dwellings being retrofitted. These were obtained first from SAP estimates and then through a measure of monthly meter readings and actual fuel bills. Lastly, residents were engaged to ensure that they were keen for the changes to be made and to help them understand the products being fitted. Their behaviour and attitudes towards environmental issues were also assessed to see if the scheme could bring about additional lifestyle changes. Following the completion of the retrofit scheme, this data was again collected (excluding income data) for comparison, and residents were once again consulted to obtain a personal feedback on the scheme.

Results and Analysis

At the outset, residents were found to be using 40% less energy than had been predicted by SAP, but were actually spending more on bills. This suggests that the software had underestimated actual costs of both electricity and gas. In contrast, the houses were emitting only 20% less CO^2 than was modeled, which did not match the lower levels of energy usage. This is because households were using a higher than predicted proportion of electricity than gas, which produces less CO^2 per unit.

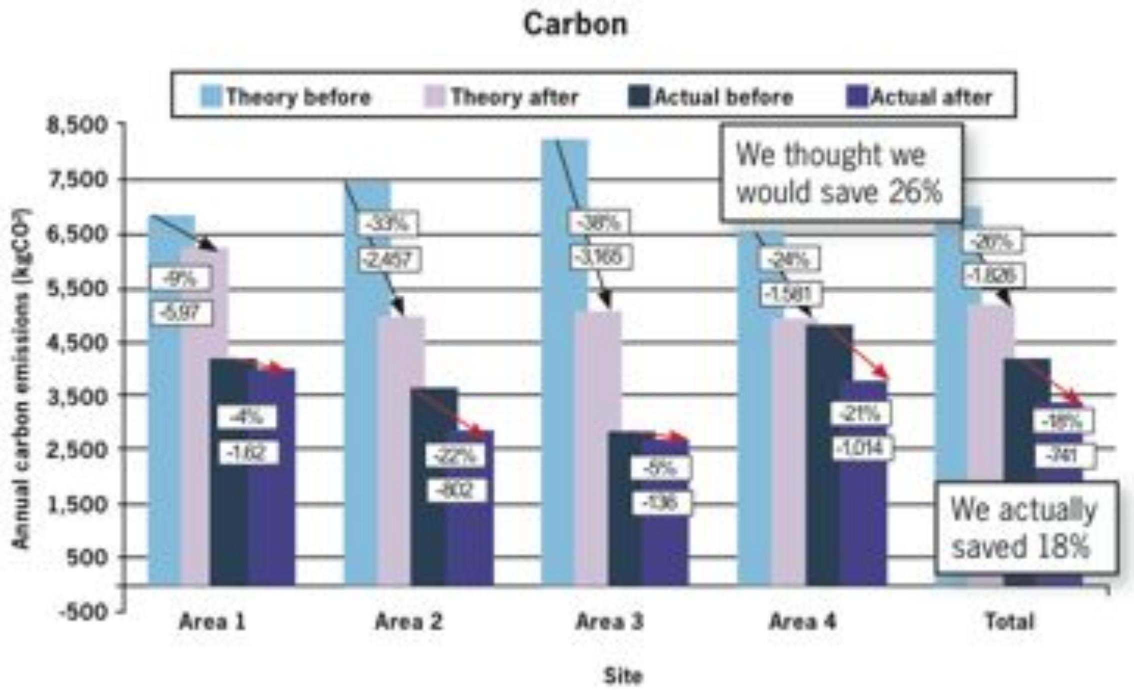
The graphs below reveal how energy consumption and fuel bills were less than had been modeled, both before and after the scheme had been completed. The percentages of the savings made were also less. However, this may to some extent be explained by the fact that savings are harder to obtain where houses are using less energy in the first instance, as was the case here.





The study found that prior to the scheme, residents were using their heating, cooking and lights less because they were trying to save money. Yet following completion of the scheme, the reduction in overall energy consumption (-25%) was far more than the reduction in fuel bills (-12) as people now used more electricity, which is more expensive than gas. This suggests that residents may in fact prefer household comfort and warmth to monetary savings, particularly as many commented that their houses were now warmer than before.

The increased use of electricity may also account to some extent for the discrepancy between the predicted, and the actual decrease in CO^2 emissions, which is displayed below. However, it is again worth mentioning the fact that savings are harder to come by when the initial starting point is lower than expected.



Findings and Conclusions

- Although the measures did reduce energy costs, substantially deeper retrofitting is required to raise people out of fuel poverty
  - However, 87% of people were made happier by the improvements
- It is extremely difficult to find out how much energy people actually use
  - Utility companies provided inconsistent, unreliable data and subsequently the collection of billing information was the 'hardest most time consuming' part of the research
  - Increased transparency of information is required for future projects
- SAP makes a number of incorrect assumptions with regards to; the cost of energy, the occupancy and lifestyle patterns of social housing, how warm houses actually are, how people like to heat their homes and use electricity
- Residents will act more sustainably if it is made easy for them. For example, if showers are provided as an alternative to baths

CASE STUDY 2: Cymdeithas Tai Eryri (CTE) - Evaluation of the Eithinog development

Although this is actually a new-build development and not a retrofit scheme, the four houses were built to a high environmental standard (Code level 4) and incorporated some of the technologies that could potentially be used in a refurbishment scheme. What's more, some of the technologies used in the project are quite new and it is interesting to see how effective they have actually been, particularly as they are included in the analysis of different measures, which can be found later in this paper. Moreover, the study is useful as it highlights some of the important human factors, which impact upon potential energy, fuel bill and Carbon savings.

Sustainability Measures

The homes were the first social housing development to attain Level 4 of the Code for Sustainable Homes in Wales. Therefore, the design incorporated an array of sustainability factors including energy efficiency measures and renewable energy systems. The key considerations made in the development are as follows:

- Solar thermal collectors, PV panels, Ground Source Heat Pumps, Low-energy lighting throughout, rainwater recycling, highly insulated loft and cavity walls.

Method of Assessment

The independent study was conducted a year after the tenants had moved into the new homes. The evaluation was twofold and aimed to assess the house's performance and the opinions of the tenants and the staff about their experiences. Thus, **part one** comprised of a quantitative analysis of each house's:

- Energy use, (for heating and equipment), CO^2 emissions, water use and the water that had been saved by recycling systems
- Support received from CTE staff during the year

While **part two**, the 'descriptive component', aimed find out how the houses actually performed as homes. This section was completed through interviews with four tenants and with the staff responsible for developing and maintaining the houses.

Results

The following table displays results from part one of the study. The UK average column has been added to allow a comparison of the figures.

House Number	11	12	13	14	Average UK household estimate
Time Monitored:	30/11/08 - 01/12/09 (366 days)	12/01/09 - 01/12/09 (323 days)	12/01/09 - 01/12/09 (323 days)	12/01/09 - 01/12/09 (323 days)	1 Year
Household Occupancy	4 (1 adult, 3 children)	3 (1 adult, 2 children)	6 (4 adults, 2 children)	6 (4 adults, 2 children)	2.4 (1.8 adults, 0.5 children)*
Total electricity used (KWh)	5371	3247	10847	10292	4457**
Average electricity used per day (KWh)	14.67	10.05	33.58	31.86	12.21
Total PV electricity produced (KWh)	1156.5	1153	1166.5	1274	-
Average PV electricity produced per day (KWh)	3.16	3.57	3.61	3.94	-
Total GSHP output (KWh)	3612	2400	5250	5256	-
Average GSHP output per day	9.87	7.43	16.25	16.27	-
Average GSHP contribution to heating per day (KWh)	7.30 (74%)	4.90 (66%)	4.23 (26%)	3.25 (20%)	-
Average GSHP contribution to heating water per day (KWh)	2.57 (26%)	2.53 (34%)	12.02 (74%)	13.02 (80%)	-
Total CO2 emissions (Tonnes)	2.257	1.27	5.874	5.473	About 6
Average daily CO2 emissions (Kg)	6.166	3.93	18.19	16.94	16.44
Average daily water usage (Litres)	110.22	155.84	1142.39	976.05	420 (Wales average)***

Source: Young (2010), *ONS (2011), **DBERR (2007), ***Welsh Water (2010)

Despite significant differentiation in the electricity and water use, the CO^2 emissions for every house remained below the national average. Although the sample size is small, it is evident that increased occupancy clearly correlates with rising electricity use and CO^2 emissions. Whilst this is to be expected, there are some interesting variations to consider, which highlight the extent to which so-called 'behavioural' factors may affect actual energy use and CO^2 emissions of a dwelling.

Firstly, the difference in water usage is quite remarkable, with one house using ten times that of the lowest consumer. What's more, the output of the Ground Source Heat Pumps (GSHP) also varied, as did the proportion of their contribution to both space and water heating. Perhaps unsurprisingly, the GSHPs contributed a higher proportion to water heating in the houses with the highest water consumption (numbers 13 and 14). Notably, these houses also produced far higher CO^2 emissions suggesting that the use of (hot) water was a significant contributor to emissions in these houses.

Part two of the study found that the resident's understanding of their new heating systems was far from complete. Whilst residents were happy with the reduced fuel bills, they had experienced difficulties in using the new systems and were unlikely to have realized the full potential of them. The GSHP's ability to regulate temperature isn't as instant as normal systems and some tenants complained that the Solar hot water system could not provide enough heat when the whole family needed to shower. It is noted that the tenants claimed to have received conflicting advice on how to use these systems and thus it appears that consistent, accurate guidance has been lacking from the scheme. This incomprehension around the new heating systems perhaps accounts to some extent for the great variation in CO^2 emissions produced by each dwelling. This is because some residents may be using their renewable energy systems more efficiently than others and relying less on electricity from the national grid.

Findings and Conclusions

- A more thorough education process is required in order to maximize the benefits of the new technologies
  - Although user guides were provided, tenants claimed to have mislaid them and furthermore, there is no guarantee that these would have been read and understood in the first place.
- The management of the new technologies was a difficult aspect
  - Whilst CTE received a high number of maintenance requests and enquiries about the new systems, even the staff stated that they would appreciate guidelines for helping tenants with 'green' features and sustainable living.
- It was noted that the water meter is not in a convenient place, making it difficult for the tenants to keep a close eye on it and thus regulate their usage accordingly.
  - It would appear sensible to locate this in a more prominent position, perhaps in the same place as the electricity meter
- Tenants did state that they were more environmentally aware since moving into the houses, and one tenant stated that her friend were 'fascinated' and thought that she 'had it easy' because of the new technologies
  - This suggests that the scheme has been able to raise awareness and aspirations towards green issues beyond the mere occupant level

4. Devising a Strategy

4.1. A Holistic Approach

Above all, these case studies serve to highlight the fact that the potential benefits of implementing different retrofit measures (I.e. those expressed by SAP software) should not be taken at face value. Therefore, considering the full range of factors, which impact upon a project's success, it is clear that an effective strategy must adopt a holistic consideration of these in order to determine the most suitable approach. This was indeed attempted in Gentoo's project, where extensive research was conducted prior to the commencement of the scheme. The aim of this was to ensure that the products installed were 'people friendly', and that the most suitable homes and products were selected. Another example of this approach may be observed in Ciniglio's (2009) performance review of different micro-generation measures, which assesses each technology against a wide criterion, incorporating economic, performance and human factors. This review is displayed below in table 4.

Table 2: **Micro-generation Performance Review**

Technology / assessment criteria	Ease of installation	Reliability	Performance against design expectation	Running costs	Environmental performance	Ease of resident control	Resident satisfaction	Value for money	Grants and financial incentives	Ease of maintenance and servicing	Overall score (1 – 100)
Sunergy endothermic heating system	2	3	2	3	4	5	2	1	5	5	**32**
Ground Source Heat Pumps	4	5	6	5	7	5	6	5	8	7	**58**
Air Source Heat Pumps	6	4	5	5	6	6	6	7	8	7	**60**
Exhaust Air Source Heat Pumps (NIBE)	5	5	6	2	4	3	3	6	6	4	**44**
Solar thermal	8	8	8	8	7	8	9	8	8	8	**80**
Sun warm system (Nu-Aire)	8	7	4	3	3	6	6	3	7	8	**55**
Photovoltaics (PV)	9	10	10	9	10	10	10	7	10	10	**95**
Rain Water harvesting	5	6	9	7	7	9	8	2	1	7	**61**

Source: Ciniglio, P (2009) *Low impact living for new & existing housing: Incorporating photovoltaics in design strategies and sustainable finance.* Radian Retrofit Presentation

4.2. Accounting for Costs and Benefits

Of course, achieving the best possible value for money will undoubtedly be one of the primary aims of any project. Yet in order to achieve this, a complete understanding of the costs and the benefits involved in installing different measures is required. However, this paper has already explained how establishing a full account of these is a highly complex task. In order to highlight this complexity, the following table attempts to provide a broad account of the potential costs and benefits, which must be considered when undertaking a refurbishment scheme. As it is difficult to quantify some of these, it is unavoidably difficult to determine the precise value of a refurbishment project. However, achieving the best outcome, surely requires the fullest possible understanding of these, and as such it is recommended that the full range of these costs and benefits should be accounted for in any such appraisal.

Costs	Benefits
• Capital costs of installation • Maintenance costs (Lifetime factored for each measure) • Potential cost of relocating tenants • Initial 'learning costs' associated with fitting new technologies • Costs of monitoring performance and satisfaction – *However, this may also be viewed as a benefit as it provides an opportunity for learning* • Rebound or take-back effect may reduce potential savings and environmental benefits • Cost of implementing any accompanying informational strategies e.g. Guidebooks • Additional Professional fees may have to be paid to allow enable certain alterations to be made	• Fuel bill savings • CO_2 emissions reductions • Feed-in Tariff (FiT) • Impending Renewable Heat Incentive (RHI) • Increased property value and/or rental income • Prolonged building lifetime • Increased comfort and associated health benefits • Training and employment opportunities • Opportunity to address wider housing, regeneration and sustainability issues • Opportunity to bring about wider psychological change towards energy-saving behaviour

4.3. Maximizing the rewards

As we have already seen, relying on theoretical models to inform a refurbishment approach is not necessarily conducive to achieving the best results. That is to say that there are wider aspects beyond the scale of the individual building, which must be considered both before and after the implementation of a scheme. In this respect, Greenwood (2008) recommends that a successful retrofit scheme must include an effective follow-up strategy in order to maximize the benefits for the tenants, landlords and the wider community.

Whilst it is commonplace for advice to be given to tenants, there is perhaps the tendency to treat this as something of an afterthought. However, Greenwood (2009) explains that although people are both aware and concerned about the problems relating to household energy use, there remains an uncertainty about the causality of the problems. Thus, it is argued that so called *'informational interventions'* (advice on energy saving behaviour) should be considered alongside *'technical interventions'* (installation of energy saving technologies) as an integral component of any refurbishment scheme (Greenwood, 2009:6).

There are numerous studies on the effects of informational interventions, including that of Abrahamse et al (2005) whom divide these approaches into two categories, namely 'antecedent' and 'consequence' interventions. Antecedent interventions are those aimed at influencing underlying behavioral determinants (e.g. knowledge), whilst consequence interventions are based on the assumption that the presence of positive consequences (e.g. financial savings) will influence behavior. An informational strategy should encompass both of these components and it is generally recommend that for such a strategy to be successful, it should provide advice, which is:

- Engaging
- Accurate
- Consistent
- Targeted; focusing on those aspects of their behaviour which are most detrimental to fuel and energy savings (e.g. leaving windows open or the heating on when they are out of the house)
- Does not provide information on aspects of behaviour, which people are already over familiar with.
- Is underpinned by a 'consequence' rationale I.e. stressing the financial incentives and making people actually want to change their behaviour

Therefore, developing a successful strategy will inevitably require some prior research in order to diagnose the most significant problems. Abrahamse et al (2005:283) describe this as a two-step process, firstly 'identifying behaviors that significantly contribute to environmental problems, and second, by examining factors that make sustainable behavior patterns (un)attractive, such as motivational factors (e.g. attitudes), opportunities, and perceived abilities'. Lastly, it is also worth mentioning that such advice may be given in a variety of forms, from leaflets and handbooks to DVDs, workshops and even media campaigns. Thus it is recommended that agencies should be open-minded in approaching this aspect of a refurbishment scheme and examine all options available to them.

4.4. Training and Employment Opportunities

One of the claimed benefits of refurbishment is that it offers the potential for local economic development (Power, 2008). Of course, one of the most obvious methods of achieving this is through the use of local contractors. However, this does not necessarily guarantee the actual creation of new employment or training opportunities. Therefore, using CTCHG's 'eco-terrace' scheme as a basis, we have attempted to investigate the veracity of this claim and see whether any opportunities could be created. Working with a local charitable organization called the 'Construction Youth Trust' (CYT), the organization has allowed the use of one of its vacant properties in the same street as the 'eco-terrace'. The house will be used as a base for two 10-week construction programs, aimed at young people in the Penrhiwceiber area. The commencement of the second stage of CTCHG's refurbishment scheme is due to coincide with the end of this training program. Hence, it was hoped that further opportunities for the participants of the program could be created within the second stage of this project.

However, it was somewhat unknown whether this link could actually be created as we did not know what skills were required to fit certain technologies, or if the skills learnt during the program would indeed be transferable. Therefore, as part of this process, we have attempted to ascertain which retrofit measures present the best opportunities for training and employment. Broadly speaking, we have tried to assess these measures against the following four criteria:

1. The skill required to fit/or assist in fitting the technology
2. The training required to do so E.g. Any required qualifications
3. The level of staffing or supervision required to oversee a trainee
4. What future opportunities exist in fitting the technology

We have attempted to determine this through consultation with both the Construction Youth Trust, and British Gas's new Energy Academy in Tredegar. The Academy has recently been established with the express purpose of providing training on how to install 'Green' equipment such as solar panels, smart meters and insulation measures, using purpose-built training bungalows. It is thought to be the first of its kind in the UK and is shown in Figure 5. The Manager of the Academy gave his thoughts, as did the project officer of the Construction Youth Trust Scheme, who is experienced in training of young, unemployed people and understands the challenges that they may face. The findings of this research are displayed in the following table and although the descriptions given are only anecdotal they are perhaps useful as a rough guide to what skill levels are required and what opportunities might exist. The renewable energy systems are displayed against a green background.

Measures	Skill Level	Training requirements	Staffing requirements	Future opportunities
Hot water cylinder insulation	Very basic measure, Simple to fit.	No formal qualifications required	An apprentice could be accompanied at a 1 to 1 ratio. So very simple to operate	94.4% of tanks are now insulated and the number of Cylinder tanks is now fallin. Hence this measure is close to Saturation *
Loft insulation (full and top-up)	Most simple of the measures to fit. Filling joists requires the ability to measure and cut	No Formal qualifications asides from abiding by H & S regulations.	High supervision is not required but a ratio of 2 staff to 1 trainee is reasonable due to potential dangers of working in loft space	Although between 90-95% of houses now have insulation, yet there is scope for increasing its depth and replenishment in the future*
Solid wall insulation	Far more complex than cavity wall insulation although dry lining could be done more simply using basic 'mark and measure' skills	Insulation in general is seeking to be recognized as a trade but no official recognition as yet. Basic H & S training required	As above	Far less homes have Solid Wall insulation and it is likely to be a necessity in many cases. Some suppliers are beginning to offer training.
Improved heating controls	Specialist electrical skills required.	Specialist qualifications required. However, British Gas are currently offering training to fit 'Smart Meters'	There does not appear to be many opportunities except for electrical apprentices.	More Smart Meters being fitted and Heating Controls now recognized as important retrofit component. However, opportunities will likely be within the domain of Electricians
Draught proofing	Another Simple insulation measure, requires only basic handiwork skills	Not independently recognized and so no official qualifications required.	This could be fitted safely and with minimum supervision	Not formally recognized as a trade but could be offered as part of wider carpentry services
Micro CHP	Highly Specialized	Official engineering qualifications required	N/A	Potential for further implementation but relatively unknown
Ground source heat pump	Certain elements require specialist skills, yet there is perhaps scope for trainee assistance in labouring type work	Again, specialist qualifications are required, and training is currently being offered at British Gas's Energy Academy	A high level of supervision would undoubtedly be required for the full installation of this measure due to its size and the technical aspects of fitting	Again, the potential for further implementation is relatively unknown at this stage but further implementation is likely in some capacity

Measures	**Skill Level**	**Training requirements**	**Staffing requirements**	**Future opportunities**
A-rated boiler	Gas engineering skills required	Official qualifications required but can be achieved through apprenticeships	The level of supervision will depend on that deemed necessary for the apprenticeship	Uptake has increased dramatically (from 1.5% in 2000 to 14.8% in 2006) and opportunities will exist in both fitting and in maintenance*
Photovoltaic (PV) electricity	Full installation requires specialist, technical skills (In electricals) yet the fiittng of the Panel to the roof could perhaps be fitted separately, requiring a lower skill level.	Specialist qualification (NICEIC) required and is currently offered through a range of institutions yet specific pre-requisites are required	A high level of supervision would likely be required due to the hazard of working at heights	Likely to be an area of high growth, particularly if financial incentives continue and capital costs decrease
Solar water heating	As above, but specialist plumbing skills would be required	As above. Such a course is currently being offered by the British Gas Academy. However, once again specific pre-requisites are required (NVQ Plumbing)	As above. Further supervision is required if the system is to be fitted to shower system etc.	There are currently far more Solar Systems than PV panels. However, the basic skills required to act as an assistant are likely to be similar and therefore, the opportunities may be treated similarly

Source: British Gas and CYT. *Shorrock and Utley (2008)

Although this method of research is rather unscientific, it appears that there is likely to be significant variation in the opportunities that are likely to be created for local people, depending on which measures are implemented. It seems that Insulation measures provide the most opportunities at the most basic skill level, although there is perhaps less potential for future (long term) employment in this field as the market appears to be reaching Saturation, and little maintenance is required. Conversely, the somewhat more complicated measures such as Solar and PV panels, although requiring a higher level of supervision, are likely to provide more sustainable, long-term employment opportunities. This is even more likely if the full qualifications are achieved, as the industry appears to be recognized more independently than that of insulation, and is more closely aligned with existing trades (e.g. Solar Thermal to Plumbing). This is also true of installing A-rated boilers, which requires Gas Engineering qualifications, and even Ground Source Heat Pumps, which although rather niche, will certainly require a specialized skill set.

Figure 5: Photographs of the British Gas Energy Academy in Tredegar

Source: Author's Photographs

In summation it appears that although the Insulation measures may offer a more straightforward, instant-hit for training opportunities, it is likely that the more sustainable employment routes will exist in the fitting and maintenance of renewable systems. However, both should be considered on their own merits and it is probable that key personal skills such as communication and organization could certainly be gained through the creation of any future opportunities. Thus it is important that this aspect of a retrofit scheme is attempted wherever possible as it forms an important bridge between the physical and the social regeneration efforts. What's more, it is also likely that by doing so, a greater sense of community 'buy-in' may be achieved and a greater sense of community pride/ownership may be felt.

This paper will now investigate the efficiency value of different technical interventions. Following this examination, some recommendations will be made about which combination of measures appear to provide the best value for money and accrue the highest Carbon/fuel bill savings. Rickaby (2010:9) stresses that such an evaluation of 'capital costs and Carbon cost effectiveness' is fundamental to devising a successful retrofit strategy. As such, this section may be viewed as the core component in determining the most suitable retrofit approach.

4.5. Establishing Retrofit Limits

In completing a retrofit project, Yates (2006) stresses the need to maximize investment return and remain within the project's economic 'sustainability limit'. This economic limit is the point beyond which the refurbishment costs would exceed the benefits in financial terms. Here the economic returns may be quantified according to:

- Reduced Fuel Bills
- Raised Market Value
- Increased Rental Income
- Avoidance of Carbon Emissions costs

In addition to the economic aspect, the sustainability limit outlined by Yates (2006) also takes account of environmental and social components. In general, it is likely that these impacts will be mostly positive. Nonetheless, implementing such schemes can result in detrimental environmental and community impacts and therefore, such impacts must also be considered when determining this sustainability limit.

In environmental terms, this limit relates to the emissions and pollutants created through the construction process, and also to any other potential damages caused (e.g. damages to soil and water quality or to animal habitats). Yates (2006) observes that the social impacts may be the most difficult to quantify and assess. In this respect, it is recommended that care be taken to avoid over-gentrification, which may result in the loss of original community. Above all it is advised that a genuine community buy-in should be achieved through effective pre-planning and consultation. Such community engagement is also cited as an important factor in maximizing the environmental and financial benefits of the implementing these schemes (Yates, 2006).

4.5.1. Determining the Economic Limits

By quantifying the costs of installing different retrofit measures, and the financial returns that will be accrued through fuel bill savings and carbon savings it is possible to estimate the required level of expenditure to achieve a given outcome. Such models are drawn in this paper, which attempts to determine the level of investment that would be required to prevent fuel poverty, and achieve a significant CO^2 emissions reduction. Whilst the models do not take account of all of the factors listed above in the 'costs and benefits' table, they do provide a guide as to which technical intervention measures are the most cost-effective. The estimates made relate to a pre-1919 terraced property and use a poor condition, 'hard to heat' house with no existing retrofit measures as a baseline. The methodology used to develop this model will now be discussed and different models will be presented below.

5. Methodology

5.1. Establishing a Baseline

In assessing the potential benefits of completing a retrofit scheme, it is first necessary to establish an acceptable baseline from which to measure any improvement (or decline) in performance and running costs.

As a starting point, a notional dwelling modeled using the full BRE SAP software. The modeled property was that of a poor, 'hard-to-heat' mid terraced house with none of the detailed relevant retrofit measures installed. A summary of the characteristics of this property, as well as its SAP rating and estimated CO^2 Emissions are displayed below:

Dimensions

- Mid Terraced Property
- 2 storey property
- Total floor area of $79m^2$
- Total volume of 198.15 m^3
- Total area of external elements (doors, windows, wall and roof) 104.8m2

Building Fabric

- Solid Stone Walls
- Single Glazed Windows
- Wooden doors
- Loft insulation below 2.5cm
- No Wall Insulation
- 1 Chimney

Fuel System

- Gas Fuel supply
- Gas Fired Back Boiler

Household Assumptions

- Occupancy of 2.45
- Annual mean internal temperature of 18.26°C

Performance

- A SAP of 44
- Estimated Co^2 Emissions of 5967 kg/yr
- SAP band: **E**

5.2. Detailing Retrofit Measures

The next step in developing the model was to obtain data on the costs and benefits of each individual retrofit measure. The model utilizes and builds upon the mix of domestic efficiency measures that are identified in the DCLG's (2006) 'Review of the Sustainability of Existing Buildings'. For each of these measures it was necessary to infer estimates pertaining to:

a) The capital costs of installation
b) The annual fuel bill savings
c) The annual Carbon emissions savings
d) The lifespan of each measure
e) The SAP points that would be gained through their installation

Care was taken to ensure that the estimates of each measure were taken from the same source so that that fair comparisons could be made. Thus, for the purpose of the model, estimates of the capital costs and the fuel and Carbon savings were taken from the DCLG's review (2006). Whilst it is accepted that these estimates are inextricably dependant upon a number of factors (e.g. housing stock type, household composition, the availability of grant funding etc), it is deemed necessary to use these as a guide for the reason mentioned above. However, for an idea on what the actual costs of implementing these measures might be (and how these vary considerably) a number of case studies are provided towards the end of this paper.

Meanwhile, estimates for the SAP points that would likely be gained through the implementation of each measure were obtained through consultation with the Building Research Establishment (BRE). Lastly, the lifespan of each measure was taken from CTCHG's planned maintenance program, which specifies when each measure would need to be renewed/replaced. This planned maintenance program is informed by estimates made in the HAPM component life manual, which is updated twice a year and is used as the industry standard for guidance. For measures that were not detailed in the planned maintenance, (I.e. renewable energy systems) the BRE was again consulted to make estimates on the lifespan of certain technologies.

5.2.1. Carbon Pricing

In terms of determining the financial costs and benefits, it was also necessary to put a price on the CO_2 emissions that would be saved through the use of each measure. Details of this procedure were obtained from the Welsh Assembly Government (WAG), and were based on the following prices:

- Non-Traded Emissions – £60 per Tonne
- Traded Emissions – £25 per Tonne

Emissions reductions in the electricity sector fall into the traded category, whilst reductions in the Gas, Coal, Fuel/Heating sectors fall into the non-traded category. Thus, Carbon reductions achieved through implementing measures, which heat a property and improve its thermal efficiency are treated as non-traded and are priced accordingly. Meanwhile, Carbon reductions attained through utilizing renewable energy sources are priced using the traded Carbon price as these savings reduce the need for electricity from the National Grid.

Using this data, it was possible to estimate which measures were the most cost efficient in achieving:

a) A financial return from both fuel and Carbon savings
b) An improved SAP rating
c) A Reduction in Carbon emissions

Subsequently, these measures could be ranked, and modeled to display the economic limit of financial investment and the level that would be required to achieve an acceptable SAP rating (WHQS) and accrue significant reductions in CO^2 emissions. The models are displayed below in the ‘Data Analysis and presentation’ chapter.

Table 2: Domestic Efficiency Measures – estimated costs & savings

(Renewable Energy sources highlighted in green)

Measures	Average cost (£)	Fuel costs saved (£/yr)	Carbon saved (kgC/yr)	Pay- back time (yrs) [Fuel savings only]	Priced Carbon Savings (£/yr)	Estimated SAP points gained	Estimated cost (£) to achieve 1 SAP point	Total fuel and Carbon savings (£)
Hot water cylinder insulation	14	29	53	**0.5**	3.18	1	14	32.18
Cavity wall insulation	342	133	242	**2.6**	14.52	10 - 16	21.4 - 34.2	147.52
Loft insulation (full and top-up)	284	104	190	**2.7**	11.40	5	56.8	115.40
Improved heating controls	147	43	77	**3.4**	4.62	2	73.5	47.62
Draught proofing	100	23	43	**4.3**	2.58	1	100	25.58
A-rated boiler	1,500	168	177	**8.9**	10.62	12	125	178.62
Windows (Single to Double Glazing)	4,000	41	26	**97.6**	1.56	4	1000	42.56
Solid wall insulation	3150	380	694	**7.5**	41.64	12 - 18	175 - 262.5	421.64
Micro CHP	1,571	230	508	**6.8**	12.70	12	130.9	242.70
Micro wind	2,363	224	263	**10.5**	6.58	N/A	N/A	230.58
Ground source heat pump [3]	4,725	368	990	**12.8**	59.40	N/A	N/A	427.40
Photovoltaic (PV) electricity	5,500	212	249	**46.4**	6.23	6 - 8	687.5 - 916.7	218.23
Solar water heating	5,000	48	88	**104.2**	5.28	6 - 8	625 - 833.4	53.28

Source: DCLG (2006), updated using estimates obtained from the BRE (2010)

5.3. Determining Limits

5.3.1. Carbon Emissions

Using the aforementioned emissions rate of 5.967 Tonnes/yr as a baseline it was possible to estimate the percentage of Carbon savings that could be accrued through implementing each retrofit measure. Whilst it emerged that the target of an 80% reduction was unachievable using these measures, it became apparent that there was substantial variation in their effectiveness and their cost efficiency. This variation is displayed in Graph 7. For a more detailed examination of the potential Carbon reductions that may be achieved through different measures, a Marginal Abatement Cost (MAC) curve has also been devised and is displayed later in this paper. This method of analysis is more accurate as it takes account of the lifetime of different measures and of the interest accrued on potential savings.

5.3.2. Fuel Poverty levels

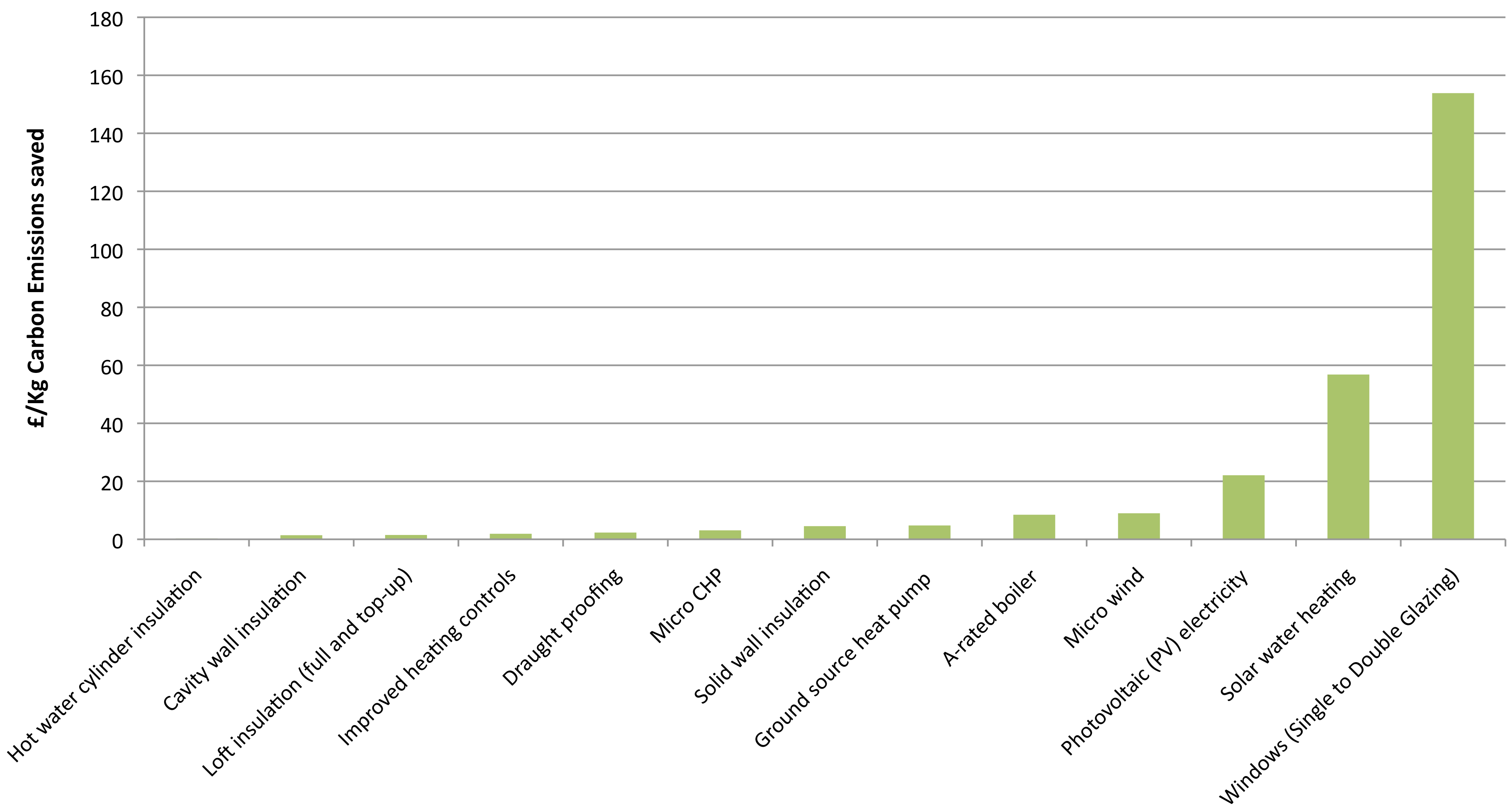
One of the key objectives of upgrading a home's energy efficiency is to reduce the cost of household bills and prevent fuel poverty. However, it is difficult to set a definitive point at which fuel poverty will be avoided, as the state of fuel poverty is dependant on a wide range of household circumstances beyond the mere efficiency of the building (e.g. household composition and income). Nevertheless, the Welsh Housing Quality Standard (WHQS) published by WAG, seeks to provide a 'common target standard for the physical condition of all existing social housing in Wales' and the standard cites the 'eradication of fuel poverty' as a 'strategic priority'. In this respect, a range of minimum energy efficiency requirements is outlined, including a minimum SAP rating for properties of varying sizes.

The floor areas of properties in a typical pre-1919 terraced street in Penrhiwceiber, South Wales, were obtained from Cynon Tâf Community Housing Group and it was then possible to establish the SAP that would be required to achieve the WHQS. The average floor space for these properties was:

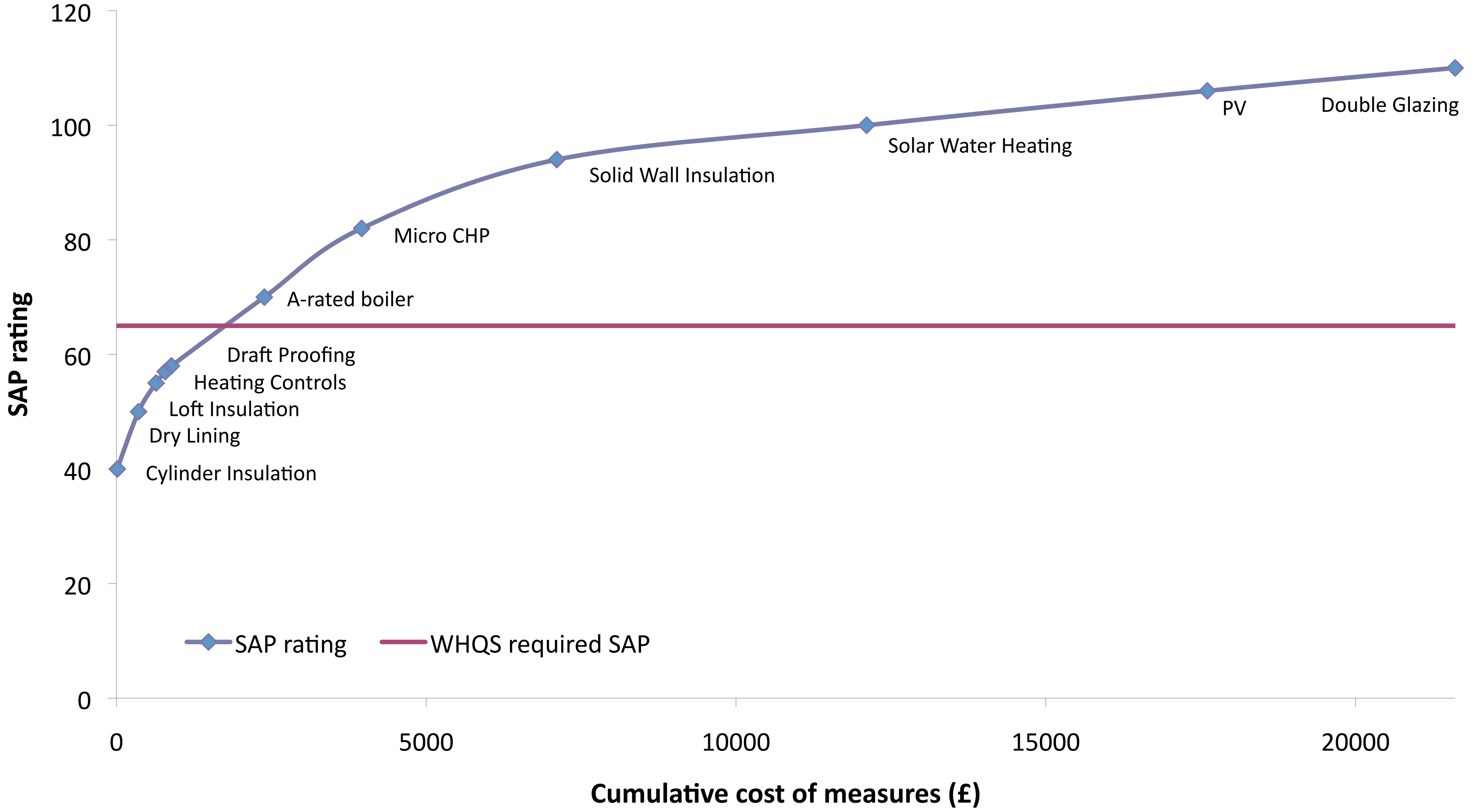
- **70m^2** for a 3 storey property
- **77m^2** for a 2 storey property

Although the floor area for a 2-storey property was actually more than that of a 3-storey property, both fell into the same category with regards to the required minimum WHQS SAP rating. This minimum SAP requirement was **65.** The required investment to achieve this standard is displayed in Graph 8.

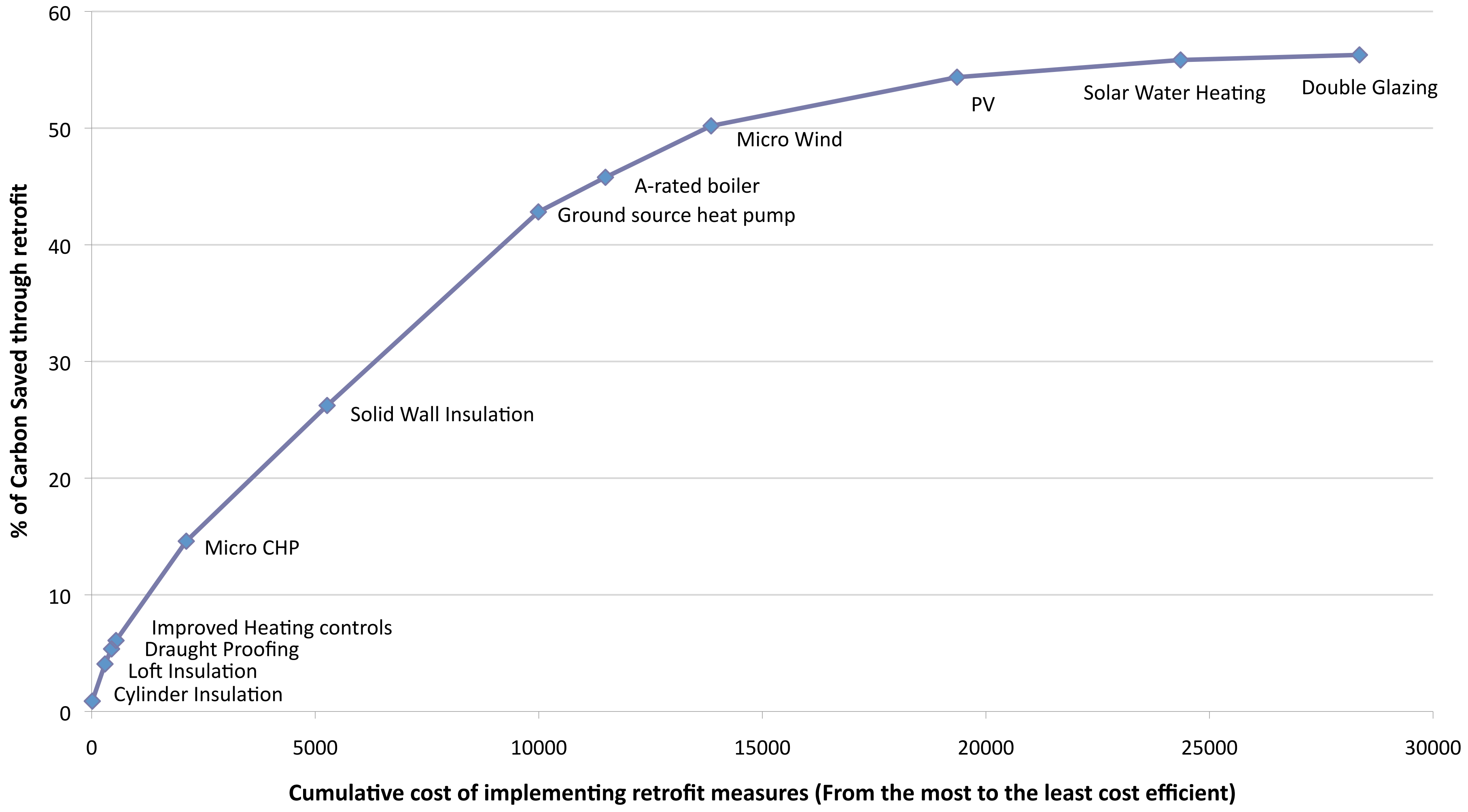
Graph 7: Cost efficiency of achieving CO^2e reductions

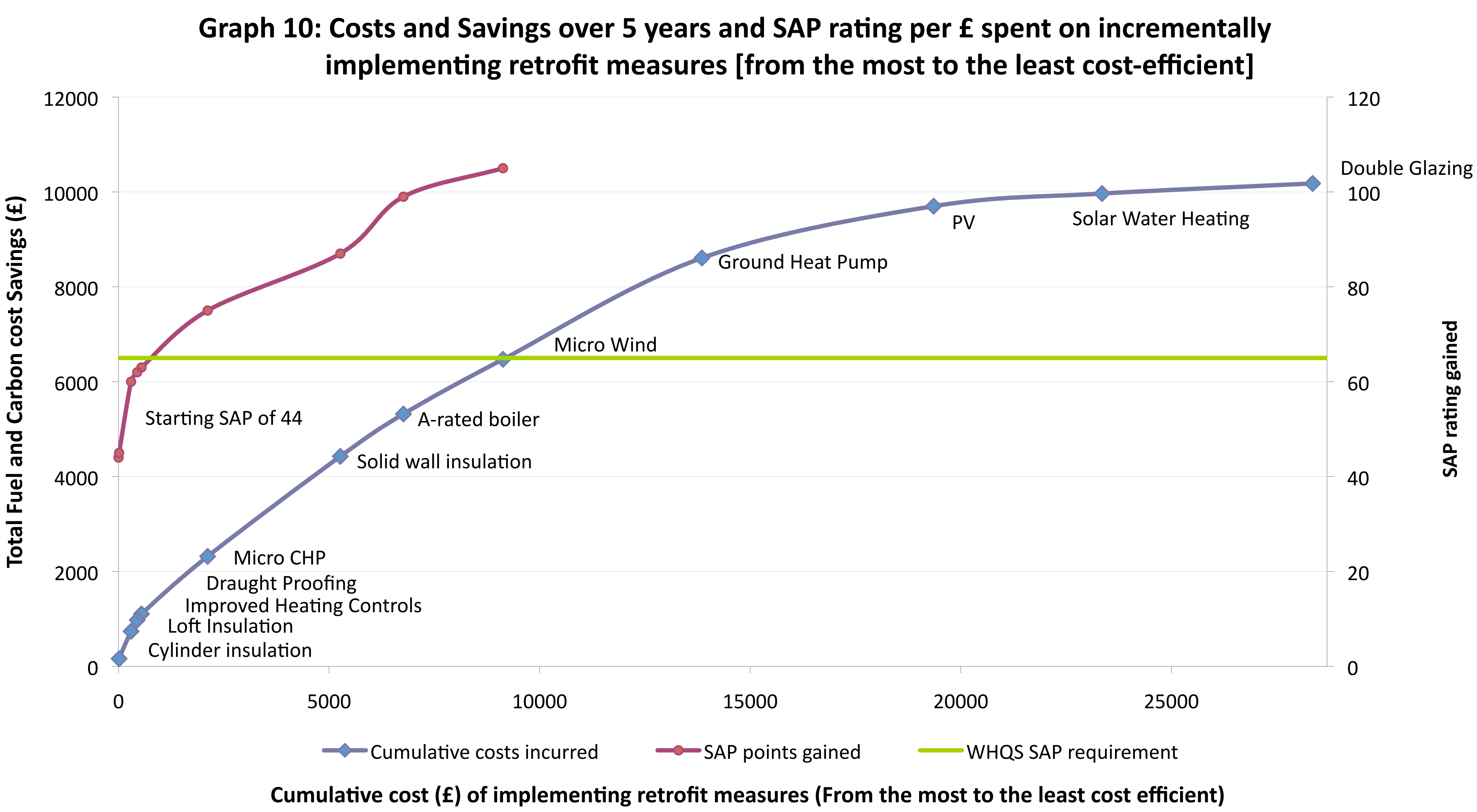


Graph 8: Most cost effective SAP improvements for a 'hard to heat' terraced house with no existing retrofit measures



Graph 9: Percentage of CO^2e saved per £ spent on implementing different retrofit measures [From the most to the least cost efficient]




Graph 10: Costs and Savings over 5 years and SAP rating per £ spent on incrementally implementing retrofit measures [from the most to the least cost-efficient]
Total Fuel and Carbon cost Savings (£)
SAP rating gained
12000
10000
8000
6000
4000
2000
0
120
100
80
60
40
20
0
0
5000
10000
15000
20000
25000
Double Glazing
PV
Solar Water Heating
Ground Heat Pump
Micro Wind
Starting SAP of 44
A-rated boiler
Solid wall insulation
Micro CHP
Draught Proofing
Improved Heating Controls
Loft Insulation
Cylinder insulation
Cumulative costs incurred
SAP points gained
WHQS SAP requirement
Cumulative cost (£) of implementing retrofit measures (From the most to the least cost efficient)

6. Data Presentation and Analysis

This section of the paper will describe the results displayed in the preceding graphs and the MAC curves, which are displayed below. It is known that there are many limitations to the true reliability of these models, yet they remain useful as a guide to the performance of the different types of retrofit intervention. To explain the limitations of this data, and to highlight how difficult it is to actually create such a comprehensive, reliable model, the 'Limitations' chapter will follow.

6.1. Graph Analysis

Firstly, Graph 7 shows that some retrofit measures are far more cost effective than others in achieving carbon reductions. The cost efficiency of implementing simple insulation measures, such as cylinder insulation and draught proofing is far higher than that of the more complex renewable energy systems. However, this graph does not tell us anything about how much Carbon can be saved by each measure. This also varies greatly as is displayed in Graph 9. Similarly, Graph 8 shows that such basic interventions may be highly effective in achieving an improved SAP rating. What's more, the graph reveals that the WHQS requirement of 65 is likely to be achievable through implementing only a handful of simple measures.

Graph 9 displays the percentage of CO_2 saved per pound spent on implementing the different measures, ranging from the most to the least cost efficient. The graph is a rather rudimentary way of analyzing Carbon savings, as it does not account for a whole range of factors, which influence actual emissions (e.g. the lifetime of the measures). However, it does show that significant savings may be made through improving the insulation of a building, and at a relatively low cost, by comparison with the use of renewable energy installations. Furthermore, it reveals that it is highly unlikely (even impossible using only the detailed measures) that an 80% reduction target can be achieved through retrofitting this type of property.

Graph 10 displays the costs and savings that would likely be made through retrofitting alongside the SAP rating that would be attained. The costs relate solely to the capital costs of installation, while the savings are only financial and are calculated by adding the potential fuel bill savings to the sum of the saved Carbon emissions, priced according to the aforementioned tariff outlined by the Welsh Assembly's Climate change division. The graph shows that there is a clear case of diminishing returns, as the rate of savings made decrease towards the tail end of the chart. Moreover, it is evident that there will become a point at which retrofitting further measures will result in a net financial loss over the 5-year period. This point may be identified in the following MAC curves, which display the net financial costs/rewards over the lifetime of these different measures. Finally, the graph also suggests that it would be cheap to achieve the WHQS, energy efficiency standard of SAP 65, as the specific measures required to achieve the target have a relatively low capital cost (see Table 2 for the specific prices used in these models).

6.2. Marginal Abatement Cost (MAC) curve

A Marginal abatement cost (MAC) curve is used as a financial tool to compare the merits of competing carbon reduction projects and technologies. Nicholls (2011) explains how a MAC curve can be used to represent the cost per tonne of CO_2 abatement (emissions reduction) and the amount of Carbon abatement potential compared to a 'without policy' baseline (taking no action). Furthermore, they are useful for determining what the price of carbon needs to be for a project to become more financially viable than inaction, and what combination of measures need to be employed to reach a specific carbon reduction goal (Somar, 2010). Consequently MAC curves are useful to both businesses and governments as they help them to make informed decisions on how best to meet carbon reduction targets or obligations (Somar, 2010).

The actual Marginal Abatement Cost of each measure is calculated by dividing its Net Present Value (NPV) by its total lifespan CO_2 savings. NPV is based on the capital cost of a measure's installation, lifespan, annual costs/savings and the discount rate. The discount rate is the minimum level of return on investment deemed acceptable. In this instance only the current rate of inflation (4.4%) is used, as the project is not presented as a commercial venture (BoE, 2011). The figures displayed below in table 4, correspond with the two following MAC curves.

Table 4: Marginal Abatement Cost (MAC) data and calculations

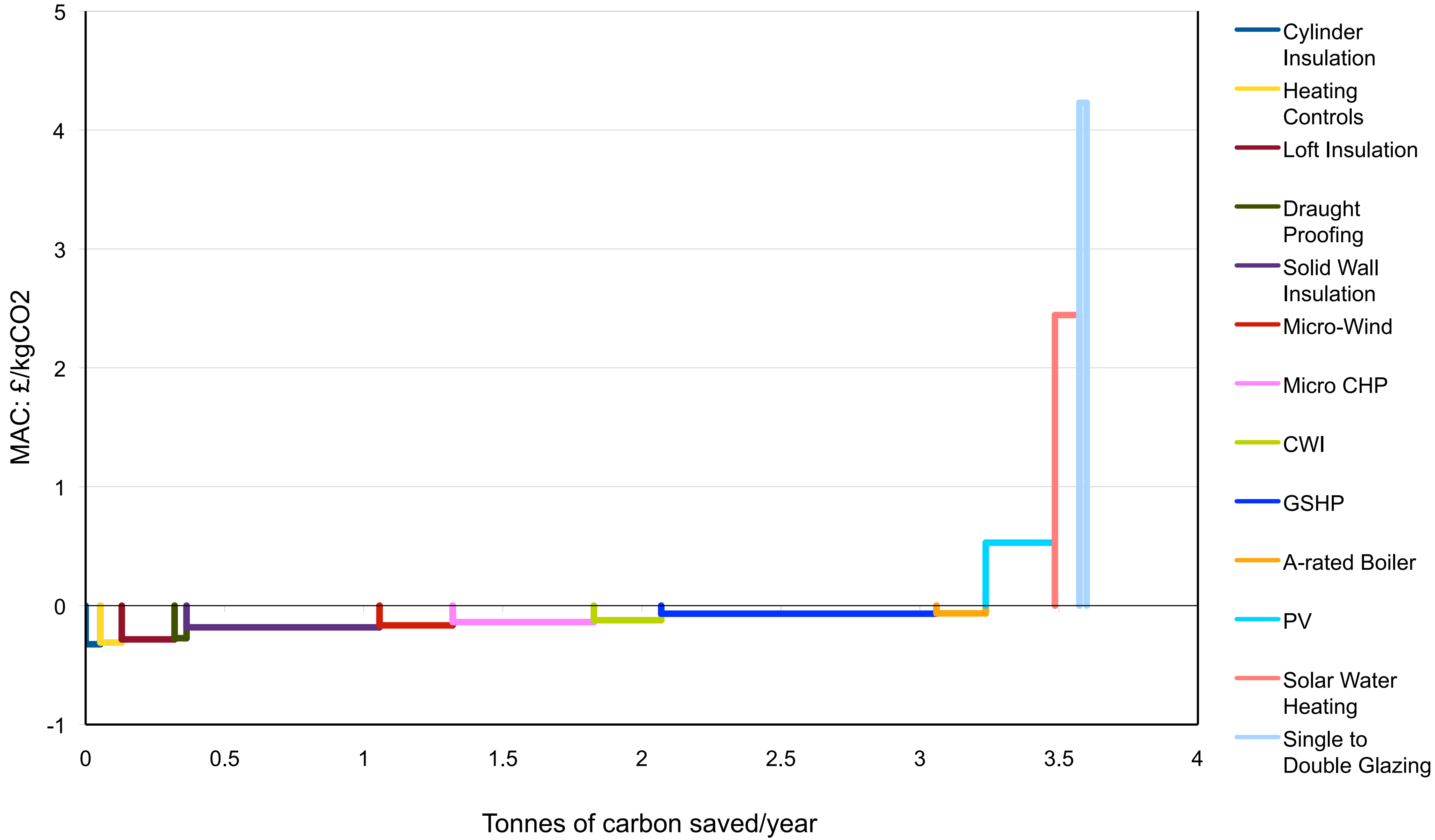
Project name	Capital cost	Annual benefit (Carbon + Fuel savings)	Annual average CO2 savings for project	Project life	Net Present Value (NPV)	Marginal Abatement Cost (MAC)	Cumulative CO2 savings for all projects
	(£)	(£)	(tonnes/year)	(years)	(£)	(£/tonne)	(thousand tonnes/year)
Cylinder Insulation	14	32	53	30	-516	-0.3	0.1
Heating Controls	147	48	77	20	-478	-0.3	0.1
Draught Proofing	100	26	43	15	-1618	-0.3	0.2
Loft Insulation	284	115	190	30	-177	-0.3	0.4
Cavity Wall Insulation	342	148	242	100	-3800	-0.2	0.6
Solid Wall Insulation	3,150	422	694	30	-1092	-0.2	1.3
Micro CHP	1,571	243	508	15	-1053	-0.1	1.8
GSHP	4,725	427	990	25	-2966	-0.1	2.8
Micro-Wind	2,363	231	263	25	-1678	-0.1	3.1
A-rated Boiler	1,500	179	177	12	-138	-0.1	3.2
PV	5,500	218	249	20	2637	0.5	3.5
Solar Water Heating	5,000	53	88	20	4301	2.4	3.6
Double Glazing	4,000	43	26	30	3299	4.2	3.6

Interpreting the MAC Curve

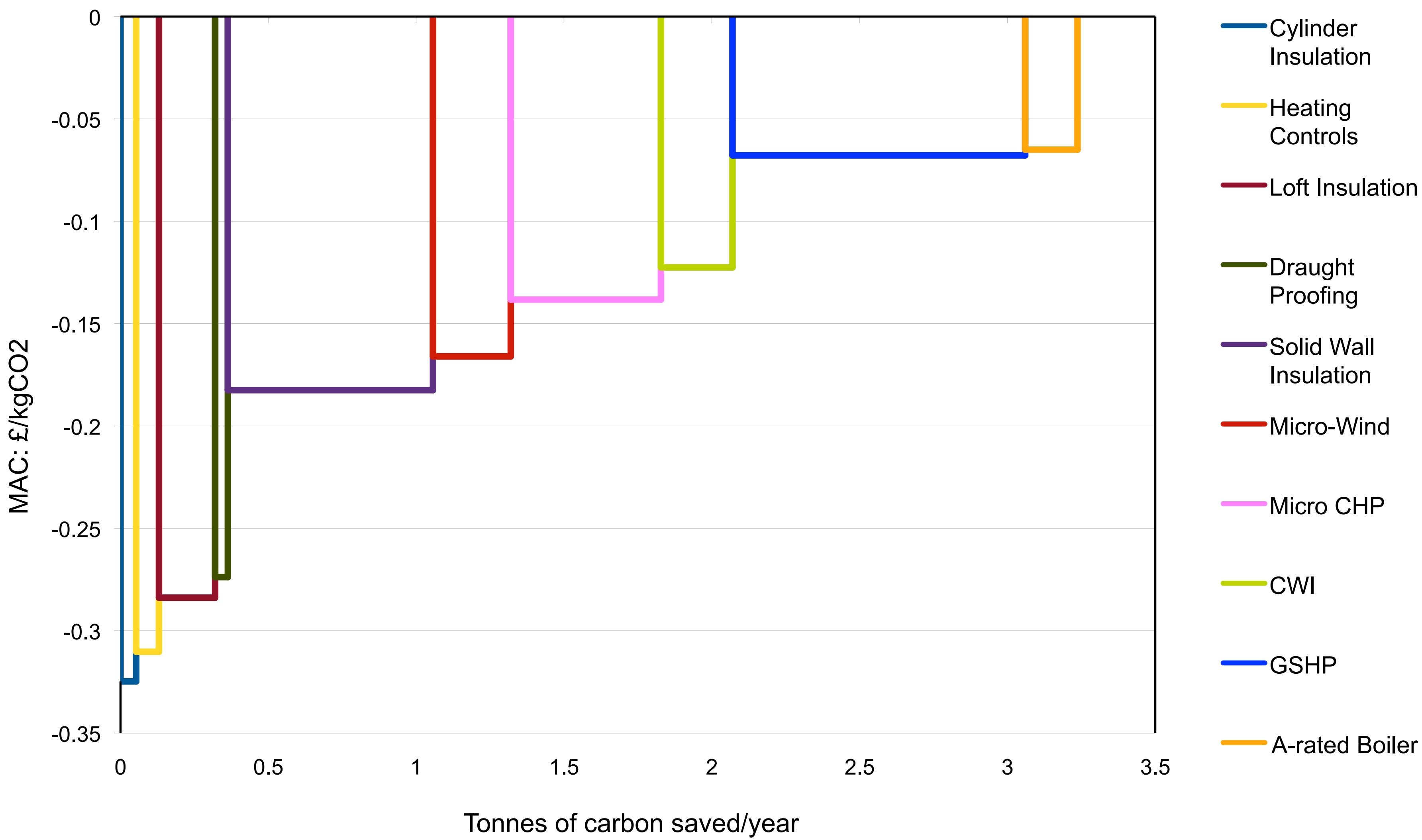
MAC curves are variable-width histograms, which plot marginal abatement cost against the amount of carbon saved. Put simply, they show the cost efficiency of different measures and the carbon emissions reductions that each one would provide. The measures are displayed in ascending order of efficiency (from the lowest to the highest marginal abatement cost). Measure's that display a negative marginal abatement cost will pay for themselves over their lifetime, whilst those which display a positive MAC will ultimately result in a loss.

The first model displayed below shows the MAC of all of the measures detailed in table 4. However, due to the large variation in the MAC of these measures, it is difficult to determine the actual details of the performance of certain measures as the chart is dominated by the most inefficient interventions (most notably; double glazing). Therefore, the second model excludes the three most cost inefficient measures, (which do not provide a net gain on investment) to allow for a more detailed comparison and analysis. For clarification, the labels on the right hand side of the model are also displayed in ascending order with the most efficient measures at the top of the list and the least efficient at the bottom.

Marginal Abatement Costs (MAC) for different retrofit measures



MACC without three most cost-inefficient measures



6.3. MAC Analysis

The MAC curves show that the most cost-efficient measures to implement are actually the somewhat more basic interventions. For example, insulation measures and improved heating controls show better value for money than installing renewable energy systems. However, it is worth noting that the use of such measures will only bring about rather modest CO_2 savings and will certainly not reach an 80% reduction target. Therefore, it is clear that further measures, including the use of renewables, will need to be introduced if we are to significantly reduce emissions. However, even if all measures are implemented, it appears that such a target is unachievable under current conditions, suggesting that changes in other areas (e.g. changes in our energy using behaviour, improvements in technology and further de-carbonization of the national grid) may be required if we are to successfully meet this objective. Nonetheless, the charts show that the majority of measures will pay for themselves over their lifetime. What's more, it is likely that even the currently non-cost-effective measures of Solar water heating and PV will become more attractive as capital costs fall and the technology becomes more mainstream. In the face of the environmental challenge, this is encouraging as it shows that there truly are financial gains to be made by cutting our emissions, and that the installation of such measures are thus incentivized in both financial and environmental terms.

Perhaps the most notable aspect displayed in the MAC curves is the great variation in value between different measures. For example the low value of double-glazing is extraordinary when compared to the majority of the other thermal efficiency measures. Nevertheless, there are of course, other reasons to implement such apparently low-value measures particularly as CO_2 reduction is unlikely to be the sole aim of a project. For example, double-glazing perhaps offers improved security and durability, while the additional income that PV panels may provide through the Feed in Tariff may make their use worthwhile. Indeed, Nicholls (2011) explains that cost effectiveness is just one of a number of criteria that must be taken into account when considering policy options. Thus, whilst these MAC curves are useful as a guide to technical interventions, there are a number of other factors, which the model does not and cannot take account of. These will be discussed below in the 'limitations' chapter.

In summation, it appears that although thermal efficiency measures are the most cost-effective measures to install, additional retrofitting through utilizing Renewable energy sources does have the potential to further improve the energy efficiency of a building and enable substantial carbon reductions. However, such measures are generally more expensive and the time taken to accrue a financial return on the initial investment will be far longer.

7. Limitations

As previously stated, it is actually very difficult to create a comprehensive, reliable model, which will display the full costs and benefits of implementing different technical interventions. This is because there is such a wide range of factors that influence actual energy use and Carbon emissions, many of which simply cannot be incorporated into a theoretical model. The constraints of the preceding models will now be outlined, and a description of these additional factors will be provided.

7.1. Reliable Data

One of the most important, yet most difficult aspects of formulating the above models was in acquiring reliable, comparable data for each of the measures. That is to say, that, the data used in the models is necessarily based on estimates, and true costs and savings will be dependent on a wide range of variables. Indeed, although empirical data could be attained for certain measures (as highlighted in the case studies), this could only be attained for certain measures, installed at a particular time, to a particular standard and on a particular dwelling type. Therefore, it was somewhat difficult to include such figures in these models, as they were too specific to the individual projects from which they were derived. Thus, a more comparable, across-the-board type of source was used to provide data on these measures (the DCLG's Review of Sustainability of Existing Buildings, 2006). Although this source provided a comprehensive set of data on these measures, this too was not without its faults.

Firstly, the data provided (capital costs, and fuel and carbon savings) could not be tailored to the specific notional dwelling that was used as a baseline. In fact the specified figures obtained from this source related to a 'typical 3-bed semi-detached property' (DCLG, 2006:8). It is likely that this discrepancy may have slightly skewed the data to overestimate the value of insulation measures as semi-detached properties have one more external wall than mid-terraced dwellings. Therefore, the prevention of heat loss through this additional wall will inevitably contribute to a greater improvement in the thermal efficiency of the building. Meanwhile, such prevention is impossible in a terraced house, as all sidewalls are shared in the first place and thus, there is logically less scope for improvement using such insulation measures.

Also noteworthy, is the fact that the data used is now 5 years old. Hence, it is highly likely that the capital costs of certain measure will have changed in that time period, as will the estimated fuel bill savings due to price fluctuations. Moreover, Nicholls (2011) notes that one of the weaknesses of MAC curves generally, is that they are static and cannot take account of future technological changes or innovation. What's more, this leads us to another issue with regards to the limits of the data. That is, that the models do not assume any decarbonization of the national grid, and are therefore fixed in a specific energy scenario, which relies heavily on the use of fossil fuels, which produce far higher emissions than renewable sources.

Another important issue regarding the reliability of the data is that although certain measures are specified (e.g. Loft insulation), the models do not differentiate between different types/brands of technology. This is important, as there is likely to be considerable variation in the price and quality of these measures, depending on the supplier, and the level to which they are applied. For example, 'aerogel' insulation is far more expensive than the standard 'Rockwool' type of insulation, but may provide improved thermal efficiency, and the added benefit of taking up far less space than the latter. However, perhaps a more important issue regarding such reliability is the fact that the on-site construction issues cannot be accounted for. Indeed, Rickaby (2010) argues that it is vital to commit time and attention to detail on site, to ensure that the measures are well installed to ensure highest possible level of performance. In fact, Rickaby (2010:23) contends that 'a poor installation may result in twice the heat loss (and emissions) associated with a good one'. This would suggest that it is particularly important to appoint a good quality contractor, to ensure that the alleged, theoretical benefits of these measures can actually be achieved in practice.

7.2. Scope of the Models

It is important to acknowledge that the models drawn in this paper are limited in their scope, and are only able to account for a certain amount of data, within a specific time frame. This is somewhat unavoidable, yet there are some important issues to consider here, which provide a more complete picture and may influence the decision-making process.

Firstly, the most obvious issue here is that the models only account for a certain number of retrofit interventions and there are far more technical interventions that may be installed as part of a scheme. Some of these are relatively new technologies that are yet to fully penetrate the market ('Powerpipe' water re-heating), whilst some are more commonplace, yet small and specific interventions e.g. A change to more efficient appliances and low energy lighting. Many of these measures may also contribute to a cost-efficient, Carbon reduction programme and thus it is recommended that such measures be investigated and considered as part of any actual Retrofit strategy. Conversely, some of the measures detailed in the models may not actually be installable on such a 'hard to treat' terraced house. Indeed, a variety of factors will be important to consider here. For example the absence of suitably orientated roof will exclude the use of Solar or PV panels, while a building made entirely from solid stone walls will exclude the use of cavity wall insulation. Furthermore, particular Planning constraints may also have to be considered if any external works are considered (E.g Solid Wall insulation to the exterior of a building).

Secondly and perhaps more importantly, the measures detailed in the models are only addressed in isolation and therefore the interaction between the different measures are consequently unaccounted for. Rickaby (2010) and Nicholls (2011) explain that accounting for these interactions is vital, as the co-ordination of certain measures is viewed as a key strategy in completing a retrofit. For example, Rickaby (2010) argues that the use of uncoordinated, incremental measures such as the use singular use of Cavity Wall insulation will not be good enough to achieve our emissions reduction targets. This is also important, as some measures may be mutually exclusive to certain dwellings (E.g. Solar heating or PV panels) and therefore, an either/or choice will have to be made between them.

Also important is the fact that the models created do not account for any other sustainability interventions e.g. Water saving or design issues. Therefore, they are only able to provide a rather narrow focus on sustainable housing (albeit upon a key issue of pressing concern). However, as they are unable to provide the solution to any of these wider issues they should be treated in isolation and their limitations should be acknowledged.

8. Conclusions

This research has found that refurbishing an old, 'hard-to-treat' terraced property to a high environmental standard is both difficult and expensive. Improved thermal efficiency will only achieve a certain standard necessitating the use of renewable systems if we are to meet our ambitious objectives. There are technical difficulties involved in selecting the most suitable combination of measures and in ensuring that these measures will operate to the standard predicted by theoretical models (SAP). Additionally, there is a wide range of costs involved which are somewhat unpredictable and difficult to account for, whilst a greater evidence base is required in order to verify the benefits of implementing certain measures. Furthermore, household composition and behavioural issues have been highlighted as major factors in achieving these alleged benefits, regardless of the quality of the scheme. Therefore, it has emerged that prior to commencing a retrofit scheme, a thorough, coordinated planning process is required to ensure that all potential costs are accounted for and the maximum value is derived from both the refurbishment itself, and the process of construction.

Despite these difficulties, the need to retrofit this old stock type is clear if we are to meet our current emissions objectives. What's more, such refurbishment may present a great opportunity, to address a whole range of additional issues and should therefore be viewed as a central element of a wider regeneration strategy. From addressing housing density problems, to the creation of training and employment opportunities, the benefits of retrofitting this stock stretches beyond the scale of the individual building.

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