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MODELLING BUILDING ENERGY USE AT URBAN SCALE

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ABSTRACT

The Energy and Environmental Prediction (EEP) model is an environmental auditing and decision making tool for cities, to be used by planners and others in pursuit of sustainable development. The EEP model is based on Geographical Information System (GIS) techniques and incorporates a number of sub-models to establish current energy use and emissions produced by buildings, transport systems and industry. Two of the sub-models are concerned with building energy use, namely, for domestic and non-domestic buildings. In order to predict building energy use over the whole of the city or local authority area, data is needed on the building stock. This paper describes the level of data required, the survey technique and the operation of the EEP model to predict building energy use.

INTRODUCTION

In order to manage the use energy of the built environment in a sustainable way and to minimise harmful emissions, the performance of the city in sectors or 'as a whole' must be considered. This is a different approach to the building design process, which generally considers buildings on an individual basis or in relatively small groups. For sustainable urban planning there is a need to consider large numbers of buildings, up to a whole city, which requires a more statistical approach. Because it is practically impossible to collect and maintain detailed data for every building, urban planning models must work with relatively low level data. An energy and environmental prediction (EEP) model has been developed in collaboration with Local Authorities in the UK as part of a unified effort to plan for sustainability and to predict and account for reductions in carbon dioxide and other emissions. The Home Energy Conservation Act (HECA) has been established by the UK Government in an attempt to reduce emissions by domestic properties. The Act requires that local authoritiess consider and implement as far as possible strategies that show a significant improvement in housing energy efficiency. The target improvement set is a 30% reduction by the year 2007 compared to the housing stock of 1997.

To fully understand the inter-relation ships between buildings, transport and industry, and the potential for using renewable energy sources on a city wide basis, a model is required that can predict the various interactive processes. The main purpose of the EEP model is to help decision-makers to plan for improved energy efficiency. Initially developed for the city of Cardiff it is now being considered by other local authorities in the UK to predict the effects of future planning decisions from a whole city level down to a local level. This paper focuses on the building energy use prediction capabilities of EEP.

OVERVIEW OF EEP MODEL

The aim of the EEP model is to quantify energy consumption and emissions for different activity sectors and spatial areas. The model is accessible through a PC Windows environment and is flexible to allow for future expansion and be transferable to other city regions. The framework for the model is shown in Figure 1. The user can access the tool via a *primary user interface*. The interface can call a range of *sub-models*, selected according to the user's needs, and will present results simultaneously through the associated *Geographical Information System* (GIS) which contains an Ordinance Survey (OS) map of the city describing the buildings and roads. Sub-models will exchange data through a *data highway*, making all data available to all sub-models.

A variety of *sub-models* are currently being developed and evaluated for use within EEP, including procedures related to building energy use, transport emissions, industrial pollution and socio-economic profiling. The sub-models are generally based on accepted procedures, for example, for predicting domestic energy use. Therefore the sub-models themselves do not require validation, although the data acquisition and operation of the sub-models within the EEP framework does require testing. The exception is the traffic flow model, which was developed

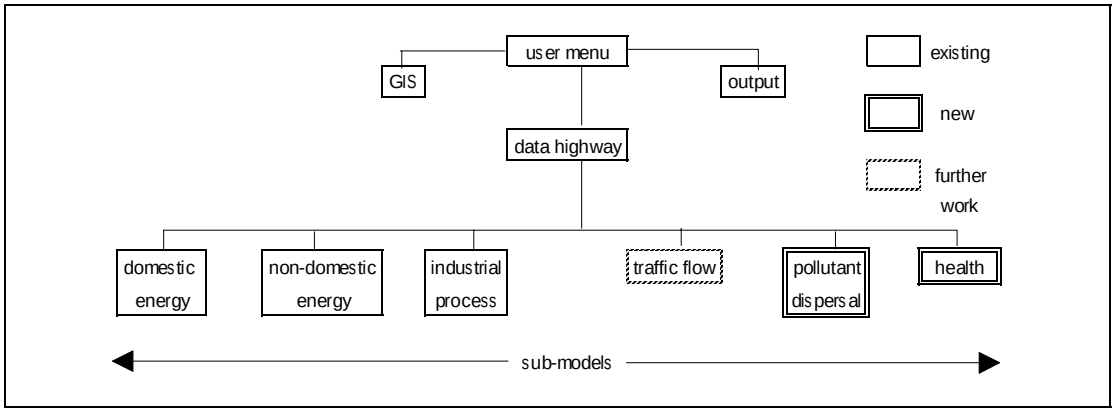


Figure 1. Conceptual framework of EEP model.

within the programme and has undergone testing against measured data

In EEP, the basic unit to describe land use is the post-code, and this is used to display results via GIS thematic mapping. It comprises typically of 10-15 houses, or a single non-domestic building. However, within the database the individual properties within a post-code are listed, so sub-post code analysis is possible.

DOMESTIC ENERGY USE SUB-MODEL

The EEP model will produce estimates for domestic energy use and emissions for properties in the city using a method based on the UK Standard Assessment Procedure (SAP) (BRE 1994). SAP is a calculation procedure, which provides a rating of domestic energy use, with values ranging between 0 and 100, the higher the number the better the standard. Compliance with current UK Building Regulations for new dwellings, would result in a SAP rating of between 80 and 85. A computer based version of SAP has been created for use within EEP, this is called DEAP (Domestic Energy Assessment Procedure. EEP calculates the SAP rating, carbon dioxide emissions and the amount and cost of energy for individual properties, 'clusters' of similar properties, or properties within an area (up to the whole domestic stock of a city).

The energy rating scheme aims to inform users of the overall energy efficiency of a home in a manner that is easy to understand and provides a method of comparison between buildings. Energy ratings enable decision makers to consider different packages of energy efficiency measures when designing new properties or refurbishing existing dwellings. Information regarding fabric, glazing, ventilation, water heating, space heating and fuel costs are required to carry out a SAP calculation.

As large numbers of properties are required to be included within the domestic sub-model when studying a city or region, information about each property has to be collected with relative ease and speed. The information is collected by means of a 'drive-pass' survey, that is, without requiring access to the property, which would greatly increase survey time and resources. A procedure has been developed for use within the model that groups properties with similar energy performance characteristics together. An initial survey has to be carried out to determine the range of sample properties within a region (estimated to be 10% of the total number of dwellings). Once this is complete the remaining houses can be assigned to a pre-defined group.

The EEP cluster analysis technique is therefore based on statistical methods, to identify properties with similar energy consumption and emissions. The cluster analysis procedure 'forces' properties into a specified number of groups or 'clusters' based on selected built form characteristics and age of the properties. The five characteristics used to describe an individual property in order to create clusters are:

- heated ground floor area,
- facade,
- window to wall ratio,
- exposed end area,
- age.

These features are considered to have the greatest influence on domestic energy performance. The information required to describe properties in order to carry out the cluster analysis is as follows:

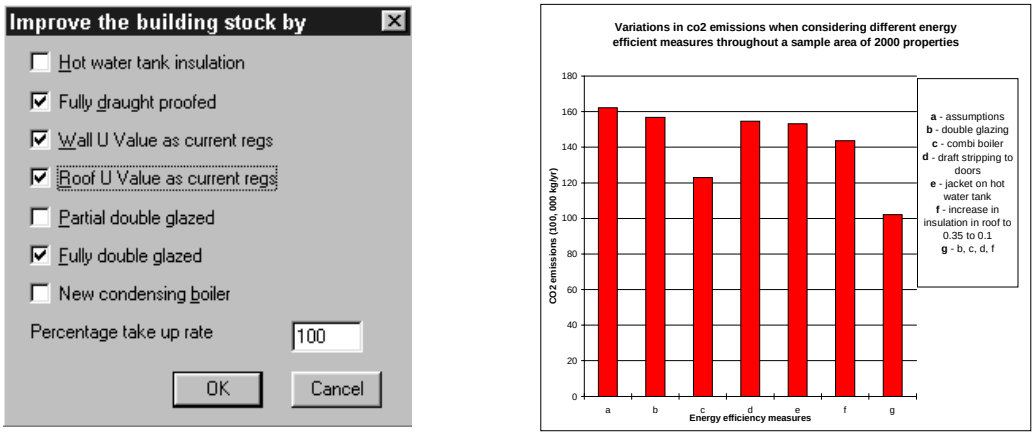
- **Location** - each property can be located in GIS using, postcode, road name, sub-postcode, sub-category (suffix to postcode for identification of cluster), number and

type of properties within the postcode, property numbers,

- **Building dimensions** - obtained from GIS, an estimate for each property of, heated ground floor area, exposed end area, storey area, facade area,
- **Age** - obtained from historical sources : each property is assigned to one of five different age groups, pre 1919, 1919 - 1944, 1945 - 1964, 1965 -1980, post 1980,
- **Built form** – obtained from the 'drive pass' survey, number of storeys, number of chimney pots, window area, storey height, facade area, storey area, and ratio of windows to wall area.
- **Assumptions** - Assumptions made during data entry into DEAP include: number of rooms (controlled by number of floors), U-values for walls, floor and roof based on age as, water heated by heating source, water tank volume (120l), space heated by wall mounted gas boiler with balanced or open flue and a gas mains heating system. These assumptions have been tested using a questionnaire that was distributed to a sample of 2000 properties (with a 20% response rate) within Cardiff. Assumptions can be designed to suit conditions within the region under investigation.

The cluster analysis method enables the model to allocate a property to one of twenty built form types and one of the five age groups, producing 100 cluster types. This is similar to the Home Energy Conservation Act (HECA) that has been set up in the United Kingdom in an attempt to reduce carbon dioxide emissions from domestic properties by 30% by the year 2007. HECA also classifies dwellings into 100 different types using the five age groups, four types of tenure and five types of built form. Discussions with the local council questioned the HECA classification due to large differences between properties that are assumed to have the same energy use, and on this basis that more built form types were included in the grouping process.

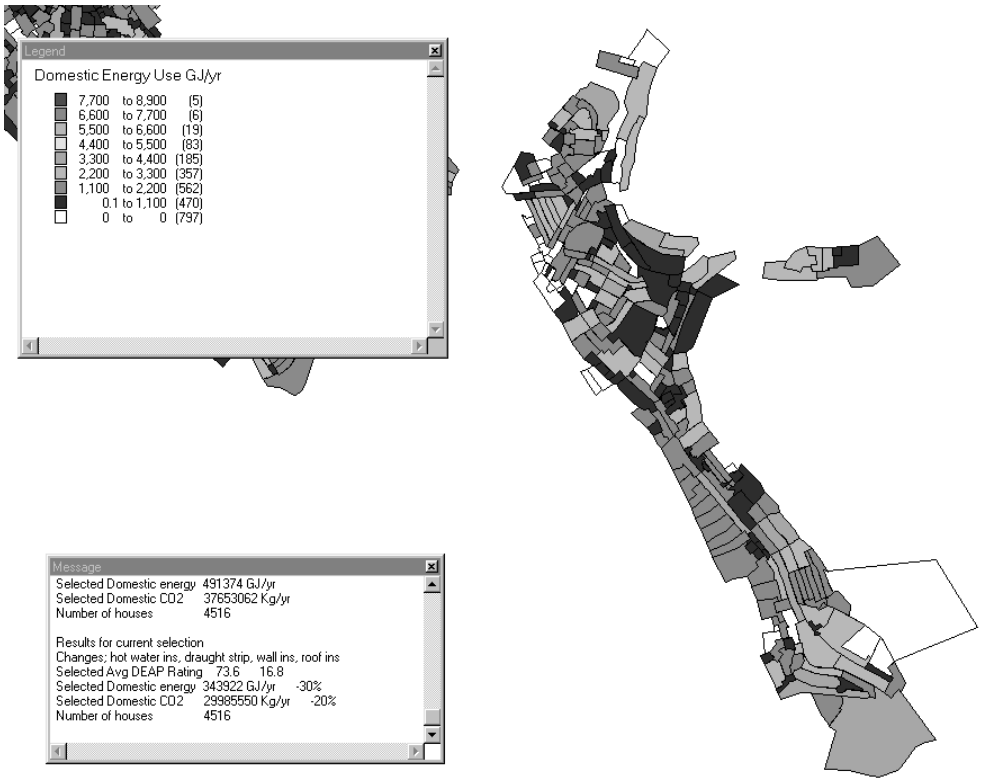
Each cluster has a calculated carbon dioxide emission value, SAP rating and yearly energy cost, these can be assumed for the property that is being analysed. The domestic sub-model can predict SAP ratings, total energy use and total domestic carbon dioxide emissions for a single property, single postcode, a group of selected postcodes, a type of property, a selected property cluster or for the entire region. The domestic sub-model has a facility to investigate the effect of common energy efficiency measures that could be applied to groups of mixed or similar property types. The current list of measures are those included within the UK HECA guidelines, including, hot water tank insulation, draught proofing, wall and floor U-value improvements, increasing double glazing and installation of a condensing boiler (Figure 2a). These options can be altered to include those measures that are available, bringing all properties within a selected area up to current standards. An analysis to compare the single and combined effect of the energy efficient measures was carried out using data from a sample of two thousand mixed type dwellings in an attempt to observe the reduction in carbon dioxide emissions. The results are presented in Figure 2b. This type of analysis can be used by Local Authorities in order to determine what measures would be required in order to achieve targets, for example, the HECA 30% reduction in energy use by 2007. More detailed modifications of an individual property or particular property type can be carried out using the DEAP tool just on the single property.



(a) (b)

Figure 2. a) menu of energy conservation measures, b) analysis of different packages of measures on a sample of 2000 houses.

(a)



(b)

Figure 3. Housing in Neath Port Talbot, a) before energy saving measures applied; b) after energy saving measures applied.

Figure 3a shows the EEP thematic mapping of the energy use and carbon dioxide emissions associated with an area of Neath Port Talbot. The change in energy use and emissions due to the modifications selected can be displayed within the message box. The results of the measures are produced graphically, as illustrated in Figure 3b. The 30% reductions in energy across the sample are attributed to a package of energy saving measures, including, insulating the wall, roof and hot water tank, and draught stripping, all carried out to current standards.

NON-DOMESTIC ENERGY SUB-MODEL

The non-domestic sub-model quantifies energy used within the commercial and public sectors of the built environment. This sub-model has been developed using energy consumption and emission figures from the series '*Introduction to Energy Efficiency Guides in the Best Practice Programme'* produced by the UK Department of the Environment, Transport and the Regions (DETR) (Energy Efficiency Office 1994). The guides were produced for use by managers of individual commercial buildings in an attempt to highlight the importance of reducing energy consumption. This series divides non-domestic properties into thirteen different groups that are further subdivided into forty-eight sub-groups as illustrated in Figure 4. For example, the group 'hotels' is split into three subgroups - small hotel, business hotel and luxury hotel. The number of sub-groups per group varies with building type.

The type of property is identified using data sources such as the Local Council rateable value database and site visits. The property floor area is obtained from the Ordnance Survey map or equivalent in the GIS system. An energy standard (low, medium or high consumption) can be selected. This is a general assessment of the current energy efficiency of the building and is usually based on the age of the property unless other information has been obtained. Every non-domestic property that has been entered is listed when a postcode is selected in EEP. Data can be entered into EEP through a Windows based routine as shown in figure 5.

OTHER SUB-MODELS

Other EEP sub-models developed or being developed include:

- *Energy Use By Industrial Processes.* The energy use and environmental impact associated with the various industrial activities in the city will be determined using both general information available from UK Government statistics, and information specific to individual sites or activities within the city.
- *Traffic Flow.* Traffic flow on every road needs to be modelled using space analysis technique (Hillier et al 1993). This is able to quantify current levels of traffic and associated levels of energy use and emissions (Highways Agency 1994), for the entire road system in a city-wide region.
- *Emission Dispersal Model.* EEP is able to link with an atmospheric dispersal model (ADMS-Urban) in order to predict the resulting dispersal of these emissions, and the results represented within the EEP GIS analysis framework.

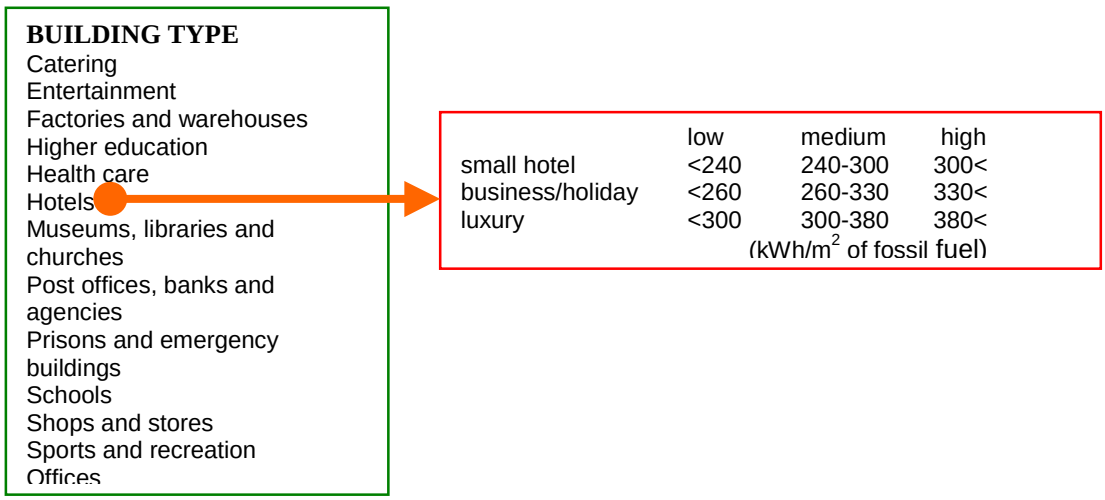


Figure 4. Example of non-domestic building types and sub-types.

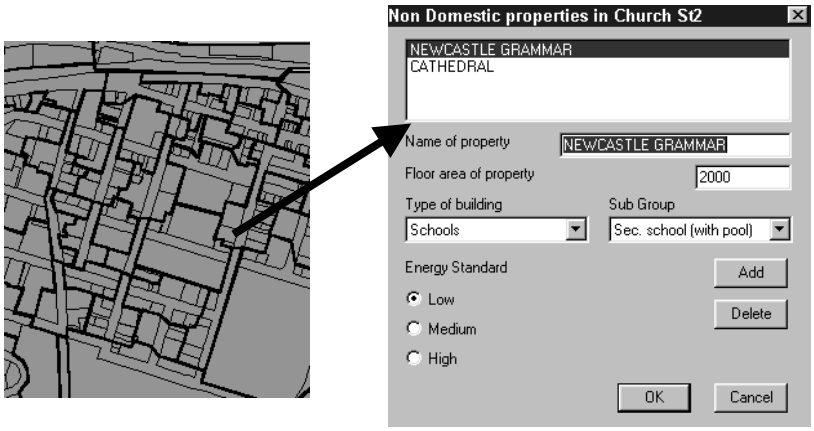


Figure 5. Data input facility

- *Health Model*. Health is a key city sustainability indicator and one that the built environment can significantly impact on. The EEP model will bring together data on pollution exposure, building and traffic use with health data to significantly improve understanding of the key health variables in cities.

CONCLUSIONS

The EEP model is primarily a planning tool for quantifying energy use and emissions for a city to plan for sustainability. Once baseline information for each of the sectors of the built environment has been established, it can be used as a planning and policy tool that will allow local government to select sites for development and improve the building stock that is already present. It can also as an impact assessment tool, which can help determine the impact of proposed developments on the city or region. Currently the model is being tested in three local authorities and fully implemented in one local authority.

ACKNOWLEDGEMENTS

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