**Modelling Energy Use in UK Buildings: Statistics Showing the Way Forward**

**Dr S P Boyle, Dr L Shorrock, Dr J Willder and Dr C Pout**
**BRE, Garston, Watford, Herts WD2 7JR**

The present Government has a target for reduction of the UK's carbon dioxide emissions of 20% of 1990 levels by the year 2010, which is in fact greater than the legal commitment set at the Kyoto summit on climate change in December 1997. Energy use in buildings accounts for approximately half of the UK's annual carbon dioxide emissions and thus a reduction in the energy used in buildings is vital for this target to be achieved. A detailed knowledge of how energy is currently used is essential for assessing the potential for reducing the UK's $CO_2$ emissions. To this end, the Building Research Establishment, funded by the Global Atmosphere and the Research, Analysis and Evaluation Divisions of the Department of the Environment, Transport and the Regions, has developed two stock models - one for domestic buildings (BREHOMES) and one for the non-domestic sector (N-DEEM). This paper describes both these models and how they can be used to investigate current and future energy use scenarios including their ability to determine the potential for cost effective energy savings within the sector. More emphasis is given herein to the service sector, as this has been less widely published than equivalent data for housing.

## Overview of the Domestic and Service Sectors and their Energy Use

The delivered energy used in the service sector (including both commercial and public sector buildings) in 1996 was 883 PJ, which is equivalent to annual carbon emissions of 23 mtC or 13.1% of UK energy consumption (1). By comparison, the energy use in domestic buildings in 1996 was 2013 PJ, producing about 40.5 mtC in emissions, or 30% of UK energy consumption (1). A BRE Information paper (2) contains more information on the energy use and trends for housing. Trends information is presented below for the service sector.

### Historical Trends for the Service Sector

Figure 1 shows that energy consumption of the service sector has risen from 727 PJ in 1977 to 883 PJ in 1996. Generally, service sector energy consumption has risen consistently over this period, although there were large increases during the economic boom of the mid-1980's and early 1990's. This recent rise is due to a large number of factors affecting the service sector, including: economic growth, increasing employment within the service sector industries, longer working hours and increased use of office equipment. Figure 1 also shows the change in the energy use attributed to the different fuel types in the service sector from 1977 to 1996. There has been a significant decrease in the use of solid fuels and petroleum products over this period, with a corresponding increase in the consumption of gas and electricity. This is due to businesses preferring the convenience of a constant 'on-tap' supply of energy i.e. gas and electricity. Figure 2 further highlights the increasing importance of the service sector and shows that the percentage of the total UK energy use attributable to the service sector has risen from 11.8% of the UK total in 1977 to 13.1% in 1996.

**Figure 1** **UK Service Sector Energy Consumption by Fuel Type**

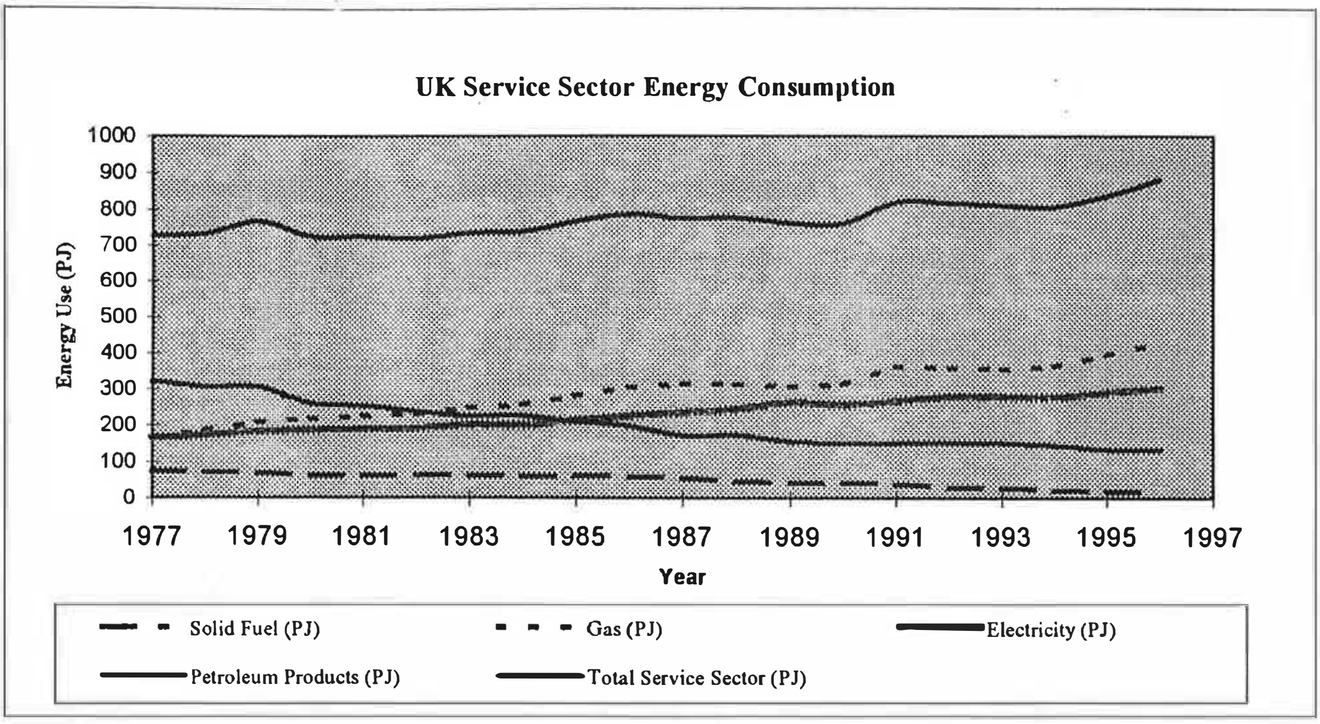
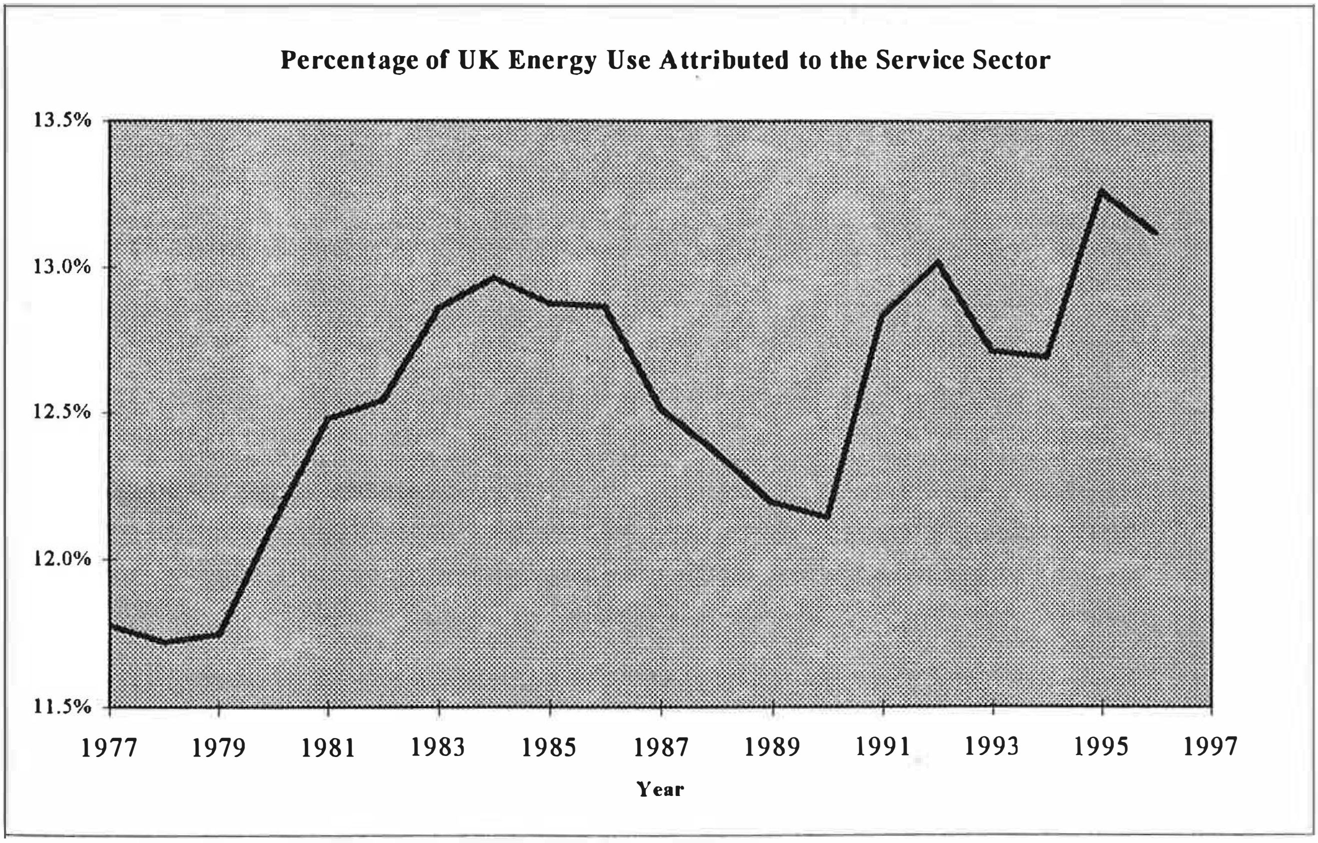



**Figure 2** **Percentage of UK Energy Use Attributed to the Service Sector 1977-1996**



## The UK Domestic and Non-Domestic Energy Models

BRE, funded by the DETR, has developed both a domestic energy model, BREHOMES (the BRE Housing Model for Energy Studies), and a non-domestic energy model, N-DEEM (the Non-Domestic Energy and Emissions Model). Two energy fact files, one for domestic buildings (3) and one for non-domestic buildings (4) have been produced using data generated from these models. In the case of the domestic fact file, several editions have been produced as more data have been accumulated.

### Description of BREHOMES

BREHOMES is a physically based model of the energy use in the housing stock which uses the BRE Domestic Energy Model (BREDEM) (11) to calculate the energy use of individual categories of dwelling. Over 1000 categories of dwelling are defined according to age, built form, tenure and the ownership of central heating. The contributions of each category are calculated and summed to produce an estimate of the stock energy use. This estimate is refined by small changes to the internal temperature assumptions until it matches the domestic energy consumption shown in the Digest of United Kingdom Energy Statistics (1). When this has been achieved the model may be used for predictive purposes, such as assessing potential energy savings (5) or developing scenarios for possible future energy use (8).

BREHOMES uses data from several sources, and it brings these together to form a coherent picture of domestic energy use and energy efficiency that the individual sources cannot provide. The main data source is an annual market research survey, from which insulation and heating system ownership levels are derived. The model has developed considerably over the years (e.g. it once only considered about 400 dwelling categories) and it continues to be developed to better meet policy advice needs. For example, a forthcoming project will use BREHOMES to develop energy efficiency profiles for the major dwelling categories in the housing stock and this will help with the targeting of energy efficiency improvements.

### Description of N-DEEM

N-DEEM provides estimates of the energy use, broken down by fuel and end use, for each of the subsectors within the service sector. The model has been constructed with data from over 100 databases, held by BRE, which contain information on the energy use and profile of the building stock within the service sector. The main data sources used for the N-DEEM are:

1. *Ratings List* - The Rating Valuation Office's Ratings List gives numbers for all non-domestic buildings that are rateable in England and Wales, of which there are approximately 1.7 million hereditaments. Notable exceptions from the Ratings List are Crown Properties (i.e. central government estate), churches and defence establishments. These are included in the other databases that form the model.

2. *Valuation Support Application (VSA)* - This is another Rating Valuation Office database that contains more detailed information, including the rateable floor area, on the hereditaments in the non-domestic building stock. It covers the majority of the hereditaments in the Ratings List database (1.4 million compared to 1.7 million for the Ratings List). Inclusion in the VSA is compulsory for a number of major activity groups. These are commercial offices, shops and retail outlets, warehouses and other storage facilities and factories and workshops. There are also significant numbers of entries for many buildings whose activities fall outside the four main bulk classes.

3. *Sheffield Hallam University (SHU) Energy Audits* - The latest versions of the SHU data sets contain detailed energy audits and includes an inventory of all plant and equipment, including hours of use, for 535 hereditaments. In order to increase the accuracy, the overall energy use data is reconciled to the fuel bills for each premises.

4. *Open University 4 Towns Database* - This contains external details (including dimensions) for all non-domestic buildings found in four designated areas in locations chosen to try to capture all common building types and activities which occur in the national stock.

5. *Other Sources* - BRE also holds other database information on the energy use and floor area of non-domestic buildings, obtained from a variety of other sources. This energy use information is less detailed than the information obtained from the SHU energy audits but contains information on a total of 15,000 non-domestic buildings.

The detailed Energy Audit data are a statistically representative sample of the 4 Towns external building data which, in turn, are a representative sample of the national Ratings List and VSA data covering virtually all the UK non-domestic building stock. In this manner the energy of the whole non-domestic stock can be modelled, with information at the detailed audit level grossed up to be representative of the UK stock. The other databases fill in any gaps and provide comparable data for checking purposes.

Future planned developments of the N-DEEM over the next few years include:

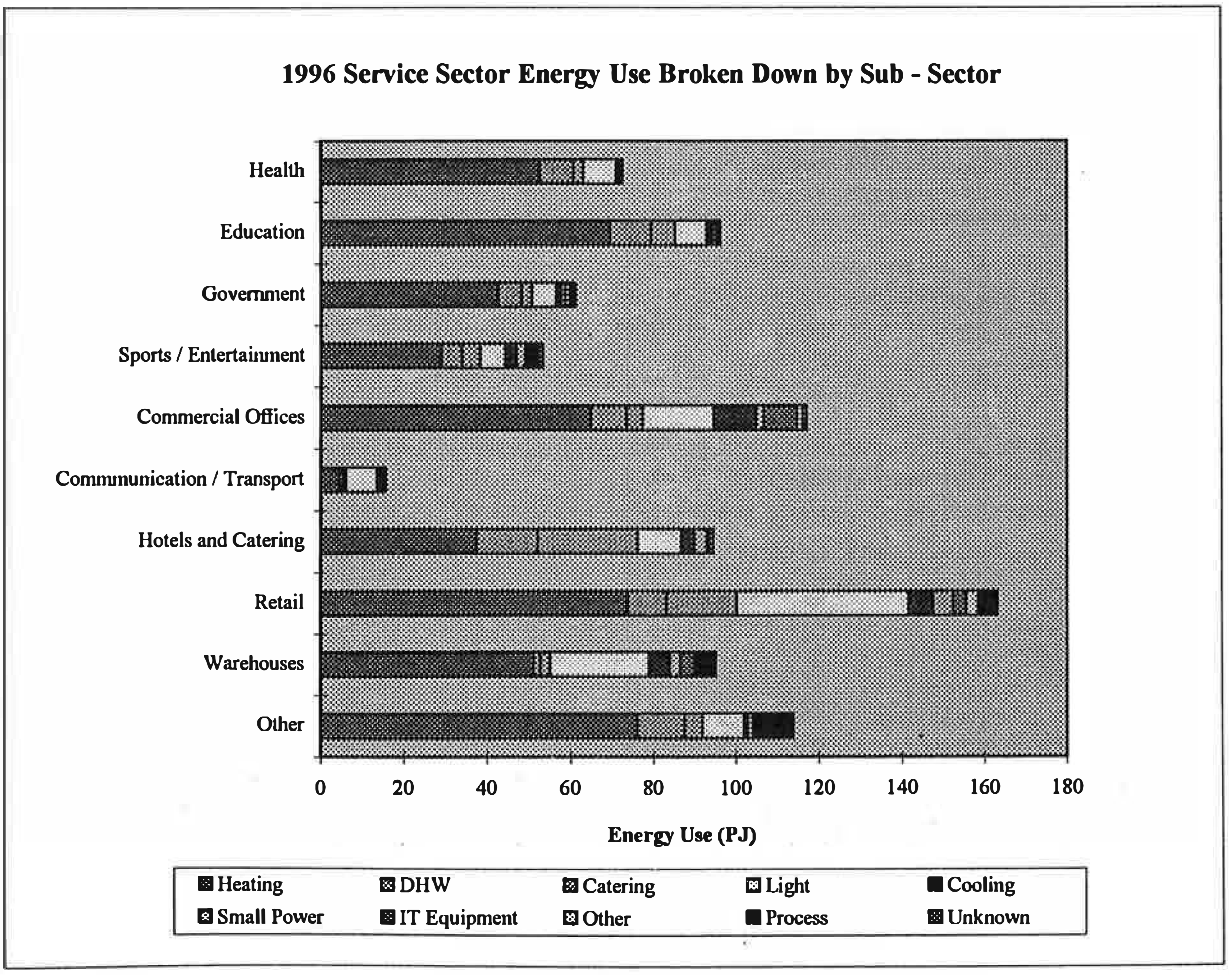
- increasing the number of energy audits in the SHU database, thus further increasing the accuracy of the estimates of the service sector energy use;
- incorporating automated inference procedures developed by the Open University to improve modelling of the effect on energy use of building characteristics (e.g. roof type, wall fabric);
- obtaining further VSA and Ratings List Databases in order to study trends in the make up and energy use of the non-domestic building stock and make predictions of future service sector energy use;
- extending the N-DEEM to include industrial buildings-related energy.

An Example Application of N-DEEM: Energy Use in the Service Sector

N-DEEM provides estimates of the energy use, broken down by fuel type and end use, for each of the subsectors within the service sector. Figure 3 shows that the greatest proportion of energy in the services sub-sectors is used for heating (57%), with lighting being the next most important - accounting for 16% of the overall service sector energy consumption. As might be expected, the retail sub-sector has the highest energy use, accounting for 163 PJ/year or 18.5% of the entire service sector energy consumption, with the next most important subsector being commercial offices, having an energy consumption of 117 PJ/year, or 13.3% of the overall service sector energy consumption.

Analysis of the pattern of energy use within each of the different subsectors highlights the high proportion of energy use attributable to lighting in the retail sector (26% of its energy use compared with the value of 16% for the service sector as a whole), and the high proportion of energy use attributed to heating in the Government and education subsectors (70% and 72% respectively, compared to 57% for the service sector as a whole).

**Figure 3 Service Sector Energy Use by Subsector (in 1996)**



**The Potential for UK Domestic & Non-Domestic Energy Savings**

BRE Information Papers (5), (6) and (7) describe the potential for carbon emission savings in housing, the service sector and for CHP in buildings respectively. The domestic predictions for (5) are largely based upon BREHOMES and, as this information has been published previously, only a short statement of the domestic potentials is made alongside the more detailed descriptions for the service sector. This paper updates the service sector and CHP in buildings information for (6) and (7). A recent article on BREHOMES (8) describes possible scenarios for energy use and carbon emissions in UK housing.

Section 3.1 presents information on the potential for energy savings for 25 measures where sufficient data is available to model their potential using a cost-abatement analysis. Section 3.2 briefly describes three other sources of information available for the service sector: office equipment not accounted for in the cost-abatement analysis; the potential for CHP savings; and the potential for energy savings through good energy management and good housekeeping.

Section 3.3 pulls together the information from Sections 3.1 and 3.2 to present the technical, and economic potentials for the service sector. Section 3.4 analyses the potentials in comparison with the Business As Usual scenario for 2010 (1, 9). Finally, the potential for energy savings from new technologies is presented.

Service Sector Cost-Effectiveness Analysis for 25 Energy Saving Techniques

The technical potential is the sum of the potential energy savings for all measures. The technical potential includes existing technologies that are available 'off the shelf' i.e. it does not include impossibly radical and costly replacement of stock. A total of 25 specific energy saving techniques concerning heating, lighting, cooling/ventilation, controls, office equipment and the fabric of the building have been modelled. In general, these measures can be applied to each of the subsectors within the service sector. However, there are specific measures that will be more applicable to a particular sector - for example, the replacement of computers with more efficient models will be particularly applicable to the commercial offices subsector.

The technical potential for energy savings is defined as the maximum uptake of all technically possible energy saving measures as soon as they are available on the market, regardless of cost. The economic potential is the energy savings over the life cycle of the items where they exceed their resource costs. An 8% real discount rate is used in determining this economic potential. The technical potential of all the 25 measures covered in the cost-abatement analysis for the service sector, is a total of 6.12 mtC/year, or 30% of the total 1996 UK service sector energy consumption. The economic potential for these measures is 3.35 mtC/year.

Potential for Saving Energy From Measures Not Included in the Cost-Abatement Analysis

The cost-abatement analysis is a highly complex process and it requires a significant amount of data. Hence only 25 measures have been modelled in this manner for the service sector. In addition to the cost-abatement analysis, the technical and economic potential has been estimated for a number of other energy saving measures in the service sector where it was not possible to undertake fully a cost-abatement analysis. These additional energy saving measures are:

1. *Other Office Equipment* (not included in the 25 measures analysed in Section 3.2.1) - In addition to the energy saving techniques discussed in Section 3.1 (replacement of computers, photocopiers and laser printers with more energy efficient new models), further measures that could be employed to reduce energy consumption specifically include the replacement of other office equipment, such as facsimile machines, scanners and vending machines, with more energy efficient designs. The combined technical potential for these further measures is a further 0.10 mtC/year with an additional saving of approximately 0.12 mtC/year saving if the cooling systems are correctly designed. The values for the economic potential of both these measures are a saving of 0.1 mtC/year.

2. *Combined Heat and Power* (CHP) - CHP can yield very high efficiencies (over 90%) compared to Combined Cycle Gas Turbine (CCGT) electricity generation at around 50% and more conventional power stations where only 34% of the primary fuel is converted to electricity. The overall economic potential for CHP in the service sector is equal to 0.87 mtC/year.

3. *Energy Management/Good Housekeeping* - The potential for energy saving through energy management and good housekeeping. Good Housekeeping is effectively good management of energy, largely through low cost measures (e.g. making sure that lights are switched off when they are not needed). Energy Management includes elements of Good Housekeeping, but is generally a more formal and structured approach. The overall economic potential for energy management.good housekeeping, not accounted for in any other part of this analysis, for the service sector is equal to 0.8 mtC/year.

## Overall Technical and Economic Potentials

Tables 1 - 3 in this section pull together the estimates in Sections 3.1 and 3.2 to determine the total technical and economic potentials for energy savings in the service sector. To put these figures into context, and to indicate the size of the entire potential for buildings, equivalent figures from the housing sector (5, 8) are also noted in the following.

*Technical Potential*
Table 1 presents estimates for the technical potential which is defined as encompassing the total energy savings which would be achieved by the implementation of all the measures, both cost-effective and non cost-effective, that are currently available. This shows that the overall technical potential for energy saving is 351 PJ/year, or 40% of total service sector energy use in 1996. For housing, the corresponding technical potential for energy saving is 596 PJ/year, or 30% of the total housing stock energy use in 1996.

**Table 1 Technical Potential for Energy Saving in the Service Sector**

| Measure/sector | Carbon savings Technical potential (mtC/year) | Energy savings Technical potential (PJ/year) |
|---|---|---|
| 25 Costed Energy Saving Measures | 6.12 | 273 |
| Other Office Equipment Measures (Including reduction in Air Conditioning) | 0.22 | 14.7 |
| CHP in Service Sector Buildings | 0.87 | 21.4 |
| Energy Management / Good Housekeeping | 1 | 41.9 |
| **Total savings** | **8.21** | **351** |
| 1996 Service Sector Energy Use | 23.0 | 883 |
| **Total Savings as a Percentage of Service Sector Energy Consumption in 1996** | **36%** | **40%** |

*Economic Potential*
Table 2 presents estimates for the economic potential, defined using an 8% discount rate. The implementation of all cost-effective measures would yield energy savings of 215 PJ/year, or 24% of 1996 service sector energy consumption in the UK. For comparison, the housing stock economic potential at the same discount rate, and assuming high costs for the measures, is estimated to be 241 PJ/year, or 12% of 1996 housing stock energy consumption.

**Table 2 Economic Potential for Energy Saving in the Service Sector**

| Measure/sector | Carbon savings Economic potential (mtC/year) | Energy savings Economic potential (PJ/year) |
|---|---|---|
| 25 Costed Energy Saving Measures | 3.35 | 157.4 |
| Other Office Equipment Measures (Including Reduction in Air Conditioning) | 0.12 | 3.0 |
| CHP in Service Sector Buildings | 0.87 | 21.4 |
| Energy Management / Good Housekeeping | 0.8 | 33.5 |
| **Total savings** | **5.14** | **215.3** |
| 1996 Service Sector Energy Use | 23.0 | 883 |
| **Total Savings as a Percentage of Service Sector Energy Consumption in 1996** | **22%** | **24%** |

*Potential Carbon Emission Savings in 2010*

The third column of Table 3 (taken from 10) shows that service sector carbon emissions are predicted to remain at similar levels to 1990 whilst energy consumption will steadily rise, as stated in the DTI's Business As Usual (BAU) projections in EP65 (8). There is also predicted to be a noticeable reduction of the ratio of the carbon emissions to the energy consumption between 1990 and 2000, with this ratio levelling off after 2000. The reason for this is the decreasing carbon emission factor for electricity generation on account of the increased use of gas fired power stations. After 2000, it is predicted that the carbon emission factor will remain relatively constant before increasing slightly between 2010 and 2020 as nuclear power stations are decommissioned.

**Table 3 Potential Carbon Emission Savings for the Service Sector in 2010**

| Scenario | Total Carbon Emissions in 1990[1] | 1996 Emissions if No Energy Saving Measures had been Implemented[2] [% Change from 1990] | EP65 BAU[3] Projections [% Change from 1990] | Take Up of All Economic Potential [% Change from 1990] | Take Up of All Technical Potential [% Change from 1990] |
|---|---|---|---|---|---|
| Service Sector Carbon Emissions (mtC/year) | 23.7 | 24.1 [+2%] | 23.8 [+0.4%] | 19.0 [-20%] | 15.9 [-33%] |

The technical potential for energy saving in the service sector can be increased further by technological advances. It is estimated that the technical potential for new technologies in the service sector could be 18 PJ/year (2% of present energy consumption) by 2010.

[1] N-DEEM figure.
[2] BRE estimate.
[3] EP65's Central Growth, High Fuel Price scenario is used.

## Conclusions

The results presented here indicate that in order to reach the present Government's stated target of 20% carbon reduction compared to 1990, all the economic potential for service sector carbon savings will have to be realised. For the housing sector, detailed scenario calculations (8) suggest that a 20% reduction is also just achievable if all of the economic potential savings can be realised.

This analysis assumes that the UK's 20% requirement would be applicable for all building sectors. However, the Government may decide that this is not required. Both BREHOMES and N-DEEM are important policy development tools and this paper has indicated how the models can be used to indicate the potential for savings and thus aid target setting.

## References

1. 1997 Digest of UK Energy Statistics. Department of Trade and Industry (DTI), The Stationery Office, London, UK.
2. Energy Use in the Housing Stock, IP 20/94. J E Dunster, I Michel and L D Shorrock, BRE, 1994.
3. Domestic Energy Fact File. L D Shorrock and G A Walters, BRE 1998.
4. Non-Domestic Building Energy Fact File. C H Pout, S A Moss, P J Davidson and Associates, BRE, 1998.
5. Potential Carbon Emission Savings from Energy Efficiency in Housing, IP 15/95. L D Shorrock, BRE, 1995.
6. Potential Carbon Emission Savings from Energy Efficiency in Commercial Buildings, IP3/96. S A Moss, BRE, 1996.
7. Potential Carbon Emission Savings from Combined Heat and Power in Buildings, IP4/96. S A Moss, and L D Shorrock, BRE, 1996.
8. The Physically-Based Model BREHOMES and its Use in Deriving Scenarios for the Energy Use and Carbon Dioxide Emissions of the UK Housing Stock. L D Shorrock and J E Dunster, Energy Policy, Vol. 25, No. 12, 1997.
9. Energy Paper 65: Energy Projections for the UK. Department of Trade and Industry (DTI), The Stationery Office, 1995, ISBN 0 11 515365 9.
10. Study on Energy and the Environment: Background Paper 3: Prospects for Energy Saving and reducing Demand for Energy in the UK, produced for the Royal Commission on Environmental Pollution. J Fisher, S P Boyle, J S Willder and Associates, March 1998.
11. A guide to the development of BREDEM, IP4/95. L D Shorrock and B A Anderson, BRE, 1995.

## Acknowledgements

The authors would like to acknowledge the DETR, particularly Global Atmosphere and Research, Analysis and Evaluation Divisions, for their continuing support of the development of both energy models.