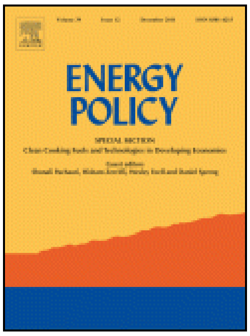

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Domestic UK Retrofit Challenge: Drivers, Barriers and Incentives leading into the Green Deal

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Abstract

This paper reviews the thermal performance of the existing UK housing stock, the main fabric efficiency incentive schemes and the barriers to obtaining deep energy and CO_2 savings throughout the stock. The UK faces a major challenge to improve the thermal performance of its existing housing stock. Millions of dwellings possess 'hard-to-treat' solid walls and have glazing which is not cost effective to improve. A range of fabric efficiency incentive schemes exist, but many do not target the full range of private and social housing. From now on, the Green Deal will be the UK's key energy efficiency policy. However, the scheme is forecasted to have low consumer appeal and low incentives for investors. Moreover, calculated Green Deal loan repayments will be reliant upon estimated energy savings, yet it is claimed that retrofit measures may only be half as effective as anticipated due to a lack of monitoring, poor quality installation and the increased use of heating following refurbishment. Looking to Germany, there has been success through the Passivhaus standard, but the UK currently lacks appropriate skills and cost effective components to replicate this approach. In addition, the embodied energy in retrofit products and materials threatens to counter operational savings.

Keywords
Hard-to-treat homes, Green Deal, Passivhaus

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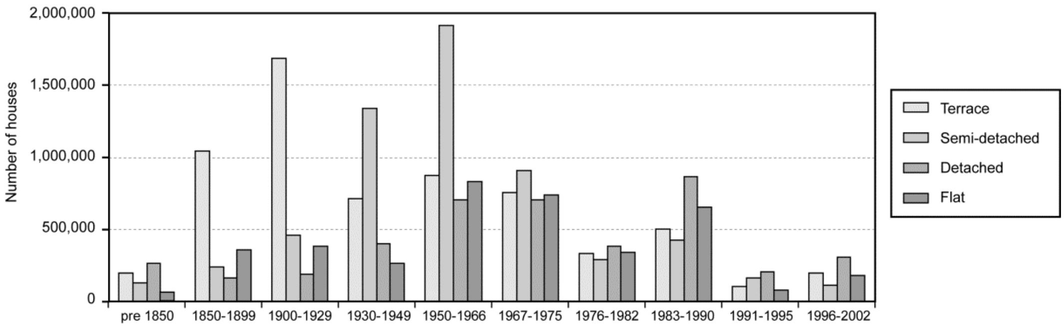
1.0 Introduction

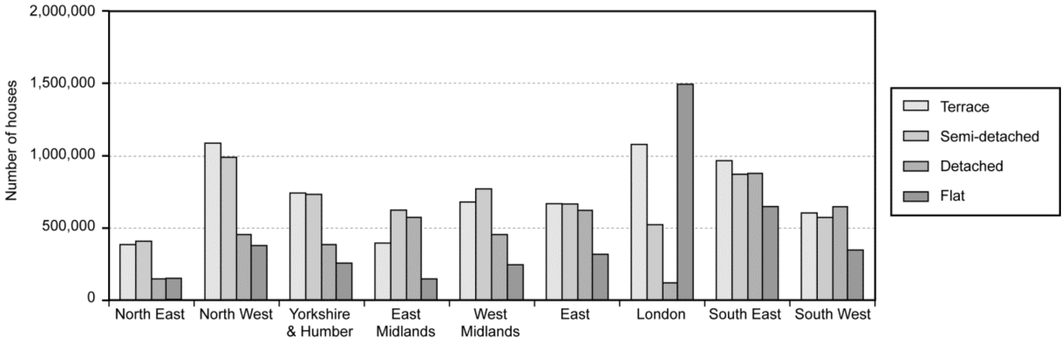
The thermal performance of our existing building stock must improve significantly for the UK to meet its target to reduce CO_2 emissions by 80%, against the 1990 baseline by 2050 (Climate Change Act 2008). In 2008, the country's 26 million dwellings were estimated to be responsible for 27% of all UK CO_2 emissions (Utley and Shorrock 2008). According to recent forecasts, 75-85% of the current UK building stock will still be in use by 2050 (Power 2008; Ravetz 2008). This is a major issue, since millions of these properties contain poorly performing solid walls, single glazing and un-insulated roofs/floors responsible for a significant amount of wasted heat. These features can be expensive and disruptive to improve, furthermore, improvement can be limited by available space and planning restrictions (Beaumont 2007, EEPH 2008). There is scope to retrofit these buildings to make deep cuts in CO_2 emissions, but effective implementation is no trivial task. Solutions must account for the variety in age, size, quality, composition, function and social value of the existing building stock, as well as the different needs, expectations and budgets of homes owners and occupiers.

2.0 Survey of English housing stock

The English Housing Survey is a national survey commissioned by the Department for Communities and Local Government to monitor the age, type, tenure and condition of the English housing stock. Approximately 6,200 houses undergo physical inspections annually by qualified surveyors with findings extrapolated to represent the 20.4 million dwellings, which make up the English housing stock (CLG 2012). Figure 1 displays a profile based on statistical data from CLG (2001), segmenting the housing stock by age and type, across each major construction period. As shown, England contains millions of Victorian and Edwardian terraced houses, post-war semi-detached houses and flats built during the 1960s. Building regulations were only enforced after 1976, setting minimum standards for insulation. As a result solid walls, un-filled cavity walls, single glazing, un-insulated roofs and un-insulated floors were common construction features before this time.



[Figure 1. Profile of the UK Housing stock by age and type]



[Figure 2. English housing stock, dwelling type by region]

Increasing housing demand, as well as the availability of construction materials and machinery over the past century, has led to distinctive types of dwellings across the English housing stock (Beaumont 2007). Figure 2 displays a regional stock profile segmented by house type generated using statistics from CLG (2003). As shown, London has a particularly high proportion of flats and terraced houses, whereas Northern regions tend to have higher concentrations of terraced houses and semi-detached houses.

3.0 History of UK Building Regulations

The thermal efficiency of the UK building stock is governed through the Building Regulations. The UKs first mandatory Building Regulations were enforced in Scotland in 1964. England and Wales soon followed with separate regulations in 1966, as did Northern Ireland in 1967 (Killip 2005). Each of these regulations was produced largely in response to public health issues rather than a need to improve the energy efficiency of dwellings. Only following the 1973 energy crisis were these standards later revised in 1976 to provide minimum U-value standards to limit the heat losses through the walls, roof and floors in new dwellings. Table 1 lists the historic minimum U-values and air permeability targets for compliance with Building Regulations for England and Wales from 1976-2006, generated using numeric data from Killip (2005). As shown, continual revisions to Building Regulations have caused U-value targets for all new buildings to become increasingly stringent. However, it should be noted that U-value requirements for exposed walls only imply the presence of full cavity wall insulation in new buildings registered after 1995. Furthermore, minimum U-values for windows were only raised beyond single glazing standards by 1990. Additional measures such as eliminating thermal bridges and limiting air permeability to reduce heat losses through infiltration also occurred as part of the 1990 Building Regulations.

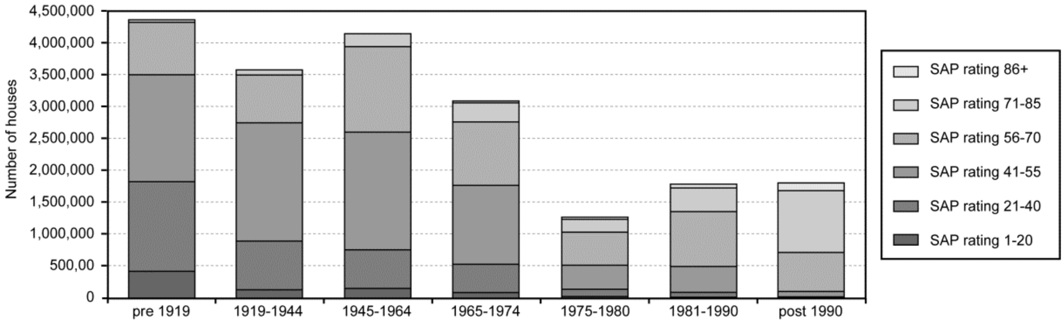
Building Regulations	Exposed walls (W/m^2 K)	Roof (W/m^2 K)	Floor (W/m^2 K)	Windows (W/m^2 K)	Air permeability (m^3/m^2h @ 50Pa)
1976	1.0	0.6	Not specified	Not specified	Not specified
1982	0.6	0.35	Not specified	Not specified	Not specified
1990	0.45	0.25	0.45	3.3	10
1995	0.45	0.25	0.35	3.3	10
2000	0.35	0.25	0.25	2.2	10
2006	0.35	0.16-0.25	0.25	2.0 – 2.2	10

[Table 1. Historic U-values & air permeability targets in the Building Regulations]

From 2006, Part L1A of the Building Regulations for England and Wales required all new dwellings to demonstrate design compliance using the Standard Assessment Procedure (SAP). SAP is a government approved calculation method, which estimates a dwellings CO_2 emissions, in $kgCO_2/m^2$/year, based upon the design U-values, air tightness level, efficiency of space heating, lighting and hot water systems, as well as pumps/fans and any savings from renewable technologies. For Part L1A compliance, the calculated Dwelling Emission Rate (DER) must demonstrate a 25% improvement over a Target Emission Rate (TER) calculated from a notional building constructed to 2002 standards. In 2010, compliance levels were raised to a 25% reduction over a notional building constructed to 2006 standards. For 2013, Building Regulations (under consultation) are expected to raise compliance levels further to a 44% reduction over 2006 standards. Future revisions are anticipated to set ‘zero carbon’ then ‘net carbon’ targets for all developers, resulting in an increasing need for well insulated building fabrics and efficient systems, with more reliance on renewable technologies. Currently, SAP only deals with ‘regulated’ loads, excluding energy use and CO_2 emissions associated with small power plug loads. Moreover SAP, currently does not allow variations in household size, heating patterns or geographic location, although all of these are expected to be introduced into SAP in connection with its use in support of the government’s new Green Deal.

4.0 Thermal efficiency of existing housing

An output of the SAP calculation is a rating from 1-100, which provides an indication of the overall efficiency of a dwelling. Larger scores represent higher efficiencies and lower running costs. For existing buildings, the SAP rating can be calculated from a reduced SAP method (RdSAP) based upon an on-site survey, which considers the dwelling's size, construction characteristics, thermal insulation levels, annual running costs as well as the installed heating and hot water systems and lighting type (DECC 2010a). Figure 3 displays a representation of the SAP ratings across the stock, based upon the findings of the English Housing Survey, presented in (CLG 2006). As seen, many of the highest SAP ratings can be found in the post 1990 stock due to the enforcement of the Building Regulations. Approximately 60% of buildings constructed after 1990 have SAP ratings over 70. In contrast, the highest concentrations of the lowest SAP ratings can be found in the older pre-1919 stock, demonstrating a large correlation between age and energy performance. Around 40% of pre-1919 homes have SAP ratings from 1-40 (Roberts 2008a).



[Figure 3. SAP ratings across the English housing stock]

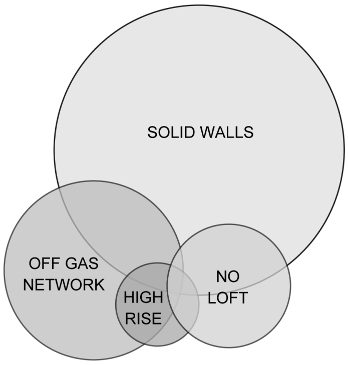
A proposed target for 2050 is to raise the average SAP rating of the UK building stock to 80, in line with today's modern building standards (Roberts 2008a). Comparatively, the national average SAP rating is much lower, being 52.1 in 2006 (BERR 2008). Apart from age, there is also a correlation between energy performance and tenure. The average SAP rating across social housing is 57, whereas the average across the private sector is 47 (Ravetz 2008). This can be attributed to higher rates of loft and cavity wall insulation in the social sector due to government interventions such as 'Warm front' and 'Decent Homes', aiming to lower fuel bills and improve the internal condition of homes. By comparison, private sector landlords have little incentive to invest in the energy efficiency of their properties, given that it is the tenants who benefit from lower fuel bills (CLG 2006, UKGBC 2008). The introduction of Energy Performance Certificates (EPCs) in 2007 may serve to help this challenge by providing information on the current energy rating of a dwelling to potential buyers or tenants (EEPH 2010). Nonetheless, this issue remains a major barrier since many properties in the private sector are amongst the lowest in terms of thermal efficiency (CLG 2006).

5.0 "Hard-to-treat" homes

"Hard-to-treat" homes are defined as dwellings which possess solid walls, no loft space to insulate, no connection to the gas network or are high-rise. Consequently, these dwellings cannot be upgraded easily or cost effectively using conventional measures such as cavity wall insulation, loft insulation and modern gas central heating. According to the BRE (2008), there are approximately 10.3 million hard-to-treat homes across the UK, equivalent to 40% of the existing housing stock. 9 million of these are in England, 6.5 million of which possess solid walls. 1.5 million have no loft space, 0.4 million are high rise and 2.7 million are off the gas grid. These statistics, from BRE (2008), are shown in Table 2, with their distribution illustrated in Figure 4.

	England	Scotland	Wales	N. Ireland	Total
Total number of dwellings	21m	2.3m	1.3m	0.7m	25.3m
Solid walls	6.5m	0.7m	0.1m	0.1m	7.5m
No loft space	1.5m	unknown	unknown	unknown	~2m
High rise	0.4m	0.5m	unknown	unknown	~1.5m
Off gas grid	2.7m	0.3m	0.5m	0.5m	2.7m
Total hard-to-treat dwellings	9m	0.7m	0.5m	0.5m	~10.3m

[Table 2. The number of hard-to-treat homes in the UK]



[Figure 4. The distribution of hard-to-treat homes in the UK]

According to Beaumont (2007), more than 66% of hard-to-treat households are in fuel poverty. A household is said to be in fuel poverty if its occupants need to spend more than 10% of their income to afford adequate energy services, for heating, lighting, cooking in their home (Boardman *et al*. 2005). In addition, dwellings that contain both solid walls and are off the gas grid possess some of the lowest SAP ratings in the UK, with a mean score of 25. Nearly 84% of these properties are in the private sector. By comparison, Beaumont (2007) states that high rise dwellings which are on the gas network typically perform much better, with SAP ratings averaging at around 60, nearly 10 points above the national average, due to their smaller size and significantly reduced area of exposed walls, resulting in smaller heat losses.

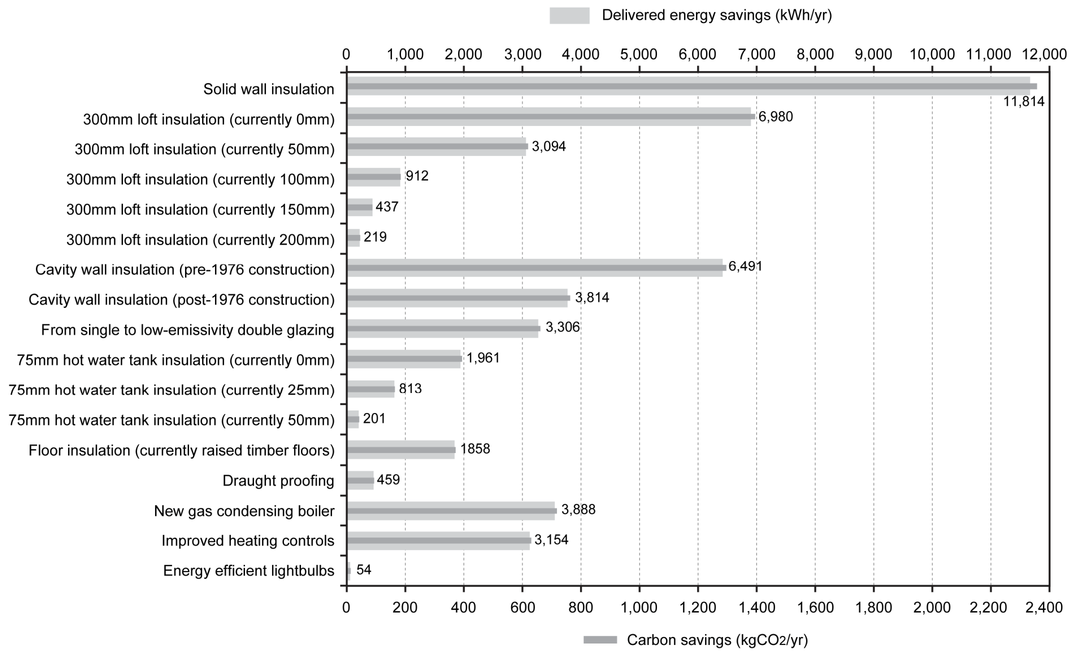
Regarding low-rise properties that are off the gas network, Beaumont (2007) states that these are particularly common in rural areas, where inaccessibility and a low urban density makes it unattractive for gas companies to build supply networks. Comparatively, safety considerations in high rise flats often means that a piped gas supply is not installed (Beaumont 2007). Hard-to-treat dwellings with no space for loft insulation typically refer to those with flat, mansard or chalet roofs built before 1990. High rise flats with at least 6 stories are typically viewed as the most difficult to treat. In particular, developments built from 1950-1970 have some of the largest heating difficulties due to poor physical condition, low maintenance and a lack of gas supply (Beaumont 2007).

According to Beaumont (2007) it is theoretically possible to internally insulate all solid walled properties in the UK, but there are restrictions on external wall insulation, since it changes the external appearance of a dwelling and planning permission prohibits its application on listed dwellings or those in conservation areas. According to Beaumont (2007) and Boardman *et al*. (2005), approximately 300,000 dwellings in the UK are listed, and a further 1.2 million are in conservation areas, representing about a quarter of all pre-1919 dwellings. In addition, installing external insulation on high rise flats may be problematic if the walls are structurally unsound, or if all owners/leaseholders do not all agree to change the external appearance. Alternatively, when internally insulating, individual flats could be improved on a room-per-room basis. It should be noted, that there are possible cost reductions through economies of scale, if an entire high-rise block is over clad in a single installation.

According to Boardman (2007), at least 800,000 of the most ‘leaky’ pre-1919 homes must be removed to meet the 2050 CO_2 reduction target. In contrast, Ravetz (2008), states that the older, worst performing stock should be seen as a resource rather than a problem, since they have the largest scope for improvements through energy efficient refurbishments. Moreover Power (2008) argues that because demolition can be very time consuming, costly and disruptive to the environment, it is likely to promote much opposition within local communities, government and industry.

6.0 Energy savings from conventional retrofit measures

Shorrock *et al*. (2005) published a study for the Building Research Establishment analysing the scope for CO_2 reductions in the UK housing stock. Focusing on insulation measures for a typical 3-bedroom semi-detached house, the study calculated the energy, CO_2 and cost savings of conventional retrofit solutions, calculated based on the BREDEM energy model, which has been continually developed since the 1980s to consider both the physical characteristics of a dwelling and lifestyles of occupants. BREDEM also underpins the SAP calculations in the Building Regulations. Figure 5 shows the calculated annual energy and CO_2 savings from conventional retrofit measures, generated using numeric data from Shorrock *et al*. (2005).



[Figure 5. Predicted delivered energy and CO_2 savings from conventional retrofit measures applied to a typical semi-detached house]

As expected, some measures provide significantly more benefit than others. A much larger saving can be experienced when insulating a solid wall in comparison to a cavity wall, since the baseline U-value is generally lower, and the level of insulation installed is not restricted to the cavity width. The distinction between cavity wall insulation savings in pre and post-1976 construction is due to a change in construction practices from brick-brick cavity wall construction to brick-block cavity walls around this time. Predicted savings from loft insulation and hot water cylinder lagging provide diminishing returns depending on how much insulation is already present. As existing insulation levels approach 300mm and 50mm respectively, the savings become so small that they are not worthwhile.

Roberts (2008a) states that cavity wall insulation can reduce heat loss through walls by up to 40% and when insulating the walls and roofs of un-insulated older buildings to post-1990 standards, then a 50-80% reduction in heat loss through these elements can be achieved. Determining the actual savings requires knowledge of how much heat was originally being lost through the fabric. This must be assessed on a case-by-case basis.

7.0 Cost-effectiveness of conventional retrofit measures

Shorrock *et al*. (2005) published figures for the capital cost of different retrofit measures against the estimated energy savings obtained from a reduced heating bill. This data is shown below in Table 3. The methodology assumes that no grant was made available and 30% of the energy savings were taken back by the homeowner for increased thermal comfort. Payback calculations assume annual fuel price rises and discount interest rates are at equal percentages, resulting in a simple return on investment calculation.

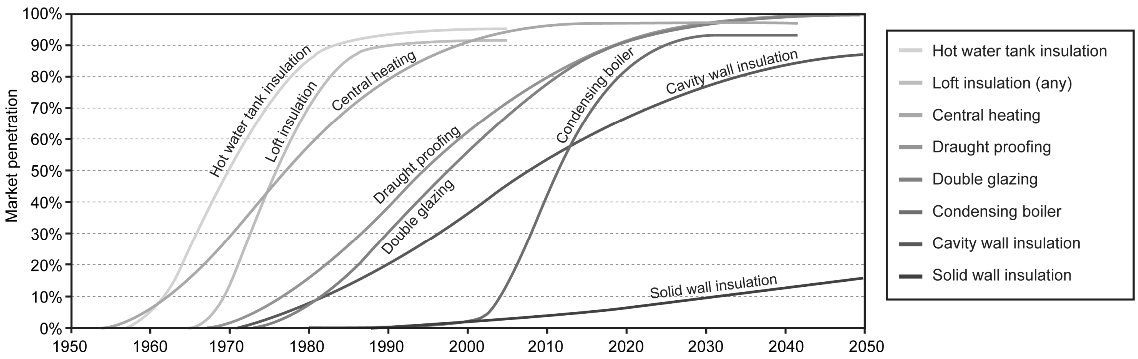
Analysis suggests that draught proofing, floor insulation, and loft insulation (with over 150mm of insulation already in place) are marginally uneconomic. Comparatively, double glazing shows an extremely poor financial return on investment since the payback period far exceeds the predicted product lifespan and the energy savings alone do not justify the capital investment. The remainder of conventional retrofitting measures do show positive returns of investment, with the largest benefit occurring from filling cavity walls within pre-1976 stock. Insulating a loft which previously had no insulation appears to provide the shortest payback at just over 3 years, far shorter than double glazing at 98 years.

Retrofit measure	Capital Cost (£)	Annual savings (£/yr)	Measure lifespan (yrs)	Lifetime saving (£)	Simple R.O.I. (£)	Payback period (yrs)
Solid wall insulation	3272	145.6	30	4376	1104	22.4
300mm loft insulation (currently 0mm)	273	86.2	30	2587	2314	3.2
300mm loft insulation (currently 50mm)	254	38.2	30	1146	892	6.6
300mm loft insulation (currently 100mm)	211	11.3	30	338	127	18.7
300mm loft insulation (currently 150mm)	199	5.4	30	162	-37	36.9
300mm loft insulation (currently 200mm)	170	2.7	30	81	-89	63.0
Cavity wall insulation (pre-1976 construction)	325	80.1	40	3205	2880	4.1
Cavity wall insulation (post-1976 construction)	325	47.1	40	1884	1559	6.9
From single to low-e double glazing	4000	40.8	20	816	-3184	98.0
75mm DHW tank insulation (currently 0mm)	20	28.8	15	431	411	0.7
75mm DHW tank insulation (currently 25mm)	20	12.0	15	180	160	1.7
75mm DHW tank insulation (currently 50mm)	20	3.0	15	45	25	6.7
Raised timber floor insulation	1000	32.8	30	983	-18	30.5
Draught proofing	110	5.7	10	57	-53	19.4
New gas condensing boiler	300	45.4	12	546	246	6.6
Improved heating controls	250	57.4	12	689	439	4.4
Energy efficient light bulbs	85	21.2	6	127	42	4.0

[Table 3. Capital cost, energy savings and simple payback period for conventional retrofit measures applied to a typical 3-bedroom semi-detached house]

8.0 Energy efficiency uptake trends

Another analysis from Shorrock *et al*. (2005) relates to the current uptake of conventional retrofit products and future forecasts. For double glazing and gas condensing boilers these figures are based on “all that is economically and technically possible”. Here it can be seen that certain retrofitting measures have more scope for installation than others. Note that projections for solid wall insulation were not available in Shorrock *et al*. (2005). However, a similar forecast from EEPH (2008), based on the industry's current capacity of 15,000-20,000 installations per year has been added. This data, generated from both sources is shown in Figure 6.



[Figure 6. Market penetration of conventional energy efficiency measures]

Looking at cavity wall insulation, evidently there is still much potential for walls to be filled in the UK. Likewise, Roberts (2008a), states that 60% of UK domestic houses had unfilled cavity walls in 2004. Regarding double glazing, despite the high capital costs, levels are expected to reach saturation over the coming decades since all new glazing renovations must achieve a minimum centre pane U-value of 1.2 W/m^2 K or an overall U-value of 1.8 W/m^2 K, except for in rare specific circumstances such as listed building status. Furthermore, considering uptakes of loft insulation have levelled off, there is considerable scope to ensure that all lofts have above 100mm of insulation.

An additional factor raised by both Ravetz (2008) and Roberts (2008a) is that many homes have first generation retrofits in need of renewal. Ravetz (2008) claims that the deterioration of many post-war retrofits such as double glazing, plumbing and electrics are clearly visible in modern homes, however there are barriers to improvements due to the capital cost of investment and the hassle of refurbishment. Roberts (2008a) believes the main issue regarding first generation double glazing is the high U-values of 3-4 W/m^2 K, due to poorly insulated frames and narrow air gaps. Comparing these heat losses against modern double glazed units with U-values down to 1.2 W/m^2 K would show considerable differences in thermal performance.

Regarding solid wall insulation, Shorrock *et al*. (2005) states that uptakes seem unlikely to reach saturation over the next few decades due to its slow uptake and high capital costs, which must be reduced to around £2500 (for the whole house) for the procedure to become marginally cost effective. Roberts (2008a), argues that solid wall insulation should be viewed as an untapped opportunity rather than a barrier since large energy savings can still be made. According to EEPH (2008), even at the upper limit of the industry's installation capacity only 15% of solid walled homes will be insulated by 2050.

Shorrock *et al*. (2005) argues that floor insulation uptake will remain slow since the procedure is generally only carried out when a floor needs repair. Similarly, Roberts (2008a) states that floor insulation is disruptive and is only likely to be economically viable during a comprehensive refurbishment of the floor.

Taking an alternate perspective, Power (2008) argues that there should be more effort from the government to realise the potential for energy savings from the 10 million homes in the UK requiring solid wall insulation. Similarly, Power (2008) believes floor insulation needs to be considered within renewal programmes, since 10 million homes have un-insulated raised timber floors and the technology is available for improvement.

9.0 Government incentive programmes

Government incentive schemes represent a key driver for reducing CO_2 emissions in the housing sector (EEPH 2010). Several focus on renewable energy, including the Renewable Energy Strategy (RES), Micro-generation Certification Scheme (MCS), Renewable Heat Incentive (RHI) and Feed in Tariffs (FITS). Alternatively, the government's Boiler Scrappage Scheme, launched in 2010, but now closed, funded over 100,000 new boilers across England. Regarding fabric efficiency, primarily these focus on installing low cost, non-disruptive measures such as cavity wall insulation and loft insulation, targeting underprivileged households mainly in the social housing sector. However, wider schemes have been set into motion, encouraging energy suppliers, electricity generators and private investors to provide grants to cover the upfront cost of refurbishments, reaching also into the owner occupied and private sector. A summary of fabric efficiency schemes is given below:

Carbon emissions reduction target (CERT)

During 2008-2011, CERT operated as one of the UK's principal energy efficiency mechanisms. This scheme required all domestic energy suppliers with a customer base exceeding 250,000 to achieve reduction targets for the amount of CO_2 emitted by their customers (equivalent to the total emissions from approximately 700,000 homes each year). At least two thirds of this target must be achieved through professionally installed insulation measures and 40% should be focused on a priority group of vulnerable households consisting of low income homes, pensioners over the age of 70 and households on disability benefits. In its first 2 years CERT resulted in approximately 1.4 million cavity walls and 1.1 million lofts being insulated. In addition, over 200 million low energy light bulbs have been delivered, 2000 ground source heat pumps installed and 30,000 solid walled properties have been upgraded through either internal or external wall insulation (DECC 2010b).

Community Energy Saving Programme (CESP)

CESP is a retrofitting scheme funded through an obligation on energy suppliers, and for the first time, electricity generators. This scheme provides funding to community partnership groups, housing associations and local authorities to improve energy efficiency in low income and hard-to-treat homes. CESP promotes a 'whole house' approach, aiming to treat as many properties as possible in a house-by-house or street-by-street approach (EEPH 2008). Between October 2009 and December 2012, CESP funded approximately 100 community schemes, benefitting around 90,000 homes. According to DECC (2011), 81% of scheme submissions included external solid wall insulation and 65% had boiler replacements with new heating controls. Key challenges during installation included weather related issues, planning delays for solid wall insulation, cash flow problems due to retrospective payments from energy suppliers, gaining access to eligible households and dealing with resentment from non-eligible householders. In a post retrofit survey, 75% of occupants agreed their homes felt warmer and were easier to heat to adequate levels. Just 25% said they had seen a decrease in their heating bills and 11% said their heating bills had increased. According to DECC (2011), this was influenced by rising energy prices.

Decent Homes

In 2000, the government made a commitment to bring all public sector dwellings in England to a basic standard of decency by 2010 through its Decent Homes programme. This placed a responsibility on local authorities, registered social landlords and, to a limited extent, private sector landlords to eliminate the backlog of repairs throughout their stock. For a property to meet the Decent Homes standard it must (i) be free of Category 1 Housing Health and Safety Rating Hazards (HHSRH), which covers an assessment of dampness, excessive cold/heat, security, hygiene, sanitation, structural integrity, accident risk, asbestos etc (ii) be in a reasonable state of repair, (iii) have reasonably modern facilities and services, and (iv) provide a reasonable degree of thermal comfort.

According to the National Audit office (2010), at the start of the programme there were 1.6 million 'non-decent' homes in the social sector, representing 39% of all social housing. By 2010, over a million houses had been treated, reducing the percentage of non-decent homes in the social sector to 14.5%, falling short of the original target. Across the entire English stock, it is estimated that 5.9 million dwellings (26% of homes) failed to meet the Decent Homes standard in 2010, compared to 7.7 million in 2006. The primary reasons for failing were not achieving the HHSRH assessment, followed by not providing adequate levels of thermal comfort (CLG 2012). In 2010, private rented dwellings had the highest percentage of non-decent homes at 37%, followed by the owner occupied sector at 25%.

According to CLG (2006), the average cost to make a home decent is approximately £3,600-£10,500 depending on the age and type of property. In order to meet the thermal comfort standard a home must have an efficient heating system, cavity wall insulation (where possible) and a minimum of 200mm loft insulation. Currently several local authorities and housing associations are in the process of adopting a new 'Decent Homes Plus' standard. This typically includes additional measures such as double glazing (except when restricted by planning), full heating controls with an energy efficient boiler, draught proofing, energy efficient doors, and energy efficient lighting in all communal areas, improved sound insulation and a modern kitchen and bathroom.

Warm Front

Warm Front is a government funded scheme providing heating and insulation grants to vulnerable owner occupied and private rented households with SAP ratings of 55 (energy performance certificate band D) or below. Qualifying households must be on income support, income-related employment and support allowance, state pension credit or Job Seekers Allowance. Housing Association or local authority tenants do not qualify. Grants up to £3,500 are available for measures such as loft insulation, cavity insulation, draught proofing, hot water tank insulation and new gas, electric or liquid petroleum gas (LPG) heating systems. Up to £6,000 may be allocated where oil central heating and other alternative technologies are required. The scheme is only available in England and it is managed by Carillion Energy Services (formerly Eaga). Equivalent schemes are the Home Energy Efficiency Scheme (HEES) in Wales and the Warm Deal in Scotland.

In a report by the National Audit Office (2009), since the scheme began in 2000, more than 2 million homes had been treated through Warm Front funding by 2009, costing approximately £2.2 billion. In a satisfaction survey, 75% of customers were 'highly satisfied' by the quality of the work done and 84% would recommend the service to a friend or relative. Eaga estimated that the work done would reduce a household's energy bill by £300 a year (depending on the measures installed). A key criticism of the scheme was that applicants are assessed on a "first come, first served" basis, yet nearly 75% of households who qualified were not necessarily in fuel poverty. In addition, it was criticised that the scheme lacked a full range of measures such as external wall insulation, meaning it was unable to address hard-to-treat households (National Audit Office 2009).

Green Deal
From October 2012, the Green Deal will be the key mechanism for improving the energy efficiency of domestic buildings in the UK. In this programme, bill payers will be able to obtain energy efficiency improvements without having to pay for the upfront costs of retrofit works (DECC 2010c). Instead, capital will be privately financed, through consortia made up of banks, consumer and business groups, local authorities etc, as well as the investor community, who recoup their investment through an instalment charge on the consumer's energy bill. The overarching 'golden rule' principle is that the estimated savings on energy bills must be equal to, or greater than, the costs attached to the energy bill. Unlike a conventional loan, the loan repayments remain attached to the property, rather than the bill payer (who may move into a different property before the repayments are complete). Its remit also covers non-domestic buildings.

Supporting Green Deal, the government plans to have smart meters installed in every home by 2020. These meters are anticipated to provide customers and energy suppliers with more information on electricity and gas usage, as well as acting as the prime mechanism for governing the claimed bill savings through the Green Deal. All measures installed through Green Deal must be recommended and approved by an accredited advisor, and installed through an accredited installer. The majority of loans are expected to be provided by industry led consortium consisting of 19 blue-chip companies called the Green Deal Finance Company, supported by the Green Investment Bank. Functioning alongside Green Deal, an Energy Company Obligation (ECO) is scheduled to replace CERT and CESP, to provide additional financing to support vulnerable low income households and hard-to-treat properties.

10.0 Green Deal criticism
During the launch of Green Deal, the Energy and Climate Change Secretary announced a "third industrial revolution: a green revolution", one that would allow the most inefficient households to save £550 per year on their fuel bills, increase the number of jobs in the insulation industry from 27,000 to 250,000 and reduce nationwide spending on gas by up to £2.5 billion per year (Huhne 2010). Whilst being an elegant idea, there are many who believe this simply will not be achieved, due to a number of fundamental issues such as low consumer appeal and investor incentives. These issues, plus others are described below:

Consumer appeal
As the Green Deal does not offer subsidies for retrofit works, it is feared this shift will make energy efficiency improvements less attractive to consumers, causing the number of homes being insulated to plummet (Gardiner 2012). According to DECC, annual cavity wall insulation installations are predicted to drop by 67% from 510,000 to 170,000 homes per year. For loft insulation, levels are predicted to drop by 93% from over 1 million to 70,000 homes per year. Early 2011 trials for the Green Deal, including Affinity Sutton's "FutureFit project" and the B&Q loft clearance service in the London borough of Sutton have not been encouraging. The FutureFit project offered to pay for the upfront cost of energy efficiency improvements through a financing mechanism resembling Green Deal. However, take-up rates from advertising were just 4.8%, and of those who took part 23% dropped out during the lead up to retrofit works (Mckann 2011). In contrast, B&Q provided a 40% grant and offered to clear out a homeowner's loft in order to install insulation. Out of 400 household who expressed an interest, 126 agreed to an energy audit and only 66 went ahead with any insulation (Withers 2011). The primary reason for the 60 homeowners not pursuing the grant following the energy audit was that they were sceptical regarding the levels of long-term energy savings that would be achieved (Withers 2011).

Investor incentives

Recently, we have been investigating the financial attractiveness of large-scale Green Deal investments by developing a series of retrofit assessment tools to facilitate strategic business modelling / 'war-gaming' workshops. When trialled internally, we assumed that each finance provider (acting as either a bank, retailer or energy company) would be looking to obtain an internal rate of return of up to 11-15% due to the unknown risks attached with Green Deal. To date, we have found that it is difficult to make the Green Deal attractive as a way to make money (although we do recognise that it can appeal to companies who are in a position to provide finance for reasons other than an internal rate of return). Our modelling has also shown that it becomes more difficult to achieve a return on investment if a property does not fall under the category of "most in-efficient", e.g. if it has a C-rated boiler as opposed to an F-rated boiler. We therefore expect investors to segment the Green Deal market and target households that offer the best returns. Only limited profiling is possible, but Green Deal companies may have to spend money on data mining and marketing to facilitate the most profitable opportunities. Further to this, our modelling has shown that the recent cut in tariff rates to renewable energy measures, maintenance costs (if included in the contract) and the upfront cost of energy audits (if not passed onto the bill payer) can prolong the investment periods detrimentally.

Technical issues

The Golden Rule was established to protect consumers and investors from over extending themselves financially. However, it could in fact be restricting the level of CO_2 savings obtainable from whole house retrofitting, because it limits the size of a Green Deal loan to the amount that can be repaid by savings generated. Paradoxically, meeting the Golden Rule will be problematic because it is a difficult to accurately predict the annual energy savings from different retrofit packages without fully understanding the technical performance of the building and the energy usage patterns of its inhabitants, including any re-bound effect with improved comfort conditions. Lainé (2012) expressed concern that the current RdSAP engine, used to facilitate Green Deal assessments, will not recommend cavity wall insulation if the existing U-value is below 0.6 W/m^2 K, despite the opportunity to implement low-cost insulation to achieve a U-value of 0.35 W/m^2 K. This would mean that up to 2.3 million cavity-walled homes built since 1983 could be given incorrect advice and would not be able to use Green Deal to finance the work (Lainé 2012).

Those in fuel poverty, a fifth of all households, look to be ignored by the scheme. If a household struggles to pay for fuel, it will be in a weak position to raise a Green Deal for building improvements. There are also problems with multiple-occupancy buildings and whether everyone needs to agree before the building fabric can be improved. It should be noted as well that the effect of a 'Green Deal' on a property's value and ease of re-sell is unknown. The Green Deal is innovative in how it attaches the loan to the building rather than the occupier but the market implications of this are untested.

11.0 Further barriers to energy efficiency

According to Power (2008) and Roberts (2008a), there are a number of conventional cost effective measures yet to be implemented throughout the UK housing stock and many older homes have vast potential for reduced energy consumption. However, Lowe and Oreszczyn (2008) and Ravetz (2008) claim that a large proportion of cost-effective measures have already been employed, yet significant energy savings are still to be experienced. As a result, both Olivier (2001) and Lowe and Oreszczyn (2008) argue that actual energy performance of the UK building stock may be significantly lower than previously assumed.

Difficulty meeting Building Regulations
In a report by Olivier (2001), it was argued that the official figures for U-values are optimistic and not achieved in practice. This is because actual U-values are often found to be higher than expected when measured in-situ, due to errors in the quality of construction, as well as thermal bridges and gaps in insulation. According to Hamza and Greenwood (2008), Building Regulations do improve design teams' abilities to meet energy targets, however, many within the industry express concern about uncertainties and difficulties with compliance. Lowe and Oreszczyn (2008) claim that little is known regarding the actual impact of updates to the Building Regulations due to a lack of monitoring following construction. Similarly, Olivier (2001) states there has been no evaluation of the 1982, 1990 or 1995 building regulations since there is no individual or legal binding body to assess energy performance after on-site retrofitting work is complete.

Too much focus on zero carbon targets
Taking a top-down approach, Lowe and Oreszczyn (2008) believe that many issues hindering the progress of energy efficiency relate to ill-advised policies from the government causing debate within industry. Lowe and Oreszczyn (2008), claim that the government is putting too much pressure on the industry to achieve zero carbon targets, particularly in new build, without fully understanding the complications surrounding fabric improvements in existing homes. Lowe and Oreszczyn (2008) propose that too much investment is being spent on expensive renewable technologies without fully understanding the importance of maximising the performance of the building fabric.

Discrepancies between predicted and actual savings
Hong *et al*. (2006) published a paper looking at the impact of energy efficient refurbishments on the space heating fuel consumption of English dwellings. Here, the performance of 1,372 properties treated through the Warm Front scheme were analysed before and after a conventional retrofit with cavity wall insulation, loft insulation and a new central heating system. The aim was to lower energy consumption to alleviate low income houses from fuel poverty, along with raising thermal comfort standards to modern levels. Prior to installation, theoretical calculations suggested that cavity wall insulation and loft insulation would save 49% of fuel consumption, however actual monitoring following the refurbishment showed that only 10-17% energy savings were achieved.

Conclusions were that the refurbishment did raise thermal comfort standards and homes were cheaper to heat, however the expected energy savings were not achieved (Hong *et al*. 2006). Regarding the complexities of achieving actual energy savings, Hong *et al*. (2006) claimed that large uncertainties related to the impacts of thermal bridges, gaps in insulation and the occupants using more heating following the refurbishment. Thermal imaging on a sample of 72 dwellings showed that 20% of cavity wall areas and 13% of the loft areas lacked insulation. It was revealed that the introduction of the new heating system resulted in 35% of savings being taken back to raise thermal comfort in the home.

Increased use of heating following refurbishment
This issue of thermal comfort 'take-back' was reported by Bell and Lowe (2000) in a study analysing the savings of energy efficient refurbishments on four similar sized semi-detached houses. The aim was to confirm that significant savings could be gained from conventional 1980s retrofit technologies. Following an extensive two-week energy monitoring period, a 47% reduction in energy consumption was observed, proving that significant savings could be achieved from conventional retrofit measures. However, this was 40% lower than their

predictions, which Bell and Lowe (2000) suggested was mostly due to people's behaviour and thermal comfort take-back from the new heating systems.

Socio-economic status of household
According to Binggeli (2008) and Roberts (2008a), before the introduction of gas powered central heating systems in the 1970s, most people preferred indoor temperatures at 20^{o}C or less, and would wear more clothes during winter to prevent paying high energy costs. By comparison, nowadays people have developed thermal comfort preferences of 23-25^{o}C, which tends to be satisfied through higher quantities of energy consumed for heating (Binggeli 2008, Roberts 2008a). Both Clinch and Healy (2001), and Milne and Boardman (2000), claim a large proportion of this take-back relates to the socio-economic status of the household prior to the refurbishment. Milne and Boardman (2000) found that low income houses originally heated to 14.5^{o}C, experience energy savings that are only 50% of those anticipated, whereas slightly higher income homes originally heated to 16.5^{o}C tended to experience 70% of the anticipated energy savings, due to a lower thermal comfort take-back. Clinch and Healy (2001) believe there is a lack of studies looking at take-backs in high income homes. Here it would be expected that dwellings would see greater energy bill savings since the home is likely to already be heated to reasonable levels.

Additional barriers within society
Ravetz (2008) claims that many people do not view energy efficient refurbishments as a high priority when updating their homes. Major barriers are the perceived hassle of installation, upfront costs, uncertainties over lower fuel bills and a lack of knowledge over payback periods (UKGBC 2008). Power (2008) states that energy efficient refurbishment is undervalued by communities. People seem to prefer amenities such as new kitchens, bathrooms, central heating, and general repairs, instead of energy efficient refurbishments since the social gains are more obvious (Bell and Lowe 2000). Ravetz (2008) forecasts that technological shifts threaten to counter the efforts of energy efficiency. For example more homes will become increasingly diverse in their use of energy with more appliances, lighting and domestic air conditioning.

Insulation causing overheating
Looking to the future, it may become apparent that climate change causes people's thermal comfort needs to adapt to higher temperatures or conversely require more cooling (Ravetz 2008, Roberts 2008b). At present little attention is given to issues such as the impacts of overheating in older buildings, security risks for opening windows or analysis of appliance heat gains with technological developments. These would be interesting to study, however it would rely heavily on predictions, which are difficult to quantify (Ravetz 2008, Roberts 2008b). Both Holmes and Hacker (2007), and Ravetz (2008) predict this will lead to greater overall energy expenditure in buildings that require active cooling. In addition more homeowners are likely to retrofit air conditioning units or buy portable air conditioning systems for their homes, which too would raise consumption.

12.0 Passivhaus refurbishment
A large wealth of experience exists with the German retrofit market due to their implementation of the Passivhaus standard within new and existing homes (Bell and Lowe 2000; Lowe and Oreszczyn 2008). Core principles of a Passivhaus rely upon the design and specification of super insulation and highly airtight fabric, combined with whole house mechanical ventilation with heat recovery (WHMVHR). Using this approach, a building has minimal fabric heat losses, and is supplied with permanent fresh air and regulated humidity, with no uncomfortable draughts. A Passivhaus must have a total heating demand of

15kWh/m^2/year or less, or 25 kWh/m^2/year or less if it is a retrofit. By comparison, the average heating consumption for the existing UK building stock is 180 kWh/m^2/year, 100 kWh/m^2/year when renovated and 50-60 kWh/m^2/year if it is a new build (Boonstra 2005).

An example of a German Passivhaus retrofit project is the 'Zukunft Haus Pilot Programme' that ran from 2003-2005. Here, 915 homes, mostly rented flats built pre-1978, were renovated in Eastern and Western Germany with high levels of insulation, external / internal cladding, triple glazing, efficient heating and energy systems, whole house heat recovery and south facing balconies where possible. Overall an 80% reduction in energy consumption throughout the households was achieved, which was twice as effective as the German building standards (Power 2008). In 2007, the German Federal Government announced that all German pre-1984 homes should reach this standard by 2020, through a system of loans, tax incentives and grants, resulting in vast incentives for energy efficient refurbishment (Power 2008).

	England and Wales new build regulations Part L1A (2010)	German Passivhaus Standard
Walls, roof and floor	Limiting U-values of 0.25-0.3 W/m^2 K	U-value should not exceed 0.15 W/m^2 K
Windows and openings	Typically 1.8-2.2 W/m^2 K	U-value should not exceed 0.8 W/m^2 K with solar heat gain coefficient of 0.5
Orientation and shading	Sometimes considered, but often overlooked in the design process	Passive solar design principles are followed
Air tightness	Design air change rate of 7-10 m^3/m^2.h @50Pa	Design air change rate of <1 m^3/m^2.h @50Pa
Whole house heat recovery	Typically not considered as buildings do not achieve air change rates below 3 m^3/m^2.h @50Pa	Incoming fresh air is pre-heated to >5C. Exhausted heat recovery efficiency is at least 85%.
Lighting and appliances	Low energy lighting and C+ rated appliances	Low energy lighting and A+ rated appliances are essential
Total heating demand	~55 kWh/m^2/year	<15 kWh/m^2/year (new build) <25 kWh/m^2/year (retrofit)

[Table 4. England and Wales Building Regulations compared to the Passivhaus standard]

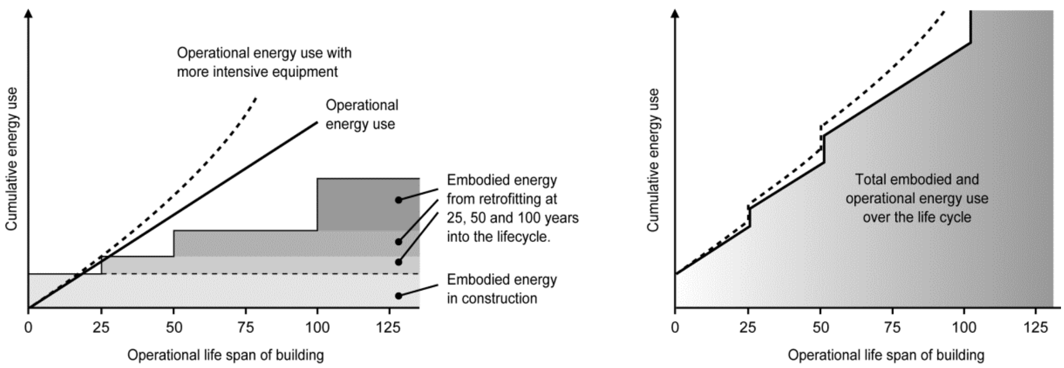
A summary of Passivhaus standards compared to 2010 new build Building Regulations, according to BRE (2011) is shown in Table 4. A key challenge with Passivhaus is achieving the required air tightness target of <1 m^3/m^{2}h @ 50Pa, as it requires a pre-defined air tightness strategy, which deals with all junctions and partitions through impermeable and durable air tight barriers, interconnected membranes, tapes and flexible sealed joints. Bell and Lowe (2000) and Lowe and Oreszczyn (2008) argue that there is a need to transfer this knowledge into the UK housing stock so that the UK construction industry will be better equipped at improving the standard of existing houses and meeting the requirements of new building regulations. This will require the transfer of components, installation procedures and training methods within the construction industry to inform workers on how to properly meet Passivhaus standards during refurbishment (Lowe and Oreszczyn 2008).

The UK's first certified domestic Passivhaus retrofit was completed in March 2011. It is a solid walled mid-terrace house at 100 Princedale Road in Holland Park, West London. The house was located in a conservation area, so external insulation and new glazing was restricted. Consequently, measures implemented included internal insulation with an air-tight barrier, custom built triple glazed windows to imitate traditional single glazed sash windows, a WHMVHR system and solar thermal collectors for water heating. The newly refurbished property has no gas boiler or radiators. According to Borgstein *et al*. (2011), energy savings of 89% are projected, equivalent to £910 saved a year on fuel bills. This project was funded through the ‘Retrofit for the Future’ competition, launched by the Technology Strategy Board in March 2009. This competition provided 86 winning teams with £150,000 to upgrade existing social homes in the UK, challenging them to reduce CO_2 emissions by 80%.

13.0 Environmental impact of refurbishments

The environmental impact of refurbishment, in particular the embodied energy and embodied CO_2 produced through raw material acquisition, component manufacture, transport to site and the onsite construction/retrofit process, is an area of research which is often overlooked. Over the lifecycle of a building, it is estimated that these ‘cradle-to-site’ embodied impacts account for about 10-20% of a building’s total energy consumption (SETAC 2003). Conversely, for low energy, high efficiency buildings, this phase of the building’s lifecycle can have a much greater significance representing around 40-75% of the total lifetime consumption of energy (SETAC 2003; Smil 2008).

According to Ravetz (2008), the embodied energy required to construct a new building may be up to 10 times more intensive than refurbishment, due to the offsite impacts of construction and transport. Power (2008) claims that the embodied energy required to build new homes is 4-8 times more intensive than a refurbishment to modern standards. These issues were also studied by the Empty Homes Agency, who demonstrated how comprehensive refurbishment generates about 15 tonnes of embodied CO_2, in comparison to demolition and rebuild which used closer to 50 tonnes of embodied CO_2. According to EHA (2008), the energy consumption of an average UK home is responsible for 5-6 tonnes of CO_2 every year, two thirds of which could be saved through simple energy efficiency measures.



[Figure 7. Illustrative embodied and operational energy costs in the life cycle of an office building refurbished at 25, 50 and 100 year intervals]

Over the life cycle, the fabric and services in a building will be adapted, maintained and renewed several times, resulting in recurring embodied energy cost. According to Cole and Kernan (1996) as well as Yohanis and Norton (2002), the recurring embodied energy for buildings with a short lifespan tends to be less than the initial embodied energy in construction; yet for buildings with life spans up to 100 years, this embodied energy can be 2-3 times greater than the impacts of the construction phase. Figure 7 illustrates the typical embodied and operational energy costs for an office that has been involved in three major refurbishments at 25 years, 50 years and 100 years into its buildings lifecycle, according to estimations by Yohanis and Norton (2002). As shown, operational energy steadily accumulates throughout the lifecycle of a building, whereas the embodied energy builds up in increasingly energy intensive phases.

Not shown in Figure 7 is the potential for operational savings following each retrofit. According to Harris (1999), there is a significant lack of studies concerning the actual embodied energy within refurbishments, particularly those measures designed for energy efficiency. According to Schmidt *et al*. (2004), in a typical application, the in-use savings from insulation are over 100 times the embodied impact of production and disposal. In contrast, Harris (1999) claims that when the thickness of loft insulation is increased beyond 200mm, the embodied energy threatens to outweigh the operational energy savings. Weir and Muneer (1998) found modern glazing systems have a particularly high embodied energy up to 1500 kWh/m^2, which could take 10-30 years to provide a positive energy contribution.

14.0 Conclusion

The aim of this paper was to (i) review the thermal performance of the existing UK housing stock (ii) assess the energy savings, financial payback and uptake trends associated with different retrofit measures, (iii) review the key outcomes of the various fabric efficiency incentives, and (iv), understand the key barriers to obtaining deep energy and CO_2 savings throughout the stock.

There is a strong correlation between the age and tenure characteristics of dwellings and their thermal efficiency, due to historic updates to Building Regulations and a lack of incentives aimed at private landlords. Millions of homes in the UK are classed as hard-to-treat. It is essential that these properties be viewed as an opportunity to reduce CO_2 emissions, since they represent some of the worst performing homes with the most potential for thermal improvement. However, many of these properties, particularly those with solid walls, will not be insulated by 2050 without stronger incentive schemes, active promotion and technological innovation.

Evidently, some measures such as double glazing have a particularly long financial payback period which threatens to counter their benefits. As millions of homes still contain single glazing or have first generation double glazing in need of improvement, careful consideration needs to be given when deciding to upgrade these units. Equally, the high capital cost of solid wall insulation is one of the many barriers preventing its widespread implementation. Opportunities to externally insulate multiple dwellings simultaneously should be sought to benefit from economies of scale.

From now on, the Green Deal is scheduled to be the UK's main energy efficiency scheme. However, there is risk this scheme will fail to meets its targets, particularly due to low consumer appeal and low investor incentives. To meet the 2050 CO_2 reduction target, it is imperative that the Green Deal targets and improves the performance of all households and not just those which are easy to treat using conventional measures. This will require more information to the bill payer, such as realistic projections for long-term fuel reductions, more transparency regarding the benefits and disruption of different retrofit packages and more information about the wider implications of the scheme such as how it impacts fuel poverty, household value and re-saleability.

We have found that strategic war-gaming exercises can be a useful tool to evaluate preliminary investment scenarios for the Green Deal. Better access to housing stock, capital cost and energy savings data at a local level, combined with more clarity on marketing, administration and energy assessment costs will help to improve the accuracy of this process. Evidently, more attention needs to be given to areas of the housing stock which are less cost effective to improve. Poor quality construction, thermal comfort take-back and a lack of monitoring following refurbishments pose a serious threat to obtaining real, long-term energy savings. This could be particularly problematic for the Green Deal, with its 'golden rule' financing mechanism, based heavily on predicted savings rather than actual fuel bill savings.

It should be noted that success has been achieved in Germany through their adoption of the Passivhaus standard in both new and existing homes. Over the next few years it can be expected that a handful of certified Passivhaus retrofits will emerge in the UK. However, without the appropriate construction skills and easy access to cost effective components, it will be difficult for this standard to become practical in the UK, particularly due to the complexities associated with achieving such high air tightness levels in old, leaky dwellings.

The significance of embodied energy over the life cycle of buildings being refurbished is an area which also needs to be better understood. Measures such as double glazing have a particularly high embodied energy, which threatens to counter their installed benefit. The full extent of materials, on-site processes and transport during refurbishment are areas that need to be carefully audited. There is a risk in particular when undertaking a deep retrofit the sum of this embodied energy will not be recovered for many years after the works are undertaken.

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