What are the energy and power consumption patterns of different types of built environment?

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ABSTRACT

This paper outlines the current energy usage patterns of various sectors of activity within the built environment. It then leads on to identify drivers and barriers to how energy consumption within the built environment could be reduced in the future.

1. Introduction

It has now been generally accepted that global warming is taking place. Many Governments around the, including the UK, world are beginning to address issues of carbon emissions from all sectors of their economies. The UK is also undergoing significant changes in its social and physical structure, which will change its emission of greenhouse gases.

In order to understand these movements in energy consumption it is necessary to look at the historical context of emissions and then to make a judgement as to how they will move in the future.

Since a period of restructuring of the industrial base in the late 1970s and early 1980s, UK energy consumption has been on an upward trend. The built environment accounts for approximately 50% of energy use, with industry and commerce taking a further 34%. The weather-corrected data does not reflect changes in the climate, which could indicate that the increase is caused by other factors. The sector breakdown (Fig. 1) suggests that although many sectors appear to be reducing their consumption, energy use in homes and for transport do not follow these general trends.

This paper attempts to shed some light on the magnitude of these emissions across the broad sectors of ‘domestic’, ‘work’ and ‘leisure’, with a view to identifying those areas where information is weak or missing. It is also intended to discover where cross-cutting research could identify operational characteristics or systems, which will contribute to making a significant impact on the reduction of emissions. It starts by looking at sector breakdowns, fuel prices, population trends and the likely effects of global warming, before looking at UK energy use in more detail and then some of the drivers and barriers for changes in sector energy use.

2. Sector breakdown

Some key indicators for the UK are presented in Table 1. These help us to focus attention on the magnitude of the energy problems facing the country. One significant statistic is the amount of electricity consumed per capita, but it is useful to look in more detail at how this is broken down between sectors.

Between 1990 and 2006 the primary energy consumed in the UK has increased by 7.15%. While energy use has grown in two of the three main sectors, housing and transport, by 11.8% and 22.9%, respectively, the third, manufacturing, has seen a 15.78% fall in its energy use. The other sectors of the economy have remained reasonably constant with overall increases of 3.49%, although mining and quarrying may show an upward trend.

Converting this energy use into a basket of greenhouse gases shows that over the same period there has been a significant downward movement in emissions in most sectors. The exception is the electricity, water and gas sector, which after the move away from coal for electricity generation is now on an upward trend. Manufacturing and housing are also following this trend, and transport emissions have continued to rise over this period. The associated carbon dioxide emissions have shown the same trends of slight reductions up to the late 1990s and increases in the early

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2000s. However, the emissions from the domestic sector have remained fairly constant over this period. The same trends can be found for hydrochlorofluorocarbons (HCFCs) and methane, reflecting government policies. However, there is a worrying trend in the emission of HCFCs. Their use is rising in the wholesale, retail and domestic sectors even after the introduction of legislation to limit their use. A similar trend has been noted in the emission of methane, which generally shows a downward trend in most sectors except agriculture, whose methane emissions have remained fairly constant since 2001.

### 3. Fuel prices

Since the early 1990s, fuel prices have fallen with respect to the retail price index (see footnote 3) as shown in Fig. 1, so that in real terms energy has become cheaper. Over a similar period of time, average gross weekly earnings have shown a steady increase. However, comparing changes in income with changes in domestic gas and electricity prices shows a significant difference between the late 1990s and early 2000s. While gas prices appear to be running parallel with income, electricity has increased rapidly in price since 2004 (Fig. 2). This could mean that consumers start to regard electricity as expensive.

### 4. Population trends

Two of the objectives of this report are to identify areas where energy usage appears to be increasing, and areas where further research is needed to understand the likely impacts of usage patterns. This requires a broad understanding of the predicted trends in the growth of population, including its age profile.

By 2050 there will be a significant growth in those of pensionable age, who will total almost 20 million people. There will be around 40 million people of working age and about 11 million children, both roughly the same as today. This increase in the number of pensioners could mean growing problems of affordability and availability of energy at home.

### 5. Global warming

Global warming is now accepted by the vast majority of experts, and the effects of climate change will have an impact on the way in which the UK uses energy.

The Intergovernmental Panel on Climate Change (IPCC; [http://www.ipcc.ch/](http://www.ipcc.ch/)) has produced many papers illustrating the effect of a wide range of developmental strategies on the global environment. There is strong evidence that in the UK, winter mean temperatures will increase, resulting in a lower demand for heating energy. In summer, on the other hand, there is evidence that there will be an increased number of hot spells. These will also have an impact on the way energy is used. The Chartered Institute of Building Services Engineers has produced a document outlining how it sees climate change affecting energy use and temperatures within buildings ([CIBSE, 2005](http://www.cibse.org)). This document predicts a significant rise in cooling degree-days and a significant reduction in heating degree-days.

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Table 1

<table>
<thead>
<tr>
<th>Key indicators</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (million)</td>
<td>59.84</td>
</tr>
<tr>
<td>GDP (billion 2000 US $)</td>
<td>1591.1</td>
</tr>
<tr>
<td>GDP (PPP) (billion 2000 US $)</td>
<td>1661.29</td>
</tr>
<tr>
<td>Energy production (Mtoe)</td>
<td>225.21</td>
</tr>
<tr>
<td>Net imports (Mtoe)</td>
<td>233.69</td>
</tr>
<tr>
<td>Electricity consumption(^a) (TWh)</td>
<td>371.3</td>
</tr>
<tr>
<td>CO(_2) emissions(^b) (Mt of CO(_2))</td>
<td>537.05</td>
</tr>
<tr>
<td>Electricity consumption/population (kWh/capita)</td>
<td>6206</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GDP – Gross Domestic Product, PPP = purchasing power parity, Mtoe = million tonnes oil equivalent, TWh = terawatt hour, Mt = million tonnes, kWh = kilowatt hour.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^a) Gross production+imports−exports−transmission/distribution losses.</td>
</tr>
<tr>
<td>(^b) CO(_2) emissions from fuel combustion only. Emissions are calculated using the International Energy Agency’s energy balances and the Revised 1996 International Panel on Climate Change Guidelines.</td>
</tr>
</tbody>
</table>
6. UK energy use in more detail

6.1. Domestic

The domestic sector accounts for almost 34% of the UK energy consumption. Over the years, governments have made a series of efforts to reduce this consumption through a significant tightening of the Building Regulations and measures such as Warm Front and Affordable Warmth. However, domestic energy use is still growing and is currently equivalent to just over 70 million tonnes of oil per year. Between 1990 and 2004 the number of households increased by roughly 13%, while the energy consumed has increased by just over 14%. This increase could be taken as a failure of the initiatives set in place to improve consumption, but it is more likely to indicate that the way energy is used in the domestic sector is changing.

Since the early 1990s the amount of energy consumed for heating has steadily increased while that for cooking, water and lighting has not. Over the same period, there have also been significant changes in electricity consumption. Up to the late 1990s there was a steady increase in electricity consumption in appliances. But since the late 1990s most areas have either reduced in consumption or at least not increased at the rates seen earlier. One particular interesting movement has been in the provision of ‘cold’, as the impact of the new and lower-energy refrigeration appliances has taken effect. However, consumption for ‘brown’ and ‘miscellaneous’ appliances continues to increase at an alarming rate (18% in miscellaneous and 15% in brown goods since 2000).

One important aspect of UK domestic energy usage is the relatively poor state of our houses. A measure of the thermal efficiency widely used is the Standard Assessment Procedure (SAP). SAP ratings were introduced in the 1995 Building Regulations and a value of between 80 and 85 was recommended as being acceptable. In the 1991 English House Condition Survey report, which was the last specifically to investigate energy usage, it was established that average SAP ratings were in the region of 50–60, and further work carried out since then has confirmed these values. When translated into energy consumption, these average SAP ratings result in homes using approximately 300 kWh/m²/year for heating. The 2006 Building Regulations call for heating to use around 100 kWh/m². In theory this improvement should result in new homes being significantly better in terms of heating requirements. The introduction of the Code for Sustainable Homes in 2008 should add further to the growing awareness of energy and environmental issues in domestic energy use. But it is worth noting that current thinking from mainland Europe under the Passive Haus programme (http://www.europeanpassivehouses.org/) envisages housing with a demand of 15 kWh/m².

6.2. Work—offices and factories

Energy consumption in the non-domestic sector covers a wide range of property types. Fig. 3 (from Lowe, 2007) shows a breakdown by property type for 2006. This indicates that the top five consuming types are industry commercial offices, state schools, small shops and hospitals.

Breaking down this data into a more general service sector shows that the sports, leisure and hotel sectors are major consumers of energy (Fig. 4).

6.3. Work—education

Although it could be argued that education does not fall neatly into the three sectors being investigated, it is a significant sector employing a significant number of people (985,000 in 2006; Universities UK, 2006) and therefore can be regarded as part of ‘work’.

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7 Warm Front—UK Government grant programme, funded by Defra, for the installation of a range of energy-efficiency measures and the provision of advice in the private sector.
Education falls into two broad categories: schools and further and higher education. Higher education had an output of over £45 billion in 2003/2004, with the equivalent of 280,000 full-time staff, and created around 300,000 indirect jobs. According to Baroness Warwick\textsuperscript{11} education and education-related services are the UK’s fastest growing export earner and have overtaken food, tobacco, drink, insurance, shipping and aircraft.

Fig. 5 shows the number of educational establishments in the UK and it is noticeable that the majority are primary schools.

Higher and further education accounts for a small proportion of the establishments (HEFCE, 2007).

The energy used by these establishments is broken down in Fig. 6. It can be clearly seen that higher education establishments consume the most energy, followed by secondary and then primary schools. Aggregate energy consumption in universities, other higher education institutions (HEIs) and nursery schools is on the increase, while the other school types are using gradually less energy.

Energy consumption in education can be summarised as follows:

- Universities and other HEIs consume the most energy within this sub-sector, while nursery schools consume the least.
Natural gas accounts for the bulk of fuels used in the sector (over 70% in schools, and just over 52% in higher education).

Electricity consumption is on the increase at all levels; the greatest increase appears to be in nursery schools where a 29.1% increase in the electricity consumption per pupil was reported between 2004 and 2006. This trend needs further investigation.

Very limited data are available on further education colleges and independent schools.

6.4. Leisure facilities

The leisure sector may be regarded as encompassing retail, sport and leisure, and hotels and catering.

These sectors alone account for some 46% of UK non-domestic energy consumption (Wiggin, 2001), which makes it perhaps the largest sub-sector after domestic use (Fig. 7). Since 1984, household expenditure on leisure has increased (Office for National Statistics, 2007), but in recent years it has tended to level off at around 18.5% of expenditure.

7. Drivers and barriers for change in sector energy use

7.1. Domestic

From Section 6 on domestic energy use, it is clear that a great deal more needs to be done to stabilise and reduce the amount of energy consumed by this sector if it is to meet the Government’s 60% reduction target by 2050.

7.2. The drivers

The main drivers identified include:

- Increased numbers of households: three million new homes are projected by 2020.
- Government commitment to low-carbon homes.
- Introduction of Code for Sustainable Homes.
- Introduction of Home Information Packs.
- Social change in energy attitude and behaviour.
- Security of supply to vulnerable groups.
7.3. The barriers

Counteracting the drivers, a range of barriers have also been identified which could act against achieving energy reductions. These are:

- Oldest housing stock in Europe, being replaced at about 1% per year.
- Increased use of electrical equipment.
- Increased use of conservatories as extra heated living space.
- Relaxation in planning permission for extensions including conservatories.
- Ageing population living in older properties not being able to afford improvements.
- Increased use of condensing boilers and combi-boilers, reducing the ability to use solar or other renewable energy that needs storage for hot water.
- Tighter Building Regulations may mean more overheating and increased use of domestic air conditioning (415% sales increase recorded in 2006).12
- Limited information on reliability of emerging technologies for energy services.
- Lack of user information to help with use and understanding of domestic heating systems, including renewable systems.
- Increase in disposable income.

In order to address these issues it is necessary for policies to be put in place which will enable conservation measures to be identified as ‘worthwhile’ by the majority of occupiers. In the social housing sector, measures are already in place to ensure that a rolling programme of improvements in the stock will occur. New homes built by the private sector are subject to regulations to ensure that they are energy efficient. This leaves a gap in the existing privately owned sector, where at the moment there are no real measures in place to help occupiers improve their properties. An ageing population on fixed incomes is unlikely to be able to afford to improve its homes. Indeed, such individuals may prefer to spend their disposable income on leisure activities rather than embarking on conservation measures that may take several years to see a payback. Those in retirement receive an annual payment from the Government to help towards the cost of fuel and there are schemes in place to help them to have cavity wall and loft insulation installed in their homes. Extending this type of scheme, linked to supplementing the annual fuel allowance with extra payments if conservation measures are put in place, may be a way forward for this sector.

7.4. Work—offices and factories

7.4.1. The drivers

Energy use is motivated by different drivers from those affecting the domestic sector. They include:

- Increased fuel costs.
- Environmental Policy Statements to stakeholders.
- Corporate responsibility concerns.
- Profitability of companies within a global market.
- Carbon levy, linked to adopting conservation measures via Carbon Trust.
- Tighter Building Regulations.
- Security of supply.
- Workplace environment issues such as health and safety.
- Home working, which may reduce transport usage but increase domestic usage and reduce the energy efficiency at the work place.

7.4.2. The barriers

The barriers working against business in improving its energy effectiveness are:

- Increased use of IT.
- Higher comfort standards.

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- Overheating resulting in increased use of air conditioning.
- Investment costs.
- Lack of readily available reliable independent information on energy issues.
- Indirect energy use related to the supply chain.
- Increase in travel distance as a result of an unwillingness to move home when changing job.

A company can only exist if it is seen to be making a profit, so any investment in energy conservation must be seen as adding to the viability of the company as well as being able to be funded. Many of the drivers listed above stem from the Government's commitment to reducing the nation's carbon emissions. Encouraging companies through a range of fiscal measures to help offset the cost of implementing better energy efficiency may be the easiest way to help this sector.

7.5. Work—education

7.5.1. The drivers

This is a large area, which is mostly in the public sector. Schools are generally under the control of local authorities, while higher education gets most of its funding from Government for teaching and research. The main drivers for this complex sector are:

- Number of schools: current population trends suggest a future mini-baby boom, which will have an impact on energy consumption in schools.
- Changing delivery methods: e-learning increases electricity consumption levels at institutions and homes.
- Higher education is growing as a business sector. The impacts are already evident in the increase in the number of institutions and in their energy consumption.
- Limited scope for income generation.

7.5.2. The barriers

The administration of this sector does not always have the cost of utilities as one of its top priorities. This, and the barriers outlined below, often means that school and colleges fail to take action to help control energy and utility use.

- Absence of a single repository of energy data for the sub-sector.
- Limited characterisation of the sub-sectors within the education sector.
- Energy is often assessed as a budgetary item and so the reporting indices do not provide for particular analysis. Data normalisation and weather correction provide good accounting results, but tend to mask actual energy consumption patterns. There may be a need to review energy accounting practices and indices.
- Energy and environmental issues are not major corporate concerns.
- Organisational structures do not offer the energy management team the opportunities to direct energy-efficiency initiatives.
- The diversity of circumstances among institutions (age of buildings, size, activities, etc.) suggest individual solutions to energy management problems and limit cross-sector learning.

Many of the buildings in this sector have been or are being refurbished or replaced. Most new buildings are constructed to the current Building Regulation standards. However, there are still a very large number of buildings in existence that have a projected life of at least 20–30 years, and there are few incentives to address the problems encountered in these buildings. Some higher education institutions have taken advantage of the Carbon Trust-funded programme aimed at improving energy management, but such schemes only address a small number of institutions. This approach could be extended to cover all institutions in this sector. Perhaps the main driver to do so is the requirement under the EU Energy directive. To ensure that such a scheme would be effective, it would be necessary to put in place mechanisms to train a significant number of assessors with expertise directly applicable to this sector.

7.6. Leisure facilities

This is a growing sector covering a wide range of activities, and as disposable incomes rise there are likely to be further increases.

7.6.1. The drivers

The main drivers in this sector can be summarised as:

- Demographic changes: an increase in the working age population means higher levels of personal disposable income, while fewer children mean more money to spend on oneself.
- Social attitudes: growing appreciation of the health benefits of exercise, with looking good, regular eating out and cinema-going seen as non-discretionary.
- Increase in domestic travel and leisure breaks (two holidays per year seen as essential).
- Increased demand for entertainment and leisure services for 'work–life balance'.
- Impact of 2012 Olympics.
- Tendency for providers to introduce frills to attract and retain customers.
- Increase in energy used for marketing purposes, for example display lighting.

7.6.2. The barriers

The barriers to improving the energy efficiency of this sector include:

- Data quality and quantity.
- Energy efficiency is not usually an organisational concern, as higher costs can always be transferred to clients, so there may be no incentive to go green or be energy efficient.
- The sector is dependent on energy-consuming products over which it has no control of efficiencies.
- This is a diverse group with varied energy behaviours and expectations.
- A skills shortage for energy and environment managers.

Without more detailed information on how much energy is used in this sector, along with a realistic trend analysis coupled with information on social change, it is not feasible to set targets or to suggest approaches to reducing demand. Profitability in this sector is dependent not only on market share but also on retail sale prices. Any conservation measures introduced must take this into account and be seen as helping the organisation maintain its position relative to its competitors.

8. Conclusions

This paper has attempted to illustrate how energy is used in the domestic, work and leisure sectors, and drivers and barriers to change have been highlighted. The following points could form the basis of further discussion on how best to proceed to help to reduce energy demand.
8.1. Lessons learnt

- **Limited impact of Government programmes**: These programmes such as Warm Front, Low Carbon Building Programme and Market Transformation, have good intentions but fall victim to the ‘rebound effect’ as people do not achieve the potential savings. They rather choose to take some of the benefit in higher temperatures. If new buildings were already capable of maintaining good comfort standards, there may be less of a temptation to take back potential savings.

- **Areas of uncertainty in social trends**: Lifestyle changes are taking place rapidly, partially fuelled by higher disposable incomes and changing work and leisure patterns. These often result in higher energy use. For example, there is evidence that those with very large plasma televisions are leaving them switched on and using them as electronic picture frames displaying their own images. These televisions usually consume around 600 W and if left on for long periods of time contribute significantly to an increase in electricity consumption.

- **Lack of detailed information on energy usage in sub-sectors**: Research such as the Carbon Reduction in Buildings project (CaRB),13 is highlighting significant gaps in our understanding of how much and why energy is used in particular sectors. Further long-term research linking social and technical understanding of how energy is used is necessary before appropriate strategies can be effectively put in place.

8.2. Future directions

- Independent, integrated appraisal of policies and programmes.
- Active international collaboration and the adoption of international best practice in carbon management.
- Understanding whether the limited success of government programmes was due to faulty implementation or the targeting of the wrong issues or groups.

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References


HEFCE, 2007. EMS Institution Report 2007. Higher Education Funding Council for UK. This report is held by each Higher Education Institution and new ones are published every year.


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13 Carbon Reduction in Buildings (CaRB; [http://www.carb.org.uk](http://www.carb.org.uk)) has five UK partners: De Montfort University, University College London, the University of Reading, the University of Manchester and the University of Sheffield. CaRB is supported by the Carbon Vision initiative, which is jointly funded by the Carbon Trust and the Engineering and Physical Sciences Research Council, with additional support from the Economic and Social Research Council and the Natural Environment Research Council.