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What is the relationship between built form and energy use in dwellings? ☆

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ABSTRACT

Energy is used in dwellings to provide four services: space heating, hot water, lighting and to power appliances. This paper describes how the usage of energy in a UK home results from a complex interaction between built form, location, energy-using equipment, occupants and the affordability of fuel. Current models with standard occupancy predict that energy use will be strongly related to size and built form, but surveys of real homes show only weak correlations, across all types of dwelling. Recent research has given us insights into occupancy factors including preferred comfort, 'take-back' from thermal efficiency improvements, and patterns of electricity use. Space heating is on a downward trend and is low in new dwellings. Energy use for lights and appliances, which is only weakly related to built form, is increasing. Strong legislation, combined with low-carbon technologies, will be needed to counteract this trend. Future challenges discussed include increases in real energy prices and climate change mitigation efforts, which are likely to improve the existing stock. Challenging targets are now in place for new housing to move towards low or zero energy and carbon standards. In the longer term, dwellings will demand less energy. Alternatives to gas for space heating will be increasingly common, including ground source heat and local combined heat and power (CHP) from biomass, while electricity could come from a more decarbonised electricity system. However, these improvements must be set alongside a demand for many new homes, demographic trends towards smaller households, and a more holistic approach to overall carbon use including personal transport.

1. Introduction

Intuitively, one might expect there to be a fairly close relationship between the energy use of a home and its built form. But surveys of real homes show very weak correlations between energy use and built form, across all types. This paper considers some of the reasons for this and the current knowledge base, and looks to the future evolution both of the housing stock and of these research challenges.

First, it is useful to define what we mean by built form and energy use in homes. 'Built form' has a variety of meanings, but is used here to mean the type of dwelling (terrace, semi-detached house, bungalow, flat etc.) and its geometry, internal layout, floor area, construction (solid or cavity wall, timber frame, solid or suspended floor etc.), its insulation level and its immediate surroundings. Many of these are directly related to a building's age, through a combination of contemporary styles, construction methods and building regulations. 'Energy' is used here to mean the total energy used within and around the dwelling in the form of electricity, by the combustion of gas and other fuels, and from centrally supplied (district) heat. Solar gains to spaces are excluded. Though important, they are hard to quantify, cost nothing, have no direct environmental impact and are not part of the energy supply system. Ground source heat pumps are included only in terms of the electricity they use.

There are about 24 million homes in the United Kingdom. Of these 21.8 million are in England,[1] comprising 29% terraces, 27% semi-detached, 17% detached, 9% bungalows, 3% converted flats and 14% purpose-built flats (DCLG, 2007). So, unlike many countries, the vast majority of dwellings in the UK are houses—86% in England. The stock is also fairly old. In England, 39% predate 1944, 42% were built between 1945 and 1980 (when thermal standards were raised significantly), and 19% after 1980. It is estimated that around a third of dwellings which will comprise the 2050 stock have yet to be built, and that by the same date 75% of the current stock will still exist.

Recent decades have seen large changes in demographics and household structures, with a trend to smaller households with fewer children. According to DCLG (2008), in England in 2007, 64%

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[1] Statistics on housing are mainly collected separately for the countries of the UK.

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of households consisted of a family group, with 29% consisting of a single person (6 million people), and the remaining 7% consisting of more than one family, or multiple people not in a family group. With more divorce and a declining marriage rate, the definition of a family has become more complex. Only 22% of households consist of a couple with dependent children, while 7% consist of a lone parent with dependent children—so less than a third of households include children. Neither are households static. Many children spend weekdays with one divorced parent and some or all weekends with the other. Household structure is important. Larger households tend to use more energy, but in general energy use per head increases with decreasing household size.

Energy in dwellings is used for space heating, hot water, lighting and to power appliances. The actual amount of energy used for these tasks results from a complex interaction between built form, location, energy-using equipment, occupants and the affordability of fuel. According to Owen (2006), 83% of energy use in the home is accounted for by space and non-electric water heating, and the vast bulk of this is done by gas. The remainder is accounted for by electricity use for other purposes, including electric water heating.

The main measure of energy efficiency, for heating, hot water and lighting but not appliances, is the Standard Assessment Procedure (SAP). This is a rating of energy costs normalised by total floor area (BRE, 2005). The calculation also gives normalised carbon emissions. For new homes, there has been a mandatory rating against the Code for Sustainable Homes (DCLG, 2006) from 1 May 2008, but this will still use the SAP to obtain carbon dioxide emissions.

A SAP rating is independent of location, using average Midlands climate for winter heating, and also assumes a standard occupancy and heating pattern. It is intended as a rating for the dwelling, not for the combination of dwelling and household. The SAP algorithm uses the areas and thermal transmission of exposed elements, air infiltration rate, efficiency of energy systems, and types of fuel. Most of these are directly related to the age of a building and to built form. SAP ratings are on a scale from 0 (worst) to 100 (zero energy cost). The average SAP in England has improved from 42 in 1996 to 48 in 2005 and new homes score 80+. If households all behaved in a similar way, then the SAP would be a good predictor of energy use, and would indicate that energy use was strongly related to built form, albeit modified by local climate. But studies have shown the SAP is actually a poor indicator for individual dwellings, which demonstrates the large influence of the household.

2. Space heating and cooling

Heat is lost through the building fabric, and by air infiltration and ventilation. Fabric loss is directly related to the insulation levels and the external areas. While insulation levels depend on age and subsequent improvements, such as loft insulation, the ratio of external roof and wall area to floor area depends on the building type—terraced houses, with two party walls, have a lower ratio than semi-detached houses, while detached houses and bungalows have the highest ratios. It has always been assumed, quite reasonably, that no heat is lost through a party wall (i.e. the shared wall between two dwellings) if both dwellings are similarly heated. However, recent research (Lowe et al., 2007) has shown there can be very significant heat loss when thermal insulation is bypassed via uninsulated and unsealed party wall cavities. We do not understand even existing dwellings as well as we think. Another source of heat loss often ignored is thermal bridging at junctions, through lintels, timber framework etc. In the past this has led to over-optimistic assessments of thermal performance. This becomes more important as the thermal transmission (*U*-value) of building elements is reduced, as the bridging accounts for a higher proportion of heat loss. Most Northern European countries have built reasonably airtight dwellings for a long time, but in the UK we tend to build much leakier buildings, with a consequent waste of heat. The 2006 Building Regulations tighten up on both thermal bridging, through stipulating minimum standards, and on airtightness through pressure testing to meet minimum standards.

Models such as SAP tend to overestimate the savings from energy improvement measures, because they assume that standard heating patterns obtain before and after the measures. There is now strong evidence that many homes were heated well below this standard before improvement and that the improvements serve to raise internal temperatures (Oreszczyn et al., 2006) and hence improve comfort (and health). This often means a much smaller reduction in energy consumption than predicted, and this is known as 'take-back' or 'comfort factor'.

Heating regimes vary widely between households, which partly explains the weak correlation between SAP and measured heating energy use. Though homes are generally getting warmer due to widespread central heating and better insulation, there is no evidence that people want substantially higher temperatures in occupied rooms than in past decades. Temperature monitoring of 14 modern, well-insulated homes in Milton Keynes in 2005, which had been previously been monitored in detail in 1989–1991, showed very similar temperatures for the two periods for the same outside temperature of 5 °C. Average living room temperatures had changed from 19.9 °C in 1990 to 20.1 °C in 2005, while average bedroom temperatures had declined slightly from 19.7 to 19.3 °C, though confidence intervals overlapped in both cases (Summerfield et al., 2007). Although the work was carried out in the same houses, many of the inhabitants had of course changed.

The traditional model used in the SAP standard occupancy pattern is of a well-heated living room at 21 °C, typically with a focal point fire, while the rest of the house is at 18 °C, during occupancy. But this ideal may no longer be appropriate for a house with central heating and reasonable insulation. Such homes tend to have more even temperatures throughout, as the Milton Keynes houses show, and many have no focal point fire. As bedrooms, in particular, become comfortable, there is a greater tendency to occupy them during daytime and evenings for recreation or work. This is likely to increase use of lights and appliances in these rooms. Larger homes and larger households, are also likely to lead to more diverse use of space.

Many homes have been extended, which is often a more cost-effective way of increasing living space than moving house. Conservatories have been particularly popular, low-cost additions. During the 1980s conservatories were seen as a beneficial passive solar design 'buffer space,' to preheat incoming air and reduce wall heat loss. But 90% of conservatories are heated, and they are often open to the rest of the house throughout the year. With large areas of glazing, they can be a major heat sink during winter. In fact, rather counter-intuitively, double glazed conservatories lose more heat from the house than those with single glazing. The latter are so cold that they tend to be shut off and not used as winter living space (Oreszczyn, 1993).

Domestic cooling is at present very rare in the UK, and most is in the form of portable units used occasionally in hot weather. Countries such as France have lived with a much warmer climate, possibly similar in some respects to a future UK climate, and also use little domestic cooling. However, new homes have been shown to have higher summer temperatures and more overheating. This is clearly related to their built form through insulation, thermal mass, windows and shading. Limiting overheating