CARBON DIOXIDE EMISSIONS AND ENERGY EFFICIENCY IN EXISTING UK BUILDINGS

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Energy used in buildings accounts for almost half of all energy demand in the United Kingdom and a similar proportion of energy-related carbon dioxide emissions to the atmosphere. Substantial improvements to energy efficiency in buildings can be made using well-proven techniques that are cost-effective in many cases. This means that reductions in emissions can be achieved by taking actions which are already justified for economic reasons.

Varying proportions of different fuels serve different end-uses of energy in buildings. Also, varying amounts of carbon dioxide are associated with each unit of energy obtained from the different fuels. Quantities of particular fuels consumed need to be attributed to particular end-uses in order to estimate the effects of energy efficiency improvements on emissions.

This paper explores the relationship between the various end-uses of energy in buildings and the emission of CO_2. It also considers the scope for reducing CO_2 emissions through the application of energy efficiency measures in existing buildings.

INTRODUCTION

Global industrial development is now widely recognised to be on a scale large enough to cause changes to the composition of the atmosphere and, consequently, changes to climate. The principal man-made agents of global climate change are increased concentrations of greenhouse gases that raise average temperatures in the lower atmosphere by absorbing infrared radiation. A very important contribution arises from the carbon dioxide (CO_2) which is released to the atmosphere whenever fossil fuels are burned. Other significant greenhouse gases include methane, nitrous oxide, ozone and the chlorofluorocarbons (CFCs).

Buildings require energy for space and water heating, lighting, refrigeration, ventilation and other services. Together with energy used for domestic appliances and office equipment, this accounts for about half of total UK demand for energy and a similar proportion of all energy-related CO_2 emissions. It follows that improvements to the efficiency with which energy is used in buildings could offer considerable opportunities for reducing those emissions. It is already widely recognised that there are many opportunities for making cost-effective improvements to energy efficiency in UK buildings, implying that a range of improvements could be undertaken at no net cost which would reduce both energy requirements and greenhouse gas emissions. The aim of the work described in this paper was to estimate the extent to which those emissions could be reduced through applying energy efficiency measures that are both cost-effective and technically well-proven.

ENERGY USE IN BUILDINGS

Information on the total quantities of energy consumed by various sectors of the economy is available from the Digest of UK Energy Statistics (Department of Energy 1989). The Digest does not have a single category for buildings, including them instead in various sectors based on economic criteria. Energy use in domestic buildings can be estimated readily, however, since it is reasonable to attribute all of domestic energy consumption to buildings. Much greater uncertainty exists for non-domestic buildings where, for present purposes, use has been made of a study by Hardcastle (1984). Figure 1 shows the energy consumed by various sectors of the UK economy in 1987 in units of delivered energy, i.e., the calorific value of energy delivered to consumers. This illustrates the importance of buildings to energy consumption, accounting for over two-thirds of all electricity consumed and a similar fraction of natural gas.

A good understanding of energy use in buildings requires a knowledge of the amounts of energy consumed for various end-uses and the fuels from which they are derived. This is needed to allow the potential effects of energy efficiency improvements to be evaluated, since such improvements generally apply to specific end-uses and, hence, to particular fuels.

Domestic buildings alone account for 28% of all energy consumed in the UK and are a particularly important market for natural gas, accounting for 55% of all consumption of that fuel. Domestic electricity consumption is also important, accounting for 36% of all electricity supplied to all consumers. By contrast, the domestic market for oil is small and accounts for only 4% of oil supplied in units of delivered energy. A detailed study of energy use in the domestic sector has been undertaken by BRE (Henderson and Shorrock 1989). Figure 2 shows a breakdown of domestic energy use by fuel and end use in units of delivered energy. This illustrates the dominance of natural gas as a heating fuel and the high proportion of total energy used for heating.

Much less detailed information is available on energy consumed in non-domestic buildings, which include many building types and variations of activity within buildings. A study of energy use in commercial and public buildings sponsored by the UK Department of Energy assembled information from many sources (Herring et al. 1988) and provides a valuable compilation of existing data. However it also pointed out many limitations in existing data.

In general, space and water heating account for a lower proportion of consumption in non-domestic buildings than in dwellings and lighting accounts for a higher proportion of consumption. Also, air

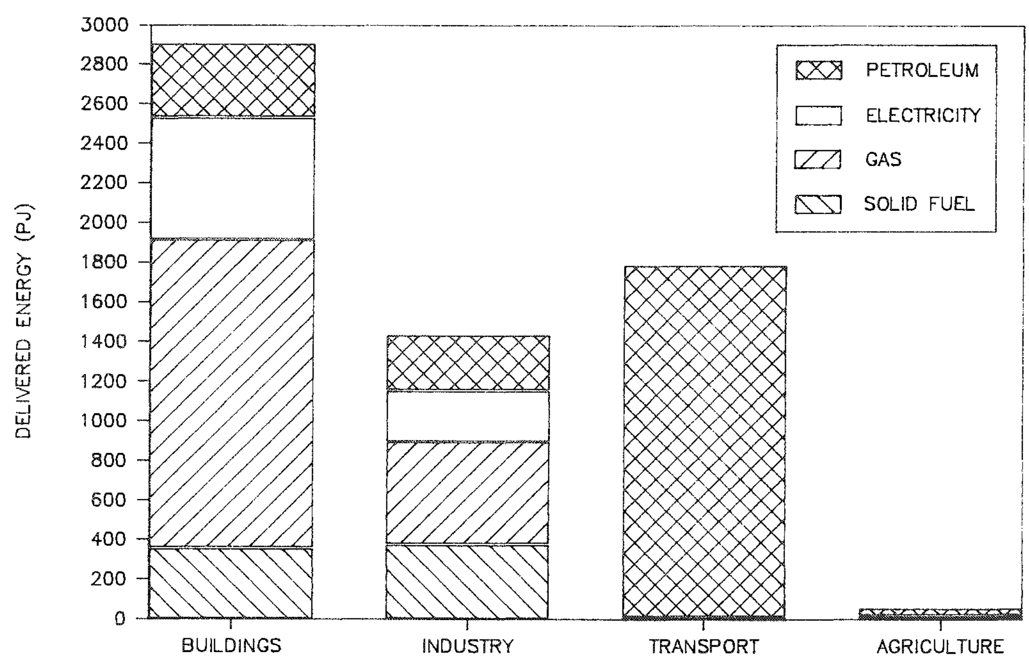

Figure 1. UK Delivered Energy Use by Sector and Fuel Type

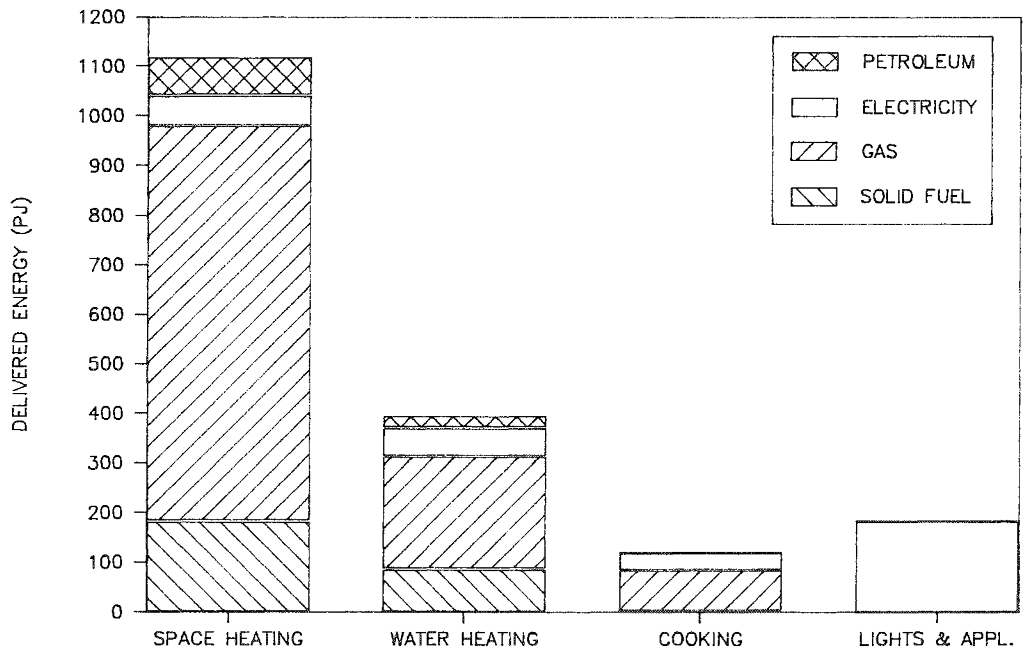

Figure 2. End-Uses of Energy in the UK Dwellings

conditioning is a significant end-use in some types of non-domestic building, while it is hardly ever installed in UK dwellings.

CARBON DIOXIDE EMISSIONS FROM FUEL CONSUMPTION

The different fossil fuels contain varying proportions of carbon and have different calorific values. Accordingly, they emit varying amounts of CO_2 for each unit of heat they produce when burned, typical figures for the main fuels used in the UK being shown in Table 1(a). Electricity presents a much more complicated picture, since its CO_2 emissions depend entirely on how it is generated. For example, hydroelectric generation does not involve the burning of fossil fuels and emits no CO_2, while electricity generated from coal or oil emits relatively high levels. For the latter case, the efficiency of the generation process is also important, since the CO_2 emissions are related to the fuel consumed rather than the electricity produced. In the UK, most electricity is generated from coal in large power stations with no means of utilising the waste heat from the generation process. Despite the relatively high efficiency of many of the power stations, the overall thermal efficiency of the process is low and about three units of energy are released by the combustion of the coal for each one that is available in the form of electricity. It is possible to calculate the CO_2 emission associated with each unit of electricity used by consumers by taking account of efficiency and the mix of fuels used in generation. Thus, although electricity produces no CO_2 at the point of consumption, an average unit of electricity consumed in the UK produces large amounts at the point of generation. Table 1(b) shows the amounts of CO_2 associated with each unit of fuel delivered to the consumer, including the overheads associated with generation and distribution. They have been calculated using the values in Table 1(a) and data from the Digest of UK Energy Statistics (op. cit.). In the case of electricity, this reflects the present mix of generating fuels which included 67% coal, 17% nuclear and 8% oil in 1988.

The figures given in Table 1(b) have been used to convert energy consumption into CO_2 emissions throughout this report. It is important to note that they only apply to the UK energy economy at the

Table 1. Carbon Dioxide Emissions from Various Fuels Used in the UK

Fuel	Carbon dioxide emissions (kG of CO_2/gigajoule) (a) based on primary energy available	(b) based on energy delivered to consumers
Coal	91	92
Natural gas	50	55
Petroleum	69	84
Electricity	-	231

present time and would not hold for other circumstances. In particular, the value for electricity applies only to that supplied by the UK national grid.

CARBON DIOXIDE EMISSIONS RESULTING FROM BUILDING ENERGY USE

When energy use is converted into CO_2 using the factors in Table 1(b), the relative importance of the various fuels and end-uses changes considerably (see Figures 3 and 4). A comparison between Figure 3 and Figure 1 shows that electricity accounts for a larger proportion of the total CO_2 emissions than of delivered energy. Similarly, Figures 4 and 2 show that lighting and appliance consumption in dwellings becomes more significant. Conversely, the relative importance of space heating is diminished although it is still the largest single contributor to CO_2 emissions. The reason for the changes in the relative importance of the different end-uses is clear: those that rely heavily on electricity become more significant, while those that rely mainly on natural gas become less so. This has important consequences when the effects of energy efficiency measures on CO_2 emissions are considered.

In total, CO_2 emissions related to energy use in buildings are calculated to be 48% of all UK energy-related emissions. This is very similar to the proportion of total delivered energy consumed by buildings.

IMPROVEMENTS TO ENERGY EFFICIENCY IN EXISTING BUILDINGS

The slow replacement rate of the building stock makes it necessary to improve existing buildings if a rapid overall improvement is to be achieved. For example, the rate at which new houses have been built in the UK over recent years is about 1% of the existing stock. The UK has many old buildings that are in good structural condition but are poorly insulated. This is partly because they were built before thermal insulation was required by the Building Regulations or the local building by-laws which preceded the Regulations. The first national Regulations were introduced in 1965 and higher standards were established in 1976, 1982 and 1990. Thus many buildings erected as recently as a decade ago have thermal insulation at well below present standards, as do a large number of older buildings.

Although it is generally most economical to install insulation at the time of construction, there are a number of cost-effective ways in which insulation can be improved in existing buildings. For example, most UK houses have pitched roofs with accessible loft spaces which can be insulated very simply and cost-effectively. Other cost-effective measures include weather-stripping of windows and doors and insulation of hot water storage tanks and external cavity walls. Further measures are cost-effective under certain circumstances, such as double glazing when windows need to be replaced.

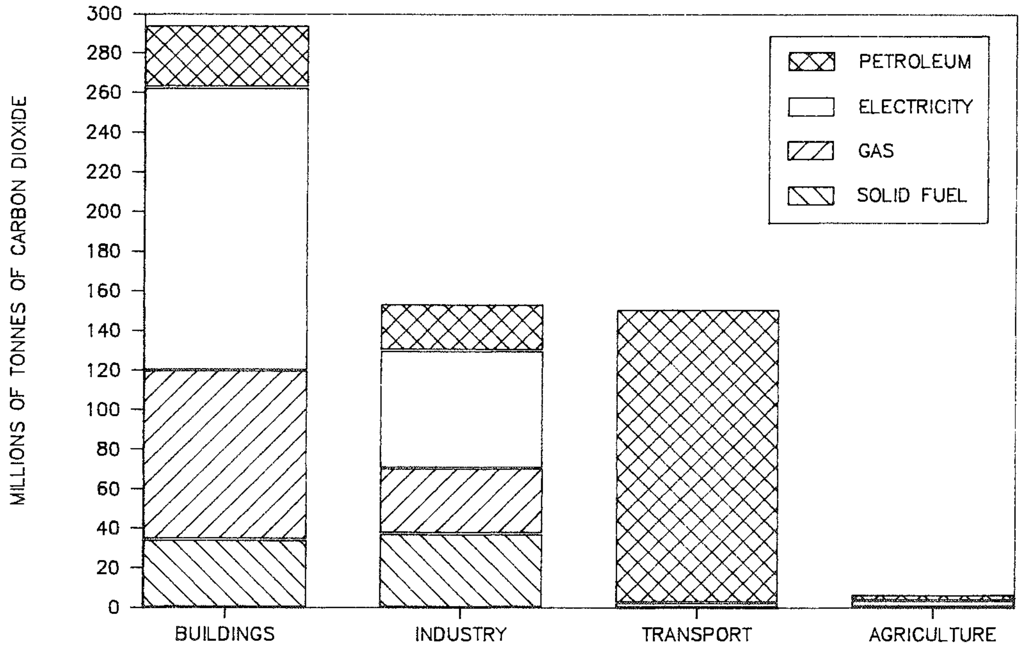

Figure 3. UK Carbon Dioxide Emissions by Sector and Fuel Type

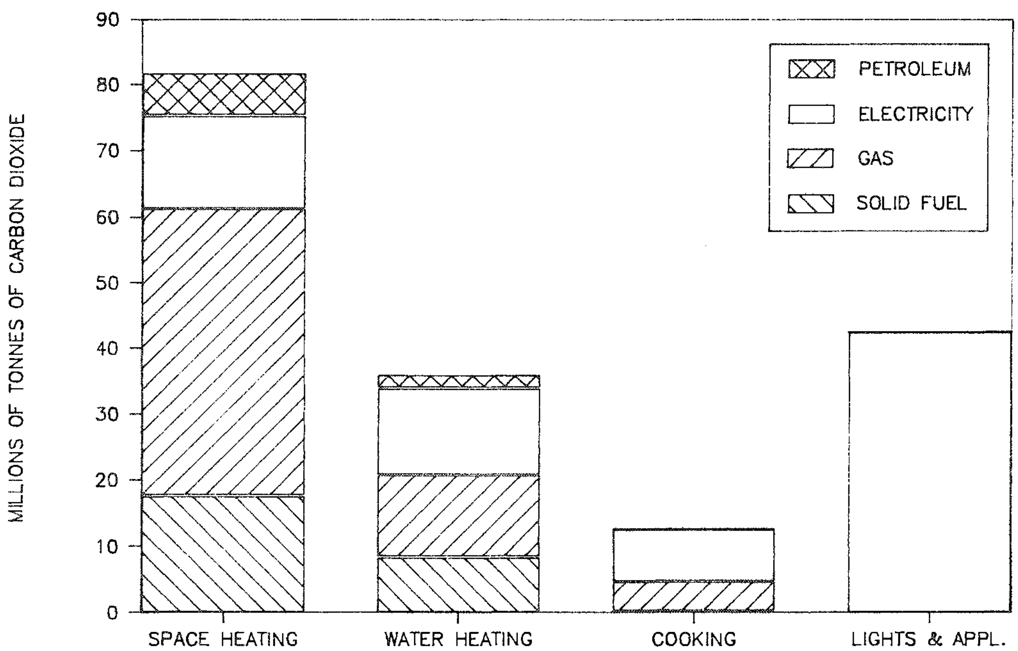

Figure 4. Carbon Dioxide Attributable to UK Dwellings, by End-Use and by Delivered Fuel

Apart from improvements to insulation, energy efficiency can also be improved by installing more efficient heating systems and better controls. A particularly important opportunity exists for improving the efficiency of domestic boilers when they need to be replaced. About half of all households have gas central heating using a boiler to heat water circulated to radiators. Many of those boilers were installed 10 to 20 years ago and are being replaced with new models. The replacements are generally more efficient than the old boilers, but it has been shown that a much greater increase in efficiency can be made when the new boiler is of the condensing type. Field trials in occupied houses have shown that condensing boilers can achieve a yearly average efficiency of about 85% compared with about 70% for a modern conventional boiler operating under the same conditions (Trim 1988).

There are also many opportunities for improving energy efficiency in non-domestic buildings. For example, a recent study of energy efficient office buildings (Brownhill 1990) highlighted the importance of lighting and the energy loads imposed by large computer installations and their associated cooling requirements. It also showed that air-conditioning significantly increased demand for energy, largely through the power consumed by the associated pumps and mechanical ventilation fans.

REDUCTIONS IN CO_2 EMISSIONS THROUGH ENERGY EFFICIENCY IMPROVEMENTS

Particular energy efficiency measures affect specific uses of energy and, hence, reduce consumption of the particular fuels which serve those uses. When considering CO_2 emissions, it is important to attribute any reductions in energy use to particular fuels because of the large differences in emissions per unit of energy shown in Table 1. This is particularly important in the case of electricity and those end-uses, such as lighting and appliances, that rely mostly on electricity.

BRE has analysed the reductions in CO_2 that could be obtained from energy efficiency improvements to the housing stock in some detail (Shorrock and Henderson 1990). Two cases were considered. The first case was confined to those measures that are considered to be cost-effective, while the second also included measures that are technically quite feasible but not generally found to be cost-effective at present prices and fuel costs.

The cost-effective category was based on results from a variety of existing sources rather than new analysis specifically carried out for this study. Accordingly, no single criterion for investment appraisal has been used to define the cost-effective category. The "Cutting home energy cost" booklets published by the UK Department of Energy give examples of costs and savings for various house types (Department of Energy 1966). Most improvements have a simple payback of less than 7 years in terms of reduced energy expenditure by the household. Double glazing is an exception in that reduced energy expenditure is only one of the benefits perceived by the household. Reduced condensation on windows and value added to the home are also important benefits.

The "technically possible" category has been defined very conservatively, being based on improvements which can be carried out now using well-tried methods and readily-available materials. In the case of lighting and domestic appliances this has been taken to mean equipment that can be bought in the UK at present. Both categories of improvements are partly based on judgements made by the authors and are intended to be indicative rather than definitive. The improvements included in each category are shown in Table 2.

The scope for applying the various improvements and the associated reductions in energy use were calculated using BREHOMES, a model of energy use in the UK residential sector (Henderson and Shorrock 1988). Reductions in CO_2 emissions were then calculated using the emission factors shown in Table 1(b). Ideally, the emission factor for electricity should have varied with the merit order in which power stations are used on the national grid. In the absence of detailed information on the merit order, the overall factor given in Table 1(b) was used. This is likely to cause a slight underestimate, since the avoided load is mostly served by coal-fired stations across a wide range of loads.

The calculated reductions amount to about 25% of present emissions for the cost-effective case and about 35% for the "technically possible" case. Figure 5 shows the estimated reductions in CO_2 which could be derived from the cost-effective case. About two thirds of the reductions are due to insulation measures and the remainder due to improvements in the efficiency of heating systems and appliances. We estimate the total capital cost of

Table 2. Energy Saving Improvements that are Cost-Effective or Technically Possible

Cost-effective	Technically possible
80% of all cavity walls insulated	All walls insulated
Lofts with <=25 mm insulated to 150 mm	All lofts insulated to 150 mm
Full double glazing in all homes (as windows are replaced)	Full double glazing in all homes
Weather-stripping in homes with <80% of rooms already treated	Weather-stripping in all homes
Hot water tanks with <50 mm insulated to 80 mm	All hot water tanks insulated to 80 mm
Condensing boilers in all homes with gas central heating (as boilers are replaced)	Condensing boilers in all homes with gas central heating
13% efficiency improvements to gas and electric cookers	25% efficiency improvements to gas and electric cookers
38% efficiency improvements to lighting	75% efficiency improvements to lighting
25% efficiency improvements to refrigeration equipment	50% efficiency improvements to refrigeration equipment
20% efficiency improvements to washing machines	20% efficiency improvements to washing machines and tumble driers
25% efficiency improvements to televisions	25% efficiency improvements to televisions

applying the cost-effective case to be 25 to 30 billion $US, equivalent to about one and a half times current annual fuel expenditure by households.

No detailed calculations have yet been undertaken for non-domestic buildings. However, Herring et al. 1988 identified cost-effective potential reductions of 40-55% of delivered energy in commercial and public sector buildings. Taking account of the mix of fuels used, it is reasonable to assume that substantial reductions in CO_2 emissions could be achieved in their case also. In general, there is more scope for making reductions through better energy management and better maintenance of plant than in dwellings, with much greater emphasis on the efficiency and control of lighting.

CURRENT TRENDS IN CO_2 EMISSIONS

It is important to note that the foregoing analysis is not a forecast of what is likely to happen over the next 20 years but rather an estimate of the likely effect of applying those measures to present patterns of use. Estimates of actual emissions at some point in the future require that trends in patterns of demand should also be considered, taking account of saturation effects where appropriate. A detailed

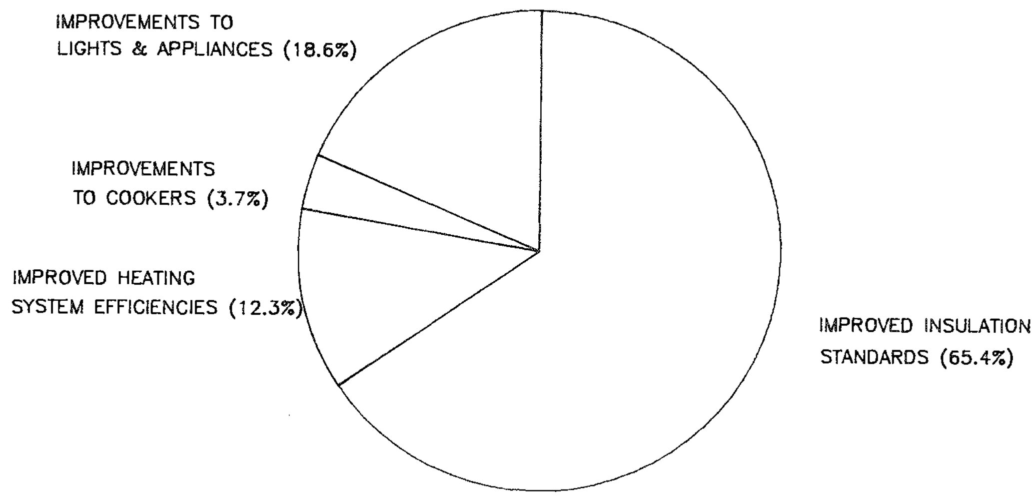

Figure 5. Potential Reductions in Carbon Dioxide Emissions through the Application of Cost-Effective Energy Efficiency Measures in UK Dwellings

analysis of this sort has not yet been undertaken by the authors but preliminary work indicates that, given a continuation of present trends, emissions from the residential sector are likely to remain close to present levels over the next decade. A similar conclusion was reached by Leach and Nowak 1989. Emissions have actually fallen by about 5% since 1970 despite a growth of 15% in the number of households and greatly increased penetration of central heating during the intervening period. The reduction has been due to the retrofitting of insulation measures to existing stock and to natural gas displacing coal as the main fuel for space and water heating (Henderson and Shorrock 1989). Central heating must begin to reach saturation within the present decade and growth in the number of households is forecast to be slower than in the two preceding decades, both factors tending to produce a slowing in the growth in underlying demand. On the other hand, fuel switching to natural gas for heating must also reach saturation, as must the insulation of previously uninsulated roof spaces. It must also be recognised that average indoor temperatures are still well below North American and Scandinavian levels and could rise considerably.

Lights and appliances are of particular interest because this category of energy use has shown the fastest growth of all domestic end-uses over the past two decades. Table 3 shows the estimated consumption by type of appliance and level of ownership in the UK. Refrigeration equipment accounts for 35% of the total, lighting 16% and home laundry equipment 12%. In many cases there is a reasonable prospect that increased efficiency could compensate for increased ownership level. In others, considerable increases in ownership levels are likely following patterns already established in other some European countries and North America, resulting in increased energy consumption. For example, dishwashers are heavy energy users and are at present owned by less than 10% of households in the UK. One of the largest potential reductions would result from the replacement of incandescent light bulbs by low energy units that are available but have a low market penetration at present.

An analysis of possible reductions in CO_2 emissions from electricity generation is beyond the scope of this paper, but it is important to note that all estimates of potential reductions of CO_2 above assume a continuation of present electricity generation patterns. Clearly, any reductions deriving from a reduced demand for electricity would be lower if the CO_2 emission factor for electricity were itself to be reduced. This would need to be taken into account when considering future levels of emissions in order to avoid double counting of possible reductions brought about by energy efficiency improvements.

Table 3. Energy Use in UK Dwellings for Lights and Appliances (1987)

Appliance(s)	Typical Consumption (KWh/year)	Ownership Level (%)	Aggregate Consumption (Petajoules)
Washing machines	200	86	14.2
Tumbles driers	300	31	7.6
Dishwashers	500	7	2.9
Refrigerators	300	57	14.4
Fridge/freezers	740	43	26.1
Freezers	740	39	23.4
Kettles	250	86	17.9
Irons	75	98	6.1
Vacuum cleaners	25	98	2.0
Televisions	235	98	19.2
Lighting	360	100	30.1
Miscellaneous	240	100	20.0
TOTAL			184 PJ

Source : data supplied by the UK electricity supply industry

OTHER GREENHOUSE GASES

Greenhouse gases other than CO_2 are also associated with buildings. CFCs are widely used as working fluids in refrigeration equipment that is vital to the proper functioning of some types of building, both for storage and for air-conditioning. They are also used as foaming agents in some types of insulation used in buildings. Present day buildings, therefore, are important sources of CFCs released to the atmosphere. CFCs are already the subject of international agreements which will greatly reduce their future use, so their significance as greenhouse forcing agents should also decline. However, one effect of such restrictions will be to require substitutes for the CFCs used at present. Some of the proposed substitutes could cause a small increase in the amount of energy required for refrigeration and a consequent increase in CO_2 emissions. Some are also significant greenhouse gases. Building related emissions in the UK are estimated to have accounted for about 8% of UK total UK CFC emissions in 1986 (Butler 1989). This proportion will already have increased considerably as CFCs were still widely used in aerosols sold in the UK in 1986 and have since been phased out.

Methane is another greenhouse gas which is associated with building energy use, being the main constituent of natural gas. Any leakage of methane from the gas distribution network could be seen as an "overhead" to be added to the CO_2 that results from its combustion. This could be a very significant effect if such leakage was more than a few per cent because methane is much more effective as a greenhouse gas than CO_2.

Nitrous oxide is produced in low concentrations during the burning of fossil fuels. No reliable data are yet available on the quantities involved but they are thought to be small, both in relation to other building emissions and to other emissions of nitrous oxide.

CONCLUSIONS

- Energy use in buildings is responsible for about half of total UK emissions of CO_2 at present.
- In the residential sector, those emissions could be reduced by a quarter of present levels through applying energy efficiency measures that are already considered to be cost-effective, if present levels of demand were maintained.

- Actual future emissions will depend both on the rate at which energy efficiency is improved and the rate of growth in demand. Trends over the last decade have shown CO_2 emissions from residential energy use staying at about the same level.

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