Carbon footprint of a 100-year old house: Case-study of improvements and implications for the UK housing stock.

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Abstract: Before 1930, most houses in the UK were built with solid brick walls, which have high heat losses and are difficult to insulate. These homes represent nearly one-quarter of the UK housing stock. This paper covers a case-study that shows some of the difficulties to meet the UK government's target to reduce carbon emissions by 80% by 2050. Such a target can only be met with refurbishment of all older properties and even then, energy-savings initiatives are probably not sufficient; integration of renewable energy sources is also necessary. Comparison with refurbishment initiatives in Germany demonstrates the massive investment that needs to take place, and some of the practical limitations. Strategies to limit increasing demand for energy use will be required in order to meet these ambitious targets. The case-study demonstrates the types of practical problems likely to be encountered, but also shows the importance of disseminating the experience gained by pioneers of refurbishing older homes in the UK.

Keywords: *Energy Efficiency, Refurbishment, Carbon Saving*

1 Introduction

In northern Europe, the energy use in residential buildings is largely associated with space heating and hot water provision as well as lights and appliances. Reducing energy consumption in residential buildings has the potential to help countries meet their targets to reduce carbon emissions. Approximately 30% of carbon emissions in the European Union are due to energy use in residential buildings, of which around 50% is used for space heating [1]. Significant reduction in these carbon emissions can be made by three methods – firstly, demolishing old homes and replacing them with new "low-carbon" dwellings; secondly, switching to energy sources that do not rely on fossil fuels; thirdly, making existing homes more energy efficient. In many parts of Europe, including the UK, the demand for new homes is high because the number of households is increasing. Apart from energy use, older houses have many attractive features, so demolition occurs at a very slow rate [2]. The second of these options requires investment in alternative energy infrastructure, which is occurring, but not fast enough to impact significantly yet on carbon emissions. The third of these options, i.e. refurbishment of existing buildings for improved energy efficiency, has other public benefits such as employment opportunities, increasing the aesthetic quality of existing housing stock and reducing the number of families suffering from fuel poverty. For the occupants, energy efficiency measures can lead to improved indoor comfort, lower running costs and a healthier indoor environment.

Government housing data shows approximately 23% of the UK housing stock is comprised of houses built between 1800 and 1930, of which over 70% are owner occupied. These houses are highly inefficient in their use of heating energy, contributing a disproportionate fraction of UK carbon emissions. It is logical that these should be a prime focus of energy efficiency improvements but there are significant barriers to implementing such changes. Before 1930, most UK houses were built without cavity walls and with other design features that make their energy performance difficult to improve. Much of the heat loss is through the walls of the house, which can only be reduced by applying internal or external insulation. External insulation has the advantage of retaining the thermal mass of the building within the insulated envelope. It has been applied within a number of social housing projects in the UK, but so far has been rarely used in owner occupied houses, which is the focus of this paper.

The case-study energy use data has been analysed to find the contribution of the energy improvements to a reduced carbon footprint. Data from other examples has also been compared in order to identify the practical limitations to reducing the carbon footprint of older residential buildings. Carbon emissions for the UK have been calculated using data for 2007 published by the Carbon Trust: electricity: 0.544 kg CO_2/kWh; gas: 0.184 kg CO_2/kWh.

2 Refurbishment Case-study

The study analyses energy savings in a detached family house of 98 m^2 built in 1910 using 225 mm solid brick walls, some of which were rendered on the outside. This house is of typical construction for its era, with slated roof and originally with single-glazed windows. It is heated by a gas-fired central heating system and also had an open gas heater in the living room. The house has been refurbished since 2001 in two phases. In the first phase, improvements were made through installation of double glazing, replacement of an inefficient gas boiler by a Worcester Greenstar combi condensing boiler, which has a SEDBUK efficiency of 90.3% (previously water was heated by an electric immersion heater). The loft insulation was topped up to 200 mm using Warmcel recycled paper insulation. Energy efficient lighting, mainly compact fluorescent, was installed throughout the property. Draught-proofing was carried out and both external doors were replaced, as the original doors were ill-fitting. The energy savings from these improvements have been estimated using values from similar properties given by Lomas [3], which suggest that the energy use for space heating was reduced by 30% and energy use for lighting by 65%. Using the figures above, the resulting CO_2 emissions reduced from 7.8 to 4.4 tonne/year. One problem that was made worse by these initial improvements (apparently common in houses of similar construction, after fitting draught-proofing and double glazing [4]) was the incidence of mildew growth in poorly ventilated areas of external wall, due to condensation.

Figure 1. View of house from south side, before and after external insulation.

In the second phase, insulation has been applied to the walls of the house, internally where limited by the architecture of the building, but mainly externally. This has the advantage (in winter) that internal temperatures drop less when the heating is off during the night time. The external insulation is 60 mm of phenolic board with a protective cement render, which achieves a total U-value of 0.32 W/m^{2}K [5]. This is very close to current UK standard for new dwellings of 0.30 W/m^{2}K. Equivalent internal insulation would also have had the disadvantage of reducing the usable floor area by around 2%. The appearance of the property was not significantly altered by the application of the insulation, as seen in Figure 1. A line of "brick slips" was applied to replicate the original features of the house.

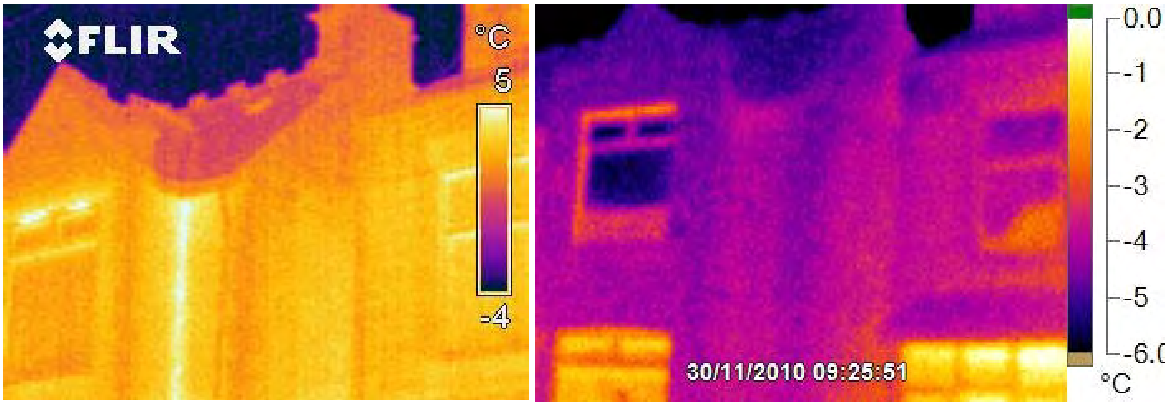

Figure 2. Thermal images of NW corner before and after insulation (and part of neighbouring house).

Thermal images of the house were taken before and after insulation, as seen in Figure 2. Both images were taken on a cold day, with the house heated to 18C, but the quantitative results are not directly comparable. Unfortunately, it was not possible to match the temperature scales exactly as a different camera was used for the second image. However, a qualitative comparison shows how the leakage of heat from the corners of the frontage has been reduced. On the end wall, no significant temperature difference now exists between the heated part of the house and the unheated loft (above the loft insulation, where the internal temperature is below +5 C). Where possible, at the top of the first floor the external insulation was brought above the level of the loft insulation in order to reduce thermal bridging.

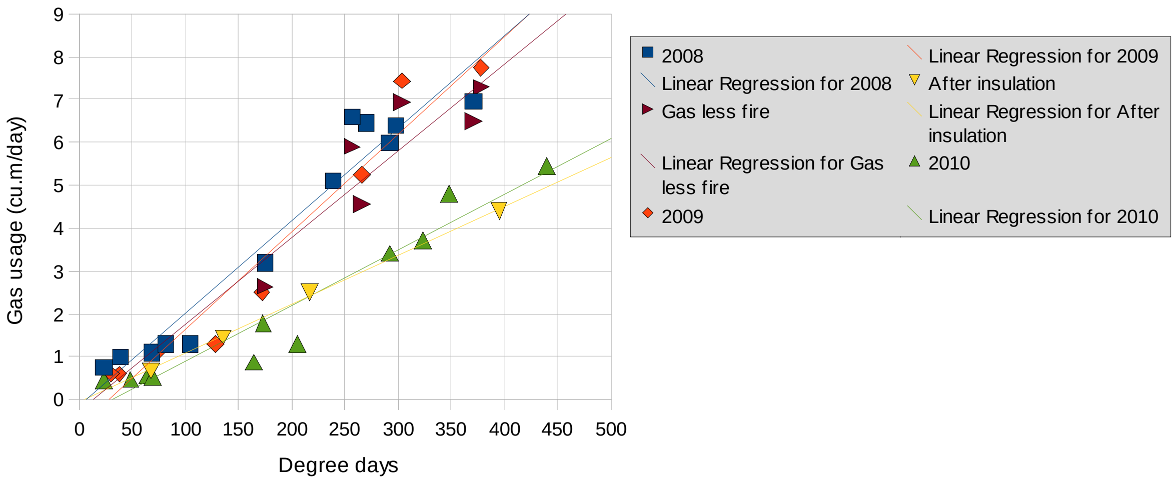

Figure 3. Mean daily gas usage plotted against heating degree-days on a monthly basis.

Evidence of the effectiveness of the insulation is shown better by looking at data for gas usage. Figure 3 shows the correlation between gas usage and degree-day values (taken on a monthly basis using values from Vesma [6]). An open gas heater in the living room was removed and replaced by a wood-burning stove. Although this was only used for supplementary heating (as there is a radiator in the room) it made up about 8% of the original gas use. Since applying external insulation, the appearance of mildew has been significantly reduced as internal wall temperatures are generally above the dew point.

Electricity use in the house is significantly below the national average. This is partly due to reduced use of electrical appliances – e.g. a kettle is used on the gas hob in preference to an electrical kettle and there is no TV, video recorder, etc. Plotting electricity use against day length shows a clear correlation due to lighting use (see Figure 4) which is estimated to be 750 kWh per year, 25% of the total. The increase in electricity consumption shown at the time of insulating the property is due to the installation of a dishwasher at around the same time. The graph shows a reduction in the minimum gas usage per day, due to less use for heating washing-up water. This contributes around 4% to the saving in gas. When this and the change to wood-burning in the living room is taken into account, the reduction in gas usage due to the insulation is 35 %, representing a carbon saving of almost 1 tonne/year based on the 20-year average temperature. The overall reduction in CO_2 emissions relative to the unimproved state of the house is approximately 60 %.

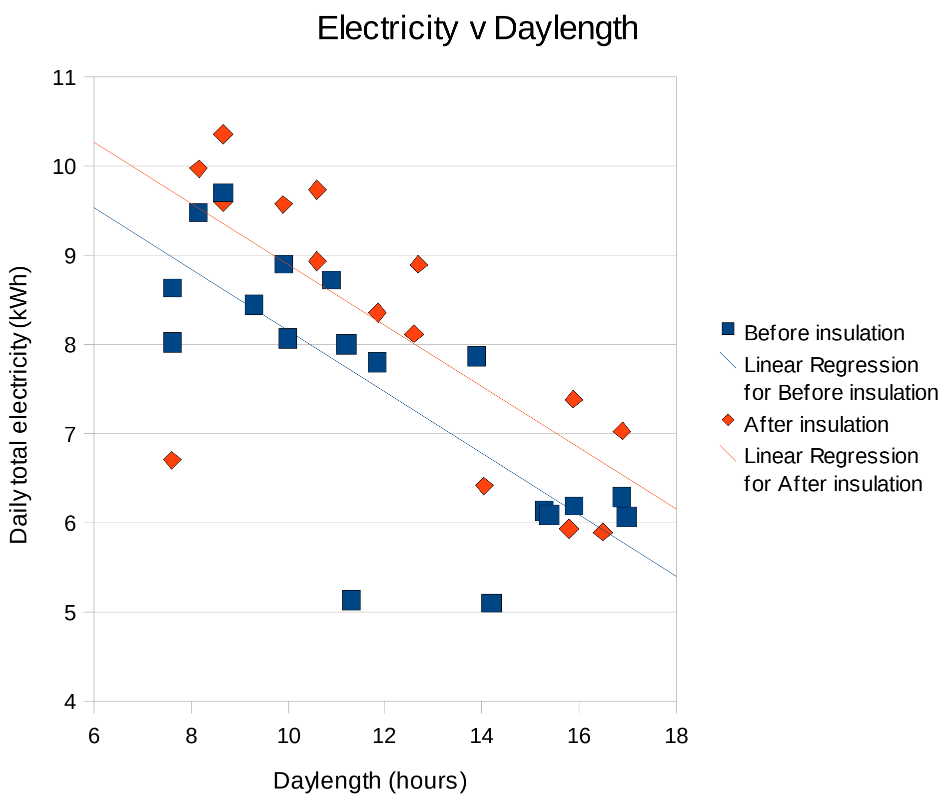

Figure 4. Electricity usage, showing the changing lighting load.

The amount of energy used for the wood-burning stove is difficult to assess, but is reckoned to be 200 kg of wood with an average energy content of 12 MJ/kg. This represents 6% of the total energy use in the home. This not only reduces carbon emissions, but so far has also reduced costs, as the wood used has been obtained free of charge. It is possible to extrapolate the number of households that could use such free sources of wood – much of it from builders' skips. According to the UK Government department Defra, the amount of waste wood from construction industry is 5 million tonne/year [7]. Just 10% of this would be enough for 1 million homes to provide a similar level of wood heating.

The overall energy use after refurbishment, corrected to average 2203 degree-days per year, is 125 kWh/m^2 of which 71% is from gas and 23% electric.

3 Comparison with other data

3.1 Scottish case-study

A refurbishment case-study of three types of dwelling in Scotland by Jenkins [8] includes a stone-built house of a similar age. The comparison is useful because the house is also detached and occupied by a family of four, with the same floor area of 98 m^2. However, in the Scottish house the window area is approximately 30% less, and the walls are much thicker. Without wall insulation but with other energy-saving interventions, Jenkins predicted a reduction from 327 kWh/m^2 to around 200 kWh/m^2 after refurbishment. Further Carbon savings (down to 4 tonne CO_2 per year) could be achieved using solar thermal, solar PV and wind energy.

The figures can be usefully compared with figures for different house types and ages given in another report on Scottish Housing [9]. Although similar data for England was not easily available, the Scottish data gives a useful comparison. Degree-day data for Scotland shows that energy demand for heating is likely to be 10 – 15% higher than in Nottingham. The Scottish data show mean CO_2 emissions of 17.5 tonne/year for pre-1919 detached houses.

3.2 Data from Germany

Most of the technologies for external insulation available in the UK are adapted from a system developed in Germany, known as *Wärmedämmverbundsystem* (WDVS). In general, German residential buildings are much more energy efficient than those in the UK. They use, on average, less energy per unit floor area, despite colder winter temperatures. Energy efficiency standards have been stringent since 1977 (similar to UK 2001 standards) and current minimum standards are still higher than in the UK. When houses are refurbished, they tend to be fitted with higher levels of insulation - 160 mm is the current recommendation for external insulation on solid walls in Germany.

In 2009, the German "Bank for Reconstruction" *(KfW)* provided loans of €8.9 bn toward the energy refurbishment of 620,000 homes, estimated to reduce carbon emissions by an average of 2.4 tonne/year/dwelling. Germany has fewer older houses than the UK – about 75% were built after 1945. A study [10] of multiple flats in larger houses in Germany *(Mehrfamilienhäuser)* – comparable in format to Scottish tenement housing - shows how older buildings have little capacity for energy improvement and predicted energy savings are often not achieved. In Figure 5 the data has been converted from kWh/m^2 using German emissions data (from *UmweltBundesAmt*) and taking an average floor area of 90 m^2.

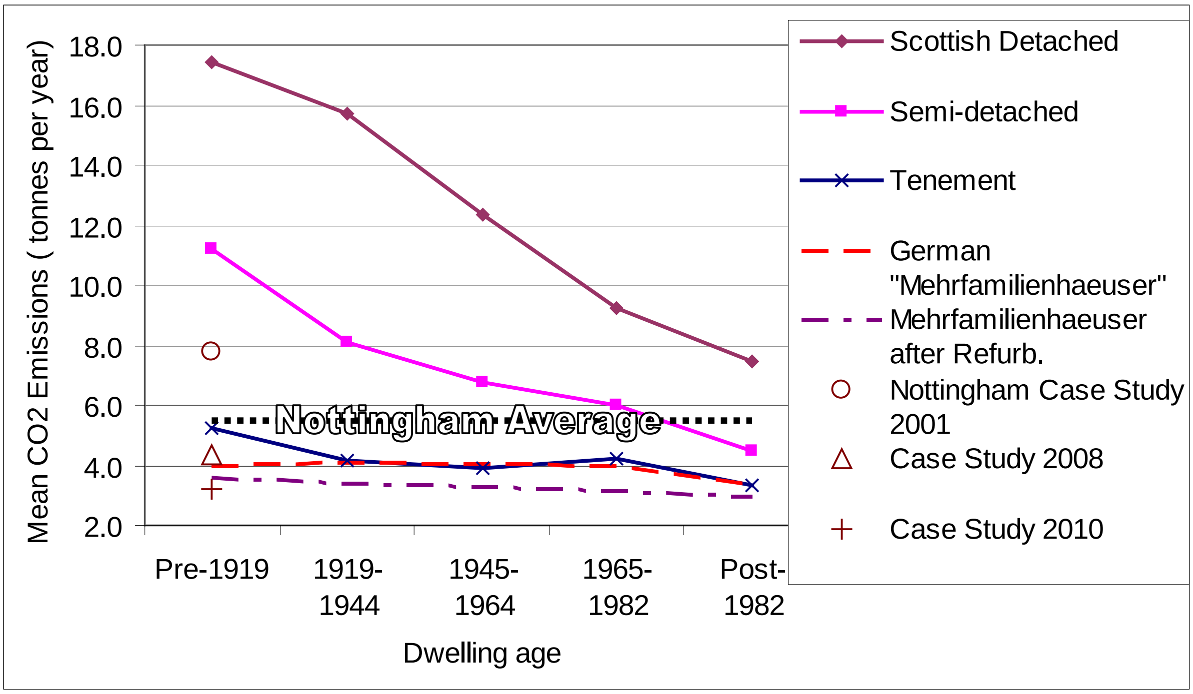

Figure 5. Comparison of CO_2 emissions per dwelling for different ages of houses and flats.

3.3 Other UK data

The previous UK government's main domestic energy efficiency programme was CERT (Carbon Emissions Reduction Target) which has been implemented through Energy Supply Companies. In contrast to the German investment, in 2009 around £400m (€0.45 bn) was invested, mostly in loft insulation (616,000 homes) and cavity wall insulation (500,000 homes); only 17,700 homes were fitted with solid wall insulation. A recent study published by the Department of Energy and Climate Change suggests that even homes in the UK with cavity walls cannot all be insulated easily. Although there are now around 5 million homes with unfilled cavities, most of these will be "hard to fill" because of the nature of the cavity walls and the materials used [11].

A portfolio of houses that have been refurbished to achieve at least 60% carbon reduction is presented by the Sustainable Energy Academy [12] under the slogan "Old Home, Superhome". This includes 39 case studies of houses built between 1800 and 1930, of which 22 were treated mainly with internal insulation and 17 with external insulation. To achieve this level of carbon reduction, very few houses rely on insulation alone: 36 of the 39 cases have at least one renewable energy source. The most common is solar thermal, but 40% have solar PV, 45% have wood stoves/boilers and 10% have ground source heat pumps. More than half have some form of underfloor insulation in addition to solid wall insulation. For the case study house, installation of 3.8 kW of PV is planned for 2011 at a cost of £13,700, with a predicted further saving of 1.7 tonnes of CO_2, approximately half of the 2010 emissions.

Lectures about existing local examples of refurbished homes gave information and inspiration before implementing the case study described in section 2. Among these were a Nottingham "Eco-home" included in the Sustainable Energy Academy portfolio and a refurbished home owned by a local Member of Parliament described in [13]. The importance of occupier behaviour is also critical to the success of such energy improvement schemes. Hence, the E-On house project at University of Nottingham, which will demonstrate the process of converting a typical 1930's house to a zero-carbon home, incorporates a sophisticated array of monitoring equipment to learn more about this aspect [13].

4 Conclusions

The energy-saving measures in the Case Study have been effective in reducing the carbon footprint of the house. However, it is clear that the main reduction in carbon emissions was made by the first stage of improvements, which were more cost-effective. The greatest contribution to carbon reduction probably came from two changes which did not affect heat loss from the house: (i) installation of a condensing boiler; (ii) changing from electricity to gas for domestic hot water. Changes in carbon emissions are highly dependent on fuel choice because currently CO_2 emissions per unit of energy are three times higher for electricity than for gas. However, the combination of energy-saving measures employed in the case study make internal temperatures much more even, reduce condensation and contribute significantly to reduction in use of fuel for heating. Nevertheless, it is clear that one reason for the low final carbon footprint is the behaviour of the house occupants. Typical room temperature in living areas is 18 C, 3.5 degrees less than the temperatures considered as normal by the Tarbase study [8].

The external insulation cost £9000, which at current gas prices will take more than 20 years to payback financially. However, it has probably enhanced the overall property value, particularly with the current requirement for Energy Performance Certificates. Nevertheless, depending on interest rates, this length of payback could mean that such improvement would not meet the requirements of the new UK government's proposed Green Deal, as costs might be greater than current fuel savings. Also, if Energy Performance Certificates are dropped, as some sources have indicated, the property value incentive would reduce.

From this case study, it is possible to extrapolate that 60% carbon savings could be made by implementing similar improvements throughout the 5 m older housing stock and 5 m "hard-to-fill" cavity homes. However, to reach this target by 2040, the number of homes treated needs to increase (from the current level of approx. 18,000) at a rate of 20% per year until 2027, by which time the level of refurbishment would be 600,000 homes per year (as currently in Germany). This level of growth cannot be envisaged without a coherent policy for incentives and appropriate dissemination of information to home owners. Some of the likely policies are set out by Boardman in [2].

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