DEVELOPMENT OF A BUILDING ENERGY MODEL FOR CARBON REDUCTION IN THE UK NON-DOMESTIC STOCK

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ABSTRACT

The requirements for a scaleable energy model for the UK non-domestic building stock are described.. The non-domestic stock is much more heterogeneous than the domestic stock. The model needs to be scaleable from a single building, to a community or regional level. Approaches to using a small number of key inputs are described, using inference to combine empirical models, with building physics such as heat loss in a hybrid approach. Varying levels of information should be accommodated. Such models can be used to identify the most effective measures for reducing carbon emissions.

INTRODUCTION

A major UK research project, Carbon Reduction in Buildings (CaRB), seeks to establish a better understanding of energy consumption in the UK building stock (http://www.carb.org.uk/). As part of this, a model is being developed for non-domestic buildings. This paper describes the requirements of such a model in relation to the options available. The model itself is in the early stages of development. The purpose of the model is primarily to predict total annual fuel use, but may also be used to predict internal conditions and electrical demand on an hourly basis.

In any country, the non-domestic building stock is very diverse in terms of built form, usage, systems etc. Non-domestic buildings are often complex with several types of usage and services in different areas, making the use of empirical data often necessary for things like lighting gains, hours of use, occupancy levels etc. Furthermore, several premises often share one building, or premises spread over several buildings.

Since the deregulation of the energy industry in the UK, there is a requirement to actually read gas and electricity meters only once every two years, making it almost impossible to relate billing information to actual consumption. Meters typically are for the whole building, so energy use cannot be disaggregated. Due to the diversity of the stock and low level of metering, reliable empirical data is often scarce, out of date or does not exist.

As with dwellings, even within a tightly defined building and usage type, there will always be wide variations in energy consumption due to different systems and operation.

A non-domestic model was required to establish a better understanding of energy consumption in the UK building stock. At the same time, the EU Energy Performance in Buildings Directive (EPBD) will require all non-domestic buildings over 1000 m^2 in floor area to be given an energy rating from January 2006. The modelling requirements for both purposes are quite similar. In contrast to detailed simulation for design, energy use needs to be calculated based on quite limited amounts of information.

This work updates a large study of UK non-domestic buildings (Steadman, Bruhns et al. 2000) and their plant systems (Rickaby and Gorgolewski 2000) in four English towns.

For CaRB, the model is required to:

- predict annual energy use for all services in a wide range of non-domestic buildings;
- deal with different levels of available data input;
- include cooling loads;
- be capable of calculation for a large number (1000+) of buildings;
- be capable of predicting on an hourly basis, for utility supply to multiple buildings.

Building efficiency is seen increasingly as a relatively easy way of meeting environmental targets. In parallel, electricity networks are changing from highly centralised systems, to more distributed systems with embedded generation and more flexible control, possibly with more load management. Information on load profiles in the non-domestic stock is scarce and, with the break-up of the UK electricity industry and the demise of the UK Electricity Association which used to provide national profile data, becoming even less available. For these reasons, this type of modelling is becoming more important

The paper considers the types of model available, then describes the modelling rationale and the main features required of the model. Model inputs and assumptions will be modified by field data, with collection starting around April 2005.

AVAILABLE TYPES OF MODEL

Table 1 shows the four main families of energy model available, classified by the amount of input data required A to E. Some programs offer more than one type of modelling – for example Type C (no plant) or Type D (including plant).

Table 1

Types of model for energy performance

***TYPE*, INPUT**	**OUTPUT**	**CALCULATION**
A Empirical building type, floor area	Energy, fuel/m^2	Look-up table
B Steady-state + wall, glazing, floor areas, U values, gains, average air changes.	Heating energy, heating plant size	Steady-state heat loss method Inference methods
C Dynamic thermal +constructions, geometry, ventilation & occupancy schedules	+ hourly heating & cooling, internal conditions	Dynamic thermal, solar gains
D Building & plant + plant systems	+ plant & control performance	Dynamic plant & control models

Type A, empirical models or benchmarks, are simply energy consumption figures for different building types, derived entirely from measurements on real buildings. They are sometimes split into sub-types – e.g. the four different office types used in the UK office benchmarks (BRECSU 2000). They include all services because they are used to provide indicative total energy use broken down by service, but only in terms of numbers, say Wm^{-2}; they cannot be used to evaluate new designs or efficiency imrovements. For example, energy used for lifts will vary with building form (and be zero for single storey buildings), but the benchmark will just give a single, average figure. Also, they reflect the existing stock (sometimes categorised) rather than new build. Type A models are mainly used for benchmarking individual buildings, and stock data (Steadman, Bruhns et al. 2000)

Type B, steady-state models, are widely used to assess seasonal heating demands using manual or simple spreadsheet methods based on temperature differences and heat loss rates, allowing for internal gains by adjusting the internal temperature value. They are less suitable for calculating cooling loads. This is because a large part of the cooling load is to remove solar gains during the day, which are complex to calculate and cannot in general be averaged over 24 hours. For the existing stock, the information which can be gained from inspection is often insufficient for a thermal calculation – in particular fabric constructions and insulation levels. Therefore inference engines are being proposed (Faber 2004) to infer parts of the input data which could generate 'most likely' heat loss factors for a given type of construction (e.g. brick) built in a certain decade (see *Thermal fabric properties*). Examples of Type B models include the Standard Assessment Procedure method for dwellings in the UK Building Regulations (ODPM 2002a), and the NEN 2916 standard for non-domestic building, (Normalisatie-instituut 1998)

Type C models require a lot more time-base information in order to model the building dynamically. Hour-by hour (or higher resolution) outputs give detailed comfort analysis and thermal loads. Heating and cooling loads are modelled in various ways, ranging from 'ideal' – meeting set point requirements exactly with, in effect, infinite heating/cooling capacity; or various control laws with the option of limited heating/cooling capacity. Part-load and distribution efficiencies of actual plant is used to predict the energy consumption from the space heating and cooling requirements.

Increasingly, such models are linked to airflow simulation, either by bulk airflow models or for steady-state 'snapshot' CFD flows using boundary conditions from the thermal model. A variant of the type C model is a reduced-parameter model, where thermal mass is 'lumped' into a small number of nodes (around 2 to 5 per zone or per building) and solved by finite difference. These have the advantage of much shorter run times; this was important when detailed models were sometimes taking hours to simulate one year, but on modern computers typical run times for detailed models are of the order of minutes or seconds. However, reduced parameter models can still have a role when simulating large numbers of buildings; a 3 time constant model called 3-TC was used in previous work on energy use in the UK non-domestic stock (DEFRA 2001). Another advantage of reduced parameter models is that with limited input data (say, basic geometry, constructions and usage patterns) it is much simpler, and more robust, to infer a set of time constants for such a model, than to infer a complete set of detailed constructions and areas for each surface for use in a detailed model.

The type C models have little if any built-in knowledge about different types of building. Standard typical figures may be given as defaults for lighting loads, hours of use, set-point temperatures, etc. which can be changed, but these usually relate to occupied office-type environments. They do not account for other areas such as circulation spaces, intermittently used spaces, special areas etc. Also, such models are intended only for thermal behaviour.

Therefore services such as lighting and small power are included because they produce heat gains, but other energy-using services are not normally included – for example lifts, hot water, catering (except as heat gain), washing equipment, etc.

Type D models add the capability to model plant and controls. Because the timescales of plant and control behaviour are typically much shorter (10^0 – 10^2 s) than those of buildings (10^2 - 10^4 s) the models are often decoupled, or steady-state plant models run at each thermal time step. Most plant modelling focusses on research into particular systems, using software such as TRNSYS; truly integrated models are still at the research stage.

All of these models generally operate with a fixed level of detail for inputs and outputs, or with limited scope for employing different levels of modelling and input data in certain areas like airflow modelling. Leading examples of public domain software with Type C and Type D capability include EnergyPlus, the leading US model (US Department of Energy 2004) and from Scotland, ESP-r (Clarke 1996).

NON-DOMESTIC MODELLING REQUIREMENTS

This section maps what existing modelling approaches have to offer, onto the general requirements of non-domestic model for the purposes described.

Level of detail

When modelling non-domestic buildings, the level of detail available will vary widely. Therefore the model should be able to use however much detail is available, but to use robust defaults where data are missing. This is often a weakness of existing software which either offers no default, or offers the same default for all building types because it has no inherent knowledge of buildings.

Geometry

There are two main approaches to geometry in building modelling. The first, more primitive, method uses façade orientations and areas, combined with space volumes given as input data independent of the façade data (though the façades will be thermally assigned to spaces). Hence the space volume could be physically inconsistent with the façade geometry. The second method is explicit geometry where each element has spatial co-ordinates, so that spaces and associated volumes can be calculated automatically, along with solar fluxes onto building surfaces, wind pressure etc. The information in the first approach is a subset of that available from the second.

For simple geometry, data is easy to enter for either method, although explicitly arranging glazing on each façade is considerably more tedious than just giving a glazed area or percentage per façade. For large, geometrically complex buildings entering just façade areas (particularly if elevation drawings are available) can be much quicker than entering the geometry. However, modelling rigour is compromised by the façade approach and the level of detail limited – for example shading by obstructions requires explicit geometry. Modern graphical interfaces make geometric entry considerably easier than hitherto –although this remains one of the weak areas in many programs. Another major advantage of explicit geometry is the ability to view the building; this is both aesthetically satisfying for the modeller, reduces input errors, and makes it much easier to communicate the process with others. A 'pure' geometric approach, however, usually ignores the thicknesses of fabric elements, treating the building as a 'wireframe' structure. Some elements, such as highly insulated walls and particularly ceiling and/or floor voids in highly serviced buildings, can occupy very significant volumes. Voids can be included as explicit zones, but thick walls are more difficult to deal with. Using internal dimensions gives the correct space volume and floor area, and is the usual approach, but it results in reduced external dimensions.

Previous work (Steadman, Bruhns et al. 2000) on the classification of built forms (in a survey of UK non-domestic buildings) used three principals to simplify the process: removal of minor details such as porches, small porticoes etc.; breaking larger buildings down into components for separate classification; and separating form from dimensions, i.e. parameterising forms. Thus a simple rectangular 'shed' with pitched roof can be described with four numerical parameters; plan dimensions of length and width, height to eaves and slope of roof, plus orientation from north of some agreed plane. Explicit geometry would in contrast require 10 (x, y, z) vertices relative to a site origin, or 30 numbers in total (though these could be generated from a much smaller number of mouse clicks in a graphical interface, more akin to the parameterised approach). Most serious simulations programs use explicity geometry.

While building shapes are diverse, they tend to approximate to a relatively small number of shapes or combinations of these, usually arranged in a rectilinear fashion. In order to allow in daylight and natural ventilation, nearly all older buildings and most modern ones designed for natural ventilation have a 'spine width' of around 10 m to16 m for each rectangular section. (The spine width is the distance between opposite walls on the narrowest dimension.) Where there are multiple such components they may be arranged around a courtyard, or in a 'letter' configuration in plan such as L, H, E etc. Such parameterised forms and overall layouts can be used rapidly to describe the main features of a building in a fully geometric way. Deep-plan buildings can be arbitrary shapes, and may be divided for environmental purposes into perimeter and core zones – the core zones of necessity being entirely artificially serviced.

Explicit geometry combined with the parametric approach, combining a number of forms for a complex building, is suggested as the best approach for the type of model required. Improving tools are making input easier, and the many advantages outweight the overhead of more input.

Thermal fabric properties

For buildings with a set of known fabric constructions, it is straightforward to assign the constructions from a database. In the case of buildings built to a given set of thermal regulations, i.e. from the 1970s onwards for the UK, it can be fairly safely assumed that the minimum permitted insulation level was used, unless it was an overtly 'energy efficient' design (in which case construction details are quite likely to be available). For the remainder, of mainly older buildings, inference models will be used to make a 'best guess' of construction based on easily gathered visual information – similarly for windows. Buildings with more modern, panel constructions are the most difficult to evaluate. The inference engine would know whether there was likely to be a cavity, and the prevailing minimum insulation standards if any.

For example, many UK buildings constructed between about 1930 and 1970 had easily recognised cavity brick walls, with internal plaster, which may or may not have later been filled with insulation. Standard bricks were 4 inches (about 10 cm) wide. Retrofit insulation is indicated on inspection by filled holes on the façade where the insulation was injected into the cavity. Both insulated and uninsulated constructions can then be inferred with a high degree of reliability. If it has not been possible to establish whether there is retrofit insulation, the inference engine would default to 'none' because that is the most likely case.

Ventilation

In naturally ventilated buildings, the actual ventilation rate will vary with wind, temperature difference, and occupant control of windows and doors. In most cases, there will be no measured data so empirical data should be used to provide typical rates for a given type of building and construction – for example window type has a large influence on the infiltration rate. When sufficiently detailed information is available it should be possible to use network flow models.

Lighting

Lighting demand should be based, as a default, on typical design standards for the building type. Use of daylight is an important issue (another advantage of a geometric model is that internal daylight levels can be modelled) and daylight availability algorithms, combined with field data, will be used to modify electrical lighting demands. More sophisticated approaches to daylight evaluation than simple daylight factor will be used where feasible (Mardaljevic 2001).

Equipment

Thermal design usually makes general assumptions about small power (or 'plug power') energy use such as 10 W m^{-2} for offices. Data from recent surveys should be used to supplement such assumptions, as equipment changes (e.g. flat computer screens) and standby low power modes become more widespread.

Occupancy and temperatures

Typical (default) occupancy patterns are known for many building types, but these assumptions are often incorrect. Therefore, actual schedules should be used if available. For example, schools may be nominally occupied by pupils from around 09:00 to 15:30 on weekdays, but real use will often extend into the evening, varying day by day, for clubs or community use, and at weekends. Heating regimes may or may not be adjusted to these schedules.

Though there are recommended temperature bands for various activities, it is known that actual temperatures can vary widely for the same type of building, between individual rooms, and according to weather. Again, field data should be used if available.

Miscellaneous services

Additional energy using services which usually operate outside the main functional areas of buildings, such as lifts and hot water, should be included. The minimum information would be an average energy figure for a given building type. Profiles of use should be developed to distribute the energy over the day. More field data are needed, from which algorithms could be developed to account for more individual effects, such as taller buildings using more lift power. Inference could then be used to predict consumption based on building form and use. Energy use of these services is not important for thermal performance, but is important for total energy consumption.

Weather data

Weather is an important determinant of energy use. Weather data is collected hourly and detailed simulations use hourly data. For the UK there are at present only three 'standard' weather years, for

London, Manchester and Edinburgh (CIBSE 2001), though more are planned. There are three options; to use local climatalogical data (e.g. monthly averages) in simplified models of the thermal processes; to generate more local 'average' weather sets; or to find ways of adapting 'average' hourly data from elsewhere such that it has the same key statistics (average monthly temperatures etc.) as the local site.

Model structure

A schematic of a possible model structure is given in Figure 1.

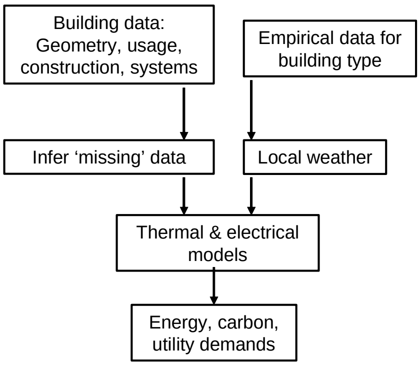

FIGURE 1 – MODEL STRUCTURE

Some pre-processing would be required to generate detailed input data by inference where this is lacking. A 'late binding' approach (by analogy with object-oriented programming) will be used for some calculations. This means that the calculation used will depend on the data available.

A Type C thermal model (see Table 1) appears to be the most suitable type. Where many buildings are being modelled, or there is a lack of detailed data, a lumped parameter form may be used. As a large amount of effort has already gone into producing models and modelling environments, such as EnergyPlus, use of these should be made wherever possible – not just to save time, but to have reliable, validated code. In addition, the practicality of using the Industry Foundation Classes for data description, weighed against the overhead involved, should be considered for making the datasets compatible with other programs.

Some miscellaneous uses of energy can be modelled outside the core thermal model, since the energy flows are not part of the normal heat flows within the building – e.g. lifts.

Electrical energy

Thermal models only consider electrical energy insofar as it contributes to heat gain – usually just lighting and small power, and sometimes fan power since this is turned into heat. It is preferable to model electrical energy use explicitly, as well as heat gains arising. Since electricity trading is done in the UK on a half-hourly basis, this is the most appropriate resolution to use.

Multiple buildings and utility demands

Fortunately, buidings do not interact significantly with each other (except for shading and other microclimate effects) so it is possible simply to add utility demands from several buildings sharing utility supplies. This is of particular value in assessing the combined electrical loads, in the context of embedded electricity generation load matching and electricity network analysis.

CONCLUSIONS

The requirements for modelling non-domestic buildings in the context of energy use prediction across the building stock have been described. Modelling options and associated problems have been considered. In the next phase of the CaRB project, field data will be collected and a prototype non-domestic model written.

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