Transforming UK non-residential buildings: achieving a 60 % cut in CO_2 emissions by 2050

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Keywords

non-domestic, building, energy, modelling, scenario

Abstract

This paper describes the development of a model to explore the energy and carbon intensity of the UK stock of non-domestic buildings from 2004 to 2050 under a range of scenarios. The model takes as its input a model of the UK non-domestic building stock as expressed in 55 different building types classed by activity and the energy intensity of the building classes as expressed by 8 types of energy end use. The paper discusses the data sources, the modelling framework and indicates how a 60 % reduction can be achieved by 2050. The work has been performed for the Building Market Transformation (BMT) program under the Carbon Vision Buildings (CVB) theme sponsored by the Engineering and Physical Sciences Research Council EPSCR) and the Carbon Trust.

Introduction

The aim of this work is to develop a model of the non-domestic sector, comparable to that for the domestic sector developed elsewhere [Boardman 2005, Hinnells 2007] and able to draw out similar key conclusions. The model describes energy usage and carbon intensity of the UK non-domestic building stock from 2004 to 2050 under a range of scenarios and is known as the UK non-domestic carbon model (UKNDCM).

The non-domestic model

The model uses floor area of each building type multiplied by indicative energy use per m^2 for the current stock (broken down by end use). The starting point for this is provided by the 2004 non-domestic stock model (NDSM) which contains for each of 55 non-domestic building categories…

- Floor area for two example years (1994 and 2004), based on Valuation Office Agency (VOA) data for commercial premises. This is for England and Wales only, since there is no central VOA data for Scotland and Northern Ireland. Estimates have been made from other data sources for premises which are not rateable (eg public sector buildings) [Murray, 2000]
- Interim energy use per m2 (for 8 end uses) which is a re-analysis of the Sheffield Hallam dataset [Elsayed, 2002] from 1990-2002.

This simple estimate of energy used in 1994 and in 2004 can be compared to the Digest of UK Energy Statistics [DUKES, 2004] energy supplied (*Table 1*). Initially this is for England and Wales. Scotland can be estimated by scaling up on a pro-rata basis for population, i.e. by 15 %. On this basis public administration is underestimated by 23 % compared to DUKES, and commercial is only 6 % underestimated. Miscellaneous is 50 % underestimated but on a small total, and Industry is underestimated because process energy is not included in this analysis.

The NDSM data on energy use per m_2 represents an average from 1990 to 2002 [Elsayed 2002] and thus an exact match with 2004 energy supplied is impossible, because it does not include natural variations (climate and energy price conditions) and underlying trends (ownership of equipment). In practice, un-

Table 1. Energy supplied to Non-domestic buildings 2004 – comparison of DUKES 2004 with NDSM

	DUKES (elec+gas)	DUKES (all energy)	NDSM	NDSM +15% (scaled to UK)	difference (elec and gas)	difference (all energy
Public administration	66.7	84.4	56.4	64.9	-3 %	-23y%
Commercial	115.3	120.2	97.7	112.4	-3 %	-6y%
Miscellaneous	20.8	26.2	11.4	13.1	-37 %	-50y%
Industry	262.4	396.4	291.9	300.8	15 %	-24y%
Total	**465.2**	**627.2**	**457.4**	**491.2**	**6 %**	**-22 %**

derlying the energy data is a trend to more equipment, more efficient equipment, and higher overall electrical consumption, which to an extent displaces gas used in space heating.

This work is thus simply a starting point for a model which explores historical trends 1994 – 2004 and projects energy use each year to 2050 under a variety of scenarios.

The work to improve data and build it into a model is structured as follows. Four areas of data are needed:

1. Current consumption. Data availability for the current stock is poor:

Floor area data is incomplete. As noted the NDSM supplies a picture in 2004 of the non-domestic building stock. Work is being undertaken to improve understanding of floor area and also of the built form, which is a significant contributor to energy demand for space heating and for lighting. Central data on Scotland may become available over the next few years, but in any case, scaling up by population is likely to be inaccurate because of the limited penetration of the gas network in Scotland. A more sophisticated estimate is needed.

Understanding of energy intensity (kWh/m^2/year) is poor. This data was based on a limited survey of around 3000 non-domestic premises [Elsayed, 2002]. But given the variety in types of activity, and types of premise, this is a small sample, and known to be skewed to smaller premises. In addition, it is not a time series, so known or expected trends (eg in internal temperatures, lighting levels, or installation of computer equipment) cannot be quantified. The uncertainty surrounding what we know has to be recognised. The original work included analysis of standard deviation, skewness and confidence intervals. But in interpreting the data, many studies have lost the important caveats. Additional surveys are being collected in a central database.

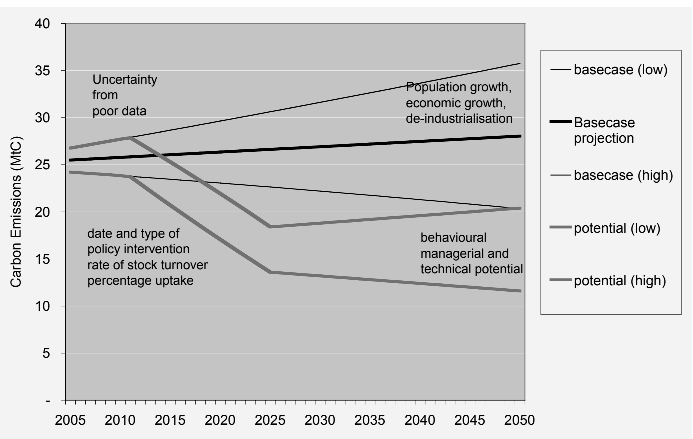

Figure 1. The structure of the non-domestic model

There are no stock condition surveys as there are for the domestic stock. The stock is hugely diverse, its condition largely unknown (eg the number of wall cavities, and the number of filled wall cavities), and occupancy levels in different builds not well understood. There is no non-domestic equivalent of the House Condition Surveys.

2. Projections of consumption under 'basecase' conditions. There are no existing projections for floor area needs, and so a coherent 'storyline' is being developed for each sector of drivers (Table 2). There are public plans for expenditure in say health and education, but building new commercial space (especially retail and offices) is highly speculative and based on local opportunity. Investors (landlords) anticipate likely demand from tenants (retailers and commercial business). There is no aggregation into UK-wide or longer term projection. A larger, older and wealthier population seems key overall, but there are different drivers in different sectors. We are also exploring drivers for consumption per m^2.

3. Estimates of saving potential. Estimates have been made of savings potential, for example, what happens if the average moves to CIBSE [CIBSE, 2004] best practice levels of energy performance, or to the twenty-fifth percentile of the energy intensity of the sites in the same sector. Beyond simple statistical scenarios we are exploring technical opportunities, for example, the savings in new build, the savings from retro-fitting CHP, savings from turnover in equipment and replacement with efficient equivalents (eg refrigeration and lighting) which may follow from the Energy Using Products Directive. The savings from measures interact, so reduced energy use in equipment may increase the need for space heating (or reduce the need for cooling), hence the aim to model buildings in Simplified Building Energy Model (SBEM) [BRE, 2007].

4. Analysis of the major points of intervention to reduce carbon emissions from buildings, i.e. build, demolition, change of use and major refurbishment. Understanding the rate of stock turnover will help to estimate the rate at which change could be achieved over time. Importantly, the rate of change is different in different sectors. Policy options will vary by sector. Commercial buildings are still subject to buying and selling (mostly by investors rather than occupiers), and mortgages and leases are opportunities for policy intervention, as are stamp duty and business rates. Policy options for public buildings are different, public buildings may be under more direct influence, but with little sale or leasing (other than office space). The impact of the energy rating (both asset rating and operational rating) will be monitored.

These four areas of analysis combine to give a model as shown below (*Figure 1*). The four areas of work are being pursued simultaneously, and the development of the model is iterative.

Table 2. Analysis of trends in non-domestic buildings

<table>
<tr><th>Issues</th><th>Sectors</th></tr>
<tr><td>Demographics
▪ population
▪ changes in social structure</td><td rowspan="4">Previous work (Pout, 2002) projects to 2020 by projecting forward historical trends, but doesn't identify causes and drivers underlying these trends. Present work is projecting forward to 2030 and even 2050, and thus must understand underlying drivers, since current trends may not continue that far into the future, or may be overtaken by other trends. In doing this, the present work is putting storylines together. Illustrative storylines are:

Retail
▪ Population has increased, In a wealthier society, the value of goods sold continues to be driven up. Floor area per capita has increased.
▪ Whilst the total floor area has increased, the number of premises has fallen, so the average premise is getting larger. Having said that, there is a trend towards both very large (superstores) and very small (boutiques).
▪ New retail is heavily planning constrained and it can take 2 decades to assemble parcels of land for a new shopping complex. When planners give consent for speculative development, they do not know what the development may house. Energy requirements at planning stage are very difficult to assess.
▪ large out of town shopping centres. Even more recent trends have seen shops move into virtual internet space, with shops becoming warehouses. This has implications for the age and type of build, the space heating requirement, the office equipment used. What has happened and might happen to town centres?

Hospitals:
▪ Short term trends are well known: Quantified trends 1994 -2004. NHS Business planning can show the trends for the next 5-10 years.
▪ Beyond this, society is expected to be larger, older, and richer (all of which can be quantified). This is expected to lead to an increase in demands for health services.
▪ However, health services are changing in nature, and are increasingly delivered as short stay or out-patient services rather than long stay care. Increasing electronic equipment is increasing electricity use per m2.
▪ Government is also putting a lot of money into rebuilding hospitals, often through PFI, as well as some contracting out to private hospitals (though there appear to be fewer private hospitals than previously) with the stock changing from old (even Victorian) and small, to new, large, and centralised. Much of this is out of town.
Prisons
▪ Quantified the trends 1994 -2004. Government planning can show the trends for the next 5-10 years.
▪ A lot of money is going into rebuilding prisons as well as some contracting out to private sector.
▪ Beyond this, education, community sentences, and tagging rather than incarceration may have more of a role in penal policy. There may be fewer prisoners in newer, less harsh environments focused more on rehabilitation. More prisoners may be at home.</td></tr>
<tr><td>Socio-Economic Trends
▪ trends and drivers in different sectors (private v public, industry v commerce)
▪ retail patterns
▪ work-leisure patterns/habits</td></tr>
<tr><td>Socio-Technological Trends
▪ thermal comfort
▪ hot water demand
▪ appliance use
▪ load profiles
▪ own generation
▪ smart metering</td></tr>
<tr><td>(Economic) Decision-Making Frameworks
▪ how decisions get made especially in organisations
▪ fuel pricing and tariffs
▪ access to capital
▪ cost of capital
▪ tenant landlord issues
▪ opportunity for innovative finance eg loans, mortgages or ESCOs</td></tr>
</table>

Embodied carbon issues in non-domestic buildings are being explored. Embodied carbon may be more of an issue in non-domestic than domestic, because the average embodied carbon is 20 % higher than for dwellings. There is a higher variation between build types dependent on construction (factor three rather than factor 2), and because of a higher rate of stock turnover, especially in commercial buildings, which means embodied carbon may be high in relation to carbon in use (*Figure 2*).

Preliminary Scenario Results

Using the assumption that the stock model represents energy use that could be considered 'typical' in the CIBSE benchmark guide, the reductions by converting to 'best practice' are 22 %, 29 % and 32 % for the non-domestic building categories which fall into the DUKES Public Administration, Miscellaneous and Commercial sectors respectively. This is far short of the 50 % by 2030 or 60 % by 2050 we are trying to achieve.

Analysis using the NDCM shows greater potential. *Table 3* shows some initial results of the scenario analysis. The difference between DUKES and the UKNDCM in 2004 is due to the

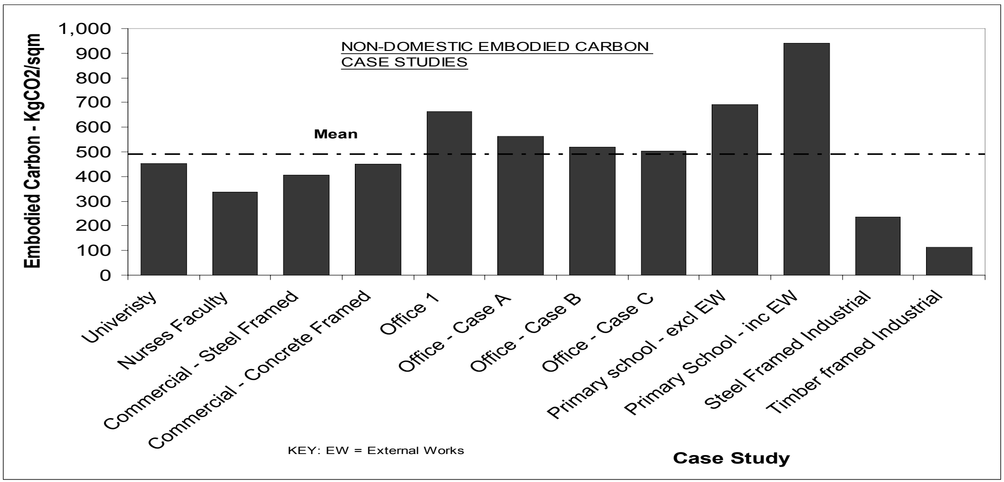

Figure 2. Embodied carbon in a sample of example new non-domestic premises

Table 3 – Initial results

	carbon emissions MT				
sector	UKNDCM 2004	DUKES 2004	scenario a 2050	scenario b 2050	% reduction (b)
Public Administration	4.26	5.66	9.16	2.34	45 %
Commercial	12	13.11	25.8	5.2	57 %
Miscellaneous	0.84	1.37	1.93	0.48	43 %

sampling problems previously discussed. The business as usual scenario (scenario a) takes the DTi prediction of a 2.25 % year on year growth in energy. The preliminary large scale reduction scenario (scenario b) assumes a change in space and water heating system technology (away from gas boilers and electrical resistance heaters and towards combined heat and power and heat pumps) and an increase in lighting, appliance and space cooling efficiency. This is calculated against the background of static demand for useful energy (energy service) whilst taking account of the change in gains due to appliance efficiency changes.

Most of the reduction (64 %) comes from the change to the heating system, with less (31 %) from lighting and the rest from other appliances and space cooling. The change to the heating system is not particularly ambitious and matched in carbon intensity that predicted for the domestic sector by 2050. This analysis used a grid intensity of 0.145 kgC/kWh which is also on the higher range of what can be expected as the grid decarbonises.

Further reductions can be expected from climate change (though offset to an extent due to demand for space cooling), grid decarbonisation and more ambitious heating system changes.

In summary, this analysis shows that large reductions in CO_2 emissions from the non-domestic sector in the UK are possible. Further work is needed to explore the possible trajectories such reductions might take.

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