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A Preliminary Model of Non-Domestic Energy Use for England and Wales

H. Bruhns[1], P. Steadman[1] and L. Marjanovic[2]

[1]*The UCL Bartlett School of Graduate Studies, University College London, Gower Street, London WC1E 6BT, United Kingdom.*
[2]*Institute of Energy and Sustainable Development, De Montfort University, Leicester, LE1 9BH, United Kingdom.*

A non-domestic stock energy model is one of the major deliverables of the project *Carbon Reduction in Buildings* (CaRB). This paper describes an interim but detailed activity based model of energy use in non-domestic premises in England and Wales for the year 2004. Floorspace data from the Valuation Office Agency and numerous other sources were combined to produce a floorspace model. Energy data summarised from a database of detailed energy surveys in some 740 non-domestic premises generated area based specific energy uses. These were combined with the floorspace model to produce a breakdown of total energy use for England and Wales subdivided into heating, lighting, cooling, computers, hot water and other uses. Much of the model development has focused on developing techniques for dealing with the heterogeneity of the non-domestic stock. Classification is central to this task and the paper describes the system used, the model structure, and plans to incorporate refinements such as the complex relationship between buildings and premises. Though preliminary, the current model does appear to give a broadly accurate overview of the stock and its energy use. It has been tested against corresponding data from the Digest of UK Energy Statistics (DUKES) and compares well for the public administration and commercial sectors.

Keywords: non-domestic, building, stock, energy, model.

INTRODUCTION

This paper describes a model of the use of energy in the non-domestic building stock of England and Wales. By 'non-domestic' we mean all buildings other than houses and flats. The model has been developed within the Carbon Reduction in Building (CaRB) project, funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Carbon Trust. Five British universities are collaborating on the project.
The model reported here is preliminary, and at the end of the paper we outline plans for its further development. In its present form, the model's structure is in principle very simple. The building stock is divided into a series of types distinguished by the nature of the activities housed: commercial offices, restaurants, hospitals, cinemas and so forth. A figure is obtained, from a variety of data sources, for total floorspace on all floors in each of these categories. A second figure is obtained for each type, from energy surveys and fuel bills, for the specific energy use (mean energy use per square metre per annum, kWh/m^2). The floorspace figures are then multiplied by the specific energy use figures to obtain estimates of total national energy use.

Much complexity arises however from the nature, variety and number of data sources involved. The complexity of this data reflects the very great heterogeneity of the stock itself. This is not just a matter of non-domestic buildings being devoted to such a very wide range of uses. Beyond this, buildings can vary greatly in size, from newspaper kiosks to car factories. The boundaries between categories are not always clear. How does a ‘guesthouse’ differ from a ‘hotel’? What are the precise differences between a ‘garage’, a ‘vehicle repair workshop’ and a ‘petrol station’? Many distinct kinds of activities may be combined within the same building; there can be cafes in museums, shops in airports, swimming pools in colleges, petrol stations in supermarkets, etc. The stock is owned and administered by a huge number of organizations - public and private. For all these reasons, many of the published sources of data on numbers and floorspace of non-domestic buildings are inconsistent in their definitions and coverage, and are difficult to reconcile. Therefore the major part of the work in building the present model has been in the development of a manageable system of classification of activities within buildings to utilise these data sources so that complete coverage can be obtained without double counting.

FLOORSPACE MODEL

The principal source of floorspace data for the model is the Valuation Office Agency (VOA) of the Inland Revenue (Bruhns, 2000). The VOA makes detailed surveys, for the purpose of assessing the rateable value, of all non-domestic premises in England and Wales liable for business rates (essentially all premises excepting churches and agricultural buildings). The VOA data contain activity classifications for all 1.7 million premises in England and Wales but has complete floorspace data only for the 1.4 million premises in the four *bulk classes* (shops, offices, warehouses and factories). Fortunately these comprise some 80% of the stock. The remaining 0.3 million premises are made up of educational and health buildings; facilities for entertainment, sports and the arts; social and community buildings; buildings associated with transport; law courts; prisons; and other diverse categories. It has been necessary here to assemble a coherent picture, painstakingly, from a mosaic of many sources including government departments, trade associations, market research companies, tourist boards, and the Census. Because it contains numbers of premises for all activity types, the VOA data can be used to reconcile information combed in from multiple sources to avoid both double counting and omitting portions of the stock.

PRIMARY CLASSIFICATION

Collation and analysis of data from multiple sources requires a single all-encompassing classification for the non-domestic stock. The classification must meet several somewhat contradictory criteria, namely:

- be applicable to all of the non-domestic stock and convey its heterogeneity.
- identify and separate activities that may be expected to be associated with substantial differences in energy use, and to some extent the physical nature of the buildings those activities tend to be carried out in.
- result in a manageable total number of categories.
- be able to be populated with data from existing data sources, while preserving as much as possible of the information content from that data.
- operate so that each type of premise found in the real world has a reasonably unambiguous place within the classification.

For this purpose a five-level hierarchical classification was developed (in work preceding the CaRB project (Bruhns *et al.*, 2000). Named the primary classification owing to its central role in non-domestic stock modelling, it adequately meets the criteria outlined above and further functions as an organising framework for the plethora of partial data sources called upon to construct the model. It incorporates four *primary divisions*, 13 *bulk types*, some 70 *primary types*, along with numerous *subtypes* and *primary components*. The categories used at all levels are collectively termed *primary classes* and in use one would normally select the most precise class appropriate to a given premises or data set.

The higher levels of the classification have been devised for summarising and presenting data to provide an overview of the stock using a small number of familiar groupings. As might be expected, these groupings are also the most common high-level groupings found in the numerous data sources that were combed to provide the information for the model. The lower levels of the classification are designed to provide a set of categories describing types of buildings that are reasonably uniform in their physical characteristics, and quantifiable from the available data. The CaRB model distinguishes activities by a mixture of primary types and sub-types. The floorspace model was developed in the following manner:

- Assign primary classes to all premises in the VOA data. Summarise these data to obtain total floorspace by primary class. Use rateable value to impute floorspace where it is missing (the VOA data contain at least a little floorspace for all activity groups that can be used for this purpose).
- Collate data from a large variety of other sources. These data may include reliable floorspace values, although more frequently they contain only numbers of premises for specified activities. On occasion the data include a variable that can be used as a proxy to estimate floorspace (eg. number of rooms). Mean areas from suitably representative surveys may be combined with numbers of premises data (Steadman, 2000).
- Collate the data into a single table containing numbers of premises and floorspace for each primary class required for the model. In some cases this required selecting what appeared to be the most robust of the resulting values from different sources, and rather broad brush estimates were unavoidable from time to time.

While there is considerable uncertainty in the floorspace values for some primary classes, they are believed to be accurate for most of those within the VOA bulk classes.

These floor space data all relate to 2004. Our estimate of total floorspace for England and Wales at this date is around 830 Mm^2. (A few categories are excluded, for which we have no floorspace data.)

ENERGY MODEL

The second step is to populate the floorspace model with energy data. For the preliminary model the energy data came entirely from the most comprehensive non-domestic energy study to date in the UK (Mortimer, 2000). Carried out by the Resources Research Unit of Sheffield Hallam University (SHU), it included 740 premises, the majority of them in four English cities of Swindon, Manchester, Bury St Edmunds and Tamworth. Most of the SHU sample was derived from a preceding street and map survey of some 6,500 premises carried out by the Open University 1990 – 1993. Both surveys were part of a decade-long research programme to develop a database of energy use on the non-domestic stock commissioned by the Global Atmosphere Division in 1992.

The SHU surveys comprised a detailed inventory of space, plant and appliances in each premise. Energy consumption was obtained from utilities billing data and reconciled with usage information to estimate energy end-uses (heating, cooling, lighting, computers, DHW, catering, other; with further subdivisions). All energy data refer to delivered energy use. Analysis of the SHU data provided mean specific energy uses (kWh/m2) by activity and end-use for each of the primary classes used in the model. Total energy use for a primary class is simply the product of total floorspace and the corresponding specific energy use for that class.

The CaRB stock energy model comprises a set of related tables containing various energy and floorspace data by primary class. It is implemented in an Access database with an associated Excel workbook containing summarised data for the stock. The workbook provides for immediate and simple use of the model and the Access database may be used to manipulate it in a little more depth. The model was developed in the following manner:

- Assign primary classes to each of the 740 premises in the SHU data.
- Define *Energy Inference Groups* where there were too few data points and aggregate energy use within these groups.
- Summarise data to get specific energy use and percentage end-uses for the energy inference groups. Reallocate inference groups to primary classes.
- Link energy data mean energy uses to primary table by primary class, and multiply.

RESULTS

A range of charts describing non-domestic stock energy use are easily derived from the model; for instance, the following breakdown of enduses.

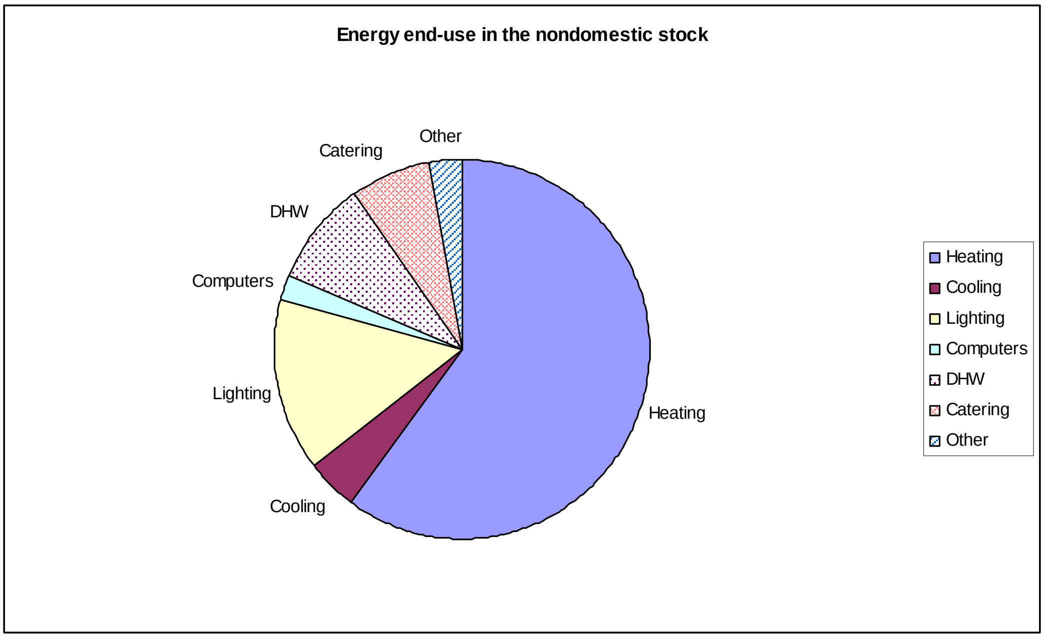

Fig. 1: Total energy use by end-use in the non-domestic stock of England and Wales.

It may be seen that heating and lighting dominate the non-domestic stock energy use, accounting for 75% of all energy use. The balance may be expected to change when looking at carbon emissions, so that lighting and cooling become more significant. Further work on the CaRB model, incorporating fuel type and carbon emissions factors is pending.

ENERGY USE BY BULK TYPE

The primary classes within the stock model can be grouped into 11 bulk types for the purposes of a simple energy summary. We thus obtain the following chart estimating energy use by bulk type and end-use for the stock.

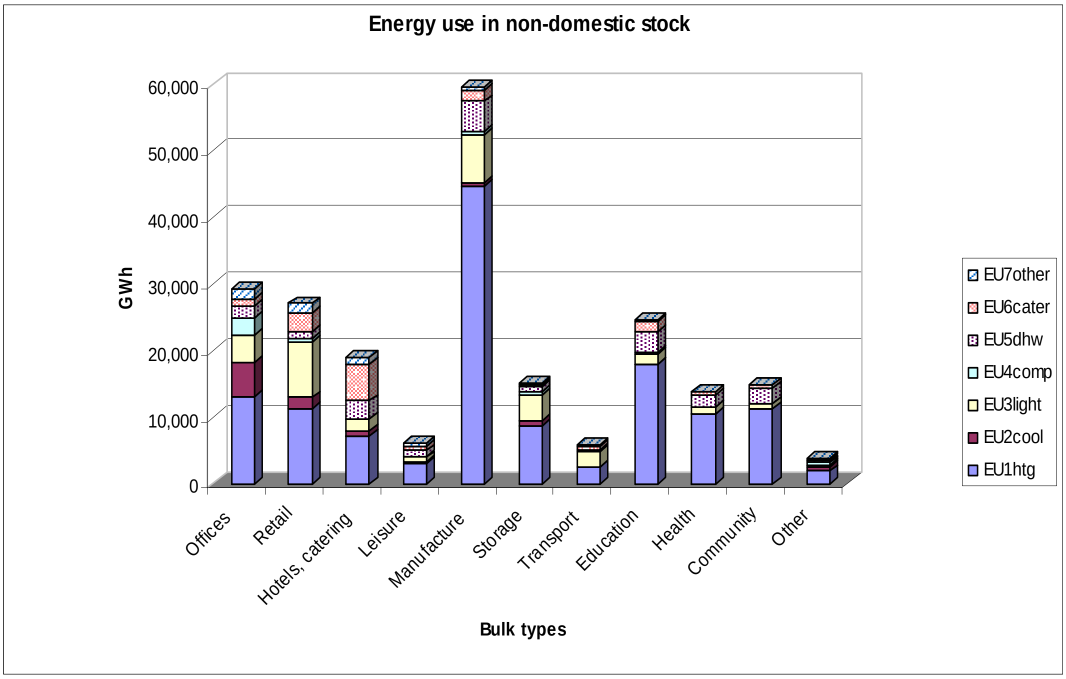

Fig. 2: Energy use by bulk type and end-use in the non-domestic stock of England and Wales.

As expected, offices, shops, hotels and restaurants, and schools and hospitals account for a major part of non-domestic energy use. Heating dominates in most bulk types, but cooling and lighting are comparable to heating in offices and shops, as is catering in hotels and restaurants. However in the preliminary model, *Manufacture* (workshops, factories, mills and works) dominates all other bulk types even though it excludes process energy use.

It must be emphasised at this point that many of the data in the model are highly provisional and that this is particularly so for the figures for industrial (manufacture and storage) energy use.

The provisionality results from uncertainty in some values of floorspace (as noted earlier) and from the extrapolation to the stock from the relatively small number of specific energy use data points available in the SHU surveys. The detailed surveys required to obtain energy end-uses are resource intensive. It was necessary to optimise the use of available resources, thus limiting the data that could be obtained for some activities. The SHU surveys concentrated on offices and shops since at that time there was little statistically reliable data for the energy use of any part of the non-domestic stock. While the study was adequate for shops (286 premises) and offices (186) premises, and tolerable for schools (50 premises), it contains only 20-30 premises for each of the remaining bulk types.

The magnitude of the total energy use bar for Manufacture is driven by the large factory floorspace in UK (some 27% of the stock) rather than a high specific energy use. It takes no account of the considerable amounts of vacant floorspace in the industrial stock (but there are no reliable and comprehensive statistics on industrial vacancy). Nor does it take account of factories and workshops that are not heated, or heated only to a minimal extent (again there are no good statistics). Whilst the total factory energy use may well be less than shown above, it might also be greater. We have at the moment no means by which to justify changing the total Manufacture energy use other than arbitrarily.

It may be noted that the breakdown above differs to some extent from the previous work on non-domestic energy use in the UK (Pout, 2002). Space does not permit an analysis of the differences but it is believed they are due to differences in the way the floorspace of the non-domestic stock has been grouped into major high-level categories and to the uncertainty in various data incorporated into the model.

While the Manufacture energy use figure is surprising, it is not completely implausible when considered in the light of the total quantity of factory space, how poorly insulated much of it is believed to be and high ventilation rates in factories, either by design for fumes clearance or inadvertently. Industrial energy use undoubtedly needs further investigation and one clear implication of the model is that we need substantially more energy data points for factories (though not factories alone).

COMPARISON TO DUKES

The major categories in the Digest of UK Energy Statistics (DUKES) are defined as follows (DTI, 2004).

Public	Public administration, defence, justice. Education. Health and social work.
Commerce	Wholesale and retail trade. Repair vehicles. Hotels and restaurants. Post and Telecommunications. Banking, insurance, real estate, business services.
Miscellaneous	Recreational, cultural, sporting activities. Other services.
Industry	Industry.

Primary classes in the stock model were regrouped to allow comparison of the model outputs to DUKES data for 2004, thus generating the following table.

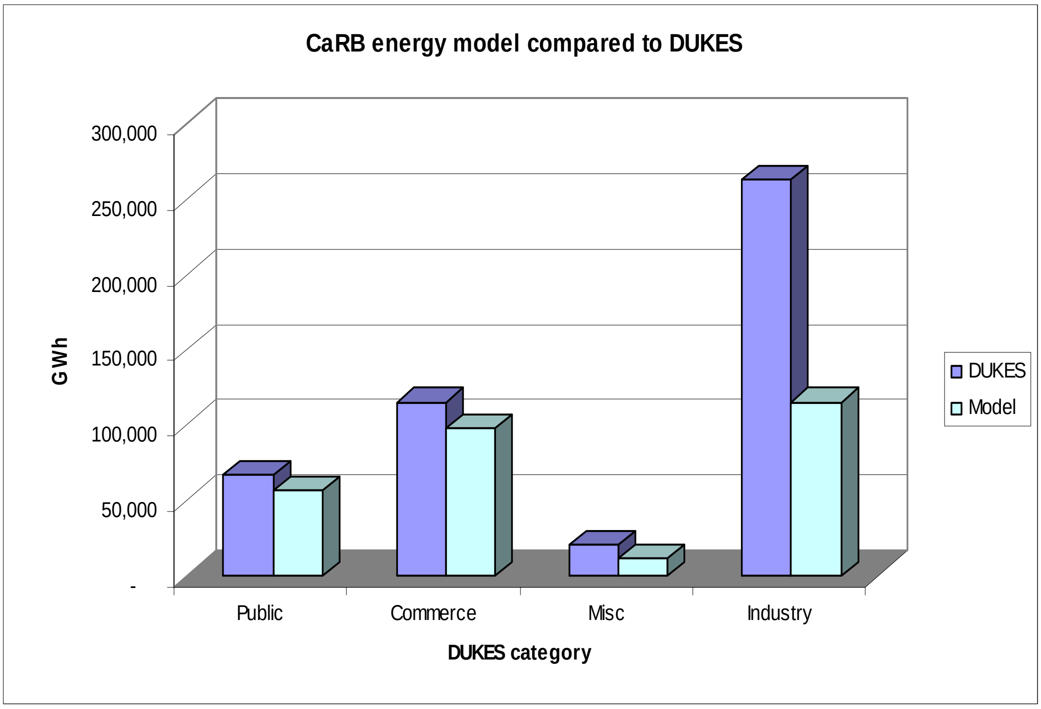

Fig. 3: Comparison of model outputs to Digest of UK Energy Statistics for 2004.

The model estimates that energy use for the Public and Commerce categories are each some 15% lower than the corresponding DUKES value. This is close to the difference expected because the model is confined to England and Wales, whereas

DUKES data cover all of the UK. However, CaRB model predictions are derived from floorspace data and energy surveys (bottom up) whereas DUKES data are aggregates of delivered energy data from electricity and gas utilities and other fuel suppliers (top down). Given that these are entirely independent sources, the close agreement for Public and Commerce suggests that the model is satisfactory for these categories.

The considerable difference between model estimates for industry and the corresponding DUKES data is to be expected because DUKES data include energy used for industrial processes and machinery, whereas these are not included in the building based end-uses (heating, lighting, cooling, appliances, etc.) dealt with by the CaRB model.

FUTURE DEVELOPMENT

Clearly the first task to improve the CaRB stock energy model is to incorporate into it more precise and statistically representative information on floorspace and energy use of those activities for which existing data are minimal. This task is underway now.

The preliminary model is based solely on floorspace and, while numbers of premises are available, these are not used in energy calculations. It is worth noting that the mean *premise* size in all bulk classes is around $100m^2$, rather less than the expected mean size of *buildings*, though no comprehensive data on the numbers and sizes of buildings in the UK exist (in contrast to premises for which there is good data for much of the stock). Thus a major model refinement would come about by basing the model on *buildings* rather than floorspace and premises. Buildings and premises have a complex many-to-many relationship and it is intended to use survey data to develop an algorithm that could generate a statistical relationship between premises and building size distributions.

With a building based stock model it then becomes possible to model energy use in a more sophisticated manner, using standard energy modelling software rather than the simple multiplication of floorspace by specific energy use. Such a development would constitute a *technical* model, able to take account of shapes, fabrics and building services and so forth. The size of the non-domestics stock and the enormous variety of activities, building sizes and services in it imply that modelling energy use technically and comprehensively for the non-domestic stock imposes severe data requirements on model development. A technical model for energy use in the non-domestic building sector must provide maximum flexibility and the ability to cope with different levels of input data, and the stock needs to be described in generalised way while keeping most of its relevant characteristics accounted for. Inference is needed to generate missing data; for example, construction properties may be able to be reasonably inferred from age, building type and size. A further stage is to infer HVAC plant configurations.

It is likely that the UK National Calculation Methodology and its implementation in the form of the Simplified Building Energy Method (SBEM) will form a central part of the CaRB stock energy model. Building simulation software (ESPr, Energy Plus) or equation based models (EES or IDA) will be used in the development of inference relationships.

Thus the model as a whole will have two essential parts: one dealing with organising and generating suitable datasets for stock modelling and the other calculating energy use. For the energy model buildings and systems, characteristics will be described by a limited number of meaningful parameters; thus the core of this model will be inference engines for building description, heat and cold demand and plant. The two parts together estimate stock energy use.

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