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A NEW GEOGRAHICAL INFORMATION SYSTEM-BASED APPROACH TO MAP AND REDUCE ENERGY-RELATED CO_2 EMISSIONS FROM UK DWELLINGS

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ABSTRACT

This paper describes the development, demonstration and validation of an award-winning, domestic energy, carbon-counting and carbon-reduction model (DECoRuM) with the capability of measuring, modelling and mapping energy-related CO_2 emissions from existing UK dwellings and aggregating them on a local scale. This enables DECoRuM to assess the cost-benefits of deploying a wide range of best practice energy efficiency measures, low carbon technologies and solar energy systems. The capabilities of DECoRuM are demonstrated by applying it to a case study in Oxford, covering 318 dwellings. The DECoRuM tool is designed to assist energy advisers and planners in local authorities to calculate and reduce CO_2 emissions in the domestic sector and mitigate effects of climate change.

INTRODUCTION

Climate change, caused by the release of greenhouse gases (mainly carbon dioxide) into the atmosphere, has been recognised as one of the greatest threats of the 21st century (IPCC, 2007). Over the last two years, a number of important strategic developments have occurred in the area of climate change and the built environment, with the publication of the EU Action Plan for Energy Efficiency (Commission of the European communities (CEC), 2006), The Stern Review (Stern, 2006) and the IPCC's Fourth Assessment Report (IPCC, 2007). The Fourth Assessment Report confirms the urgency of the problem of climate change and leaves little room for doubt about the mechanisms and causes. Whilst the Stern Review rehearses the economic and political case for action, the 'EU Action Plan for Energy Efficiency' aims to achieve a 20% energy saving by 2020 - the EU's proposals for buildings are more ambitious, with planned savings of 28% (Commission of the European Communities, 2006).

In line with these developments, the Climate Change Act 2008 has commited the UK government to making at least an 80% cut in greenhouse gas emissions by 2050 (DECC, 2009b). The government is also committed to meeting its share of the European renewable energy target (20% of Europe's energy from renewables by 2020) by providing 15% of UK's energy by renewable sources by 2020 (DECC, 2009b).

In the UK, as in most industrialised countries, energy use in the domestic sector contributes substantially to national CO_2 emissions and is directly responsible for about 27% of the UK's total CO_2 emissions (DECC, 2009a). Given that CO_2 emissions from transport and the commercial sectors are expected to rise in the future, it seems unlikely that the UK will be able to achieve large reductions in national CO_2 emissions without the savings in the housing sector being at least as large as those that are likely to be required in the economy as a whole. Most of this change has to occur in the existing housing stock, which will form three-quarters of UK housing in 2050 (Foresight Sustainable Energy Management and the Built Environment Project, 2008). Hence, it is in the sector of existing dwellings where CO_2 emissions need to be reduced if UK housing is to contribute to CO_2 abatement both immediately and in the longer term.

At the same time, there is growing recognition that action by local authorities will be critical to the achievement of the Government's climate change targets (DECC, 2009a). Studies by Shackley et al. have concluded that actions at the local to regional scale are needed to deliver extensive CO_2 emission reductions, but to date most strategic thinking has focussed on national mechanisms. There is great untapped potential for bottom-up-led CO_2 reduction (Shackley et al., 2002, p. 9). Moreover the recently-released 'National Indictaor (NI) 186' requires every UK local authority to report annually the percentage reduction in CO_2 emissions per capita from their area includes public and private housing (DECC, 2009a). The success of NI 186 depends on the ability of local authorities to identify individual properties which could benefit from energy efficiency measures, in addition to making broad citywide estimates. However, one of the problems in reporting and monitoring effectiveness of energy efficiency measures is the lack of consistent, publicly available tools and methods for calculating the potential carbon savings (DECC, 2009b, DECC, 2009a, Urge-Vorsatz et al., 2007).

It is becoming clear that such regulations will increasingly require an evaluation of the most effective measures for reducing energy-related CO_2 emissions from the existing UK housing stock. However, the first step is to estimate the baseline energy consumption of a dwelling as this provides the benchmark against which the effect of various CO_2 reduction measures can be compared.

It is within this context, this paper describes the development and application of a new domestic energy model that includes the capabilities of counting CO_2 emissions from existing UK dwellings, enabling it to evaluate the potential for domestic CO_2 emission reductions on a local scale.

RELATED URBAN ENERGY MODELS IN THE UK

There are a number of energy models concerned with predicting building energy consumption in urban areas in the UK. However, the methodology to estimate domestic energy use incorporated in most of the models is either a monthly or an annual version of the Building Research Establishment Domestic Energy Model (BREDEM), a *defacto* industry standard. Three important related urban energy models are BREHOMES, EEP and SEP.

Building Research Establishment Housing Model for Energy Studies (BREHOMES) is a physically based model of the energy use of the UK housing stock (Shorrock and Dunster, 1997). It calculates energy use in dwellings using BREDEM-12, the annual version of BREDEM. The data required by BREDEM-12 is obtained from a wide range of sources (Housing and construction statistics, Family Expenditure Survey and English House Condition Survey) and is broken down into categories defined by dwelling type, age, tenure etc. With all the data in place, BREDEM calculations are carried out for each category of dwellings in the UK. Multiplying by the number of dwellings in that category and adding each category together produces an estimate of the entire UK dwelling stock consumption. BREHOMES has been widely accepted as a valuable policy tool . BREHOMES operates by using default data derived from statistical sources and applied to average dwellings. Although acceptable for its intended use, making general predictions about energy consumption in the UK housing stock, it is unsuitable for considering individual dwellings (Gadsden et al., 2003b, p. 38).

The domestic sub-model in the Energy and Environmental Prediction (EEP) model developed by Cardiff University uses statistical clustering method to estimate the Standard Assessment Procedure (SAP) energy ratings for domestic properties. Clustering is carried out on the basis of only four variables related to built form: heated ground floor area, total façade area, ratio of window area to wall area and the end area of a property. This data is derived from drawing manually building outlines on a digital urban map and performing rapid site surveys. Knowing these four variables along with the dwelling age allows the dwelling to be placed into one of a hundred clusters. Each cluster then has a SAP rating calculated for its centroid property. Other input variables are based on global assumptions, for example that all properties are single-glazed and have a central heating system with a wall-mounted gas boiler (Jones et al., 2000, pp. 858-863). Data is stored at postcode level and results are only available for postcode regions i.e. group of dwellings (Gadsden et al., 2003b, p. 38). Even if more detailed information is available for individual dwellings, there is no scope to incorporate it into the model.

Solar Energy Planning (SEP) system developed by DeMontfort University predicts the baseline energy consumption of domestic properties using the monthly version of BRE Domestic Energy Model, BREDEM-8, and determines the potential for reducing this energy using the three key solar technologies: passive solar design (new dwellings), solar hot water heating and photovoltaic systems (Gadsden et al., 2003a, Rylatt et al., 2003). A new dwelling classification system is developed to address the major problem of data collection for citywide domestic energy modelling. However, the SEP system is intended primarily to predict and realise the potential of solar energy on an urban scale, where passive solar measures are considered for new dwellings only. At present, no provision for deploying energy efficiency measures is mentioned and it is left as future work. It also does not include economic information on the different measures to allow their payback times to be calculated.

Importantly, none of the existing models consider a complete package of best practice energy efficiency measures and solar energy technologies. The cost-benefits of applying these measures in existing dwellings are also missing. These models collectively termed as the *first generation* models typically deal with the effect of energy efficiency measures on building energy consumption, apart from SEP system which models the urban scale application of solar energy systems. The need is to develop a next generation domestic energy model that includes the capabilities of counting CO_2 emissions from individual dwellings and aggregating them on an urban scale, enabling it to evaluate the potential for domestic CO_2 emission reductions from a whole range of measures on both the demand and supply sides of energy. The Domestic Energy, Carbon counting and carbon Reduction Model (DECoRuM) developed in this study has an additional unique feature of assessing the cost-benefits of various CO_2 reduction measures and putting a financial cost to CO_2 emission reduction.

DEVELOPING DECoRuM

DECoRuM is a GIS-based domestic energy, carbon-counting and carbon-reduction model, which has been applied by the author in Oxford as a case study (Gupta, 2007). In 2006, DECoRuM research was awarded the Royal Institute of British Architects' President's medal for outstanding research. Technically, DECoRuM model estimates and maps baseline energy use and CO_2 emissions on a house-by house level, identifies 'pollution' hotspots, predicts the potential for reductions in CO_2 emissions and monitors reductions achieved as a result of deploying energy efficiency measures and renewable energy systems on an urban scale. Also, it has an additional unique feature of assessing the cost-benefits of various CO_2 reduction measures and putting a financial cost to CO_2 emission reduction (£/tonne of CO_2 saved).

The physically-based annual version of Building Research Establishment's domestic energy model, BREDEM-12, combined with the government-approved Standard Assessment Procedure (SAP) 2005 home energy rating methodology, are the underlying energy models in DECoRuM, which calculate annual energy use, fuel costs and CO_2 emissions resulting from space heating, water heating, cooking, lights and appliances, as well as a SAP energy rating (scale of 1 to 100), which is based on calculated annual energy cost for space and water heating for a dwelling (Anderson et al., 2002). The net annual cost (NAC) method is chosen to assess the cost-effectiveness of deploying individual CO_2 reduction measures. Microsoft Excel dynamically linked to the Geographical Information System (GIS) software, MapInfo, are the operating platforms for DECoRuM. The GIS software is the user interface.

Estimating baseline energy use and CO_2 emissions

Although, BREDEM-12 is a reputable, validated model, which performs calculations rapidly and at a level of detail appropriate to city planners, the quantity of input data (95 parameters) it requires, is not easy to obtain in practice, owing to the high cost of detailed on-site surveys. This poses problems for energy modelling on an urban scale. In DECoRuM, to overcome the problem of data collection, data reduction techniques have been developed to enable most of the dwelling-related data required by the underlying energy models to be supplied from traceable sources. Data reduction techniques classify the 95 input data parameters required by BREDEM-12 (linked to SAP model) into 4 categories, according to the source of data. Category 5 includes data to be collected for estimating the solar potential of dwellings . The categories along with the number of dependent parameters are listed in Table 1.

TABLE 1 List of categories used for data reduction in DECoRuM

NO.	CATEGORY USED FOR DATA REDUCTION	NUMBER OF PARAMETERS	PERCENTAGE
1.	Data common to all dwellings	50	52.7%
2.	Data derived from built form	5	5.3%
3.	Data derived from age	18	19.0%
4.	Data to be collected for individual dwellings	22	23.0%
	TOTAL (BREDEM-12 calculation)	**95**	**100%**
5.	Data collected for estimating the solar potential	4	

The data for categories 1, 2 and 3 are derived from a range of secondary sources including traceable national statistics, UK Building Regulations, BRE reports, English House Condition Survey (EHCS) 2001, and locally relevant Home Energy Survey Forms, while data for categories 4 and 5 are obtained from primary sources, which include a GIS urban map and walk-by survey. For example, the five input parameters derived from the built form of the dwelling include roof area, ground floor area, external wall area,and window area for zone 1. The window area of zone 2 is also derived from the built form itself.

Similarly, 18 input prarameters primarily about construction including U-values and building services' details are derived from the dwelling's age. Some of the key inputs are height of storeys, wall construction type, U-values of walls, ground floor, and roof; primary and secondary space heating fractions, efficiencies and responsiveness; efficiency of the hot water system if separate, type and thickness of hot water tank insulation, insulation of primary pipe-work and presence of hot water cylinder thermostat. The dwelling age also determines the sealing of the loft hatch and number of open chimneys and fans.

As a result of the data reduction techniques, only one-fifth of the data items required for a BREDEM-12 calculation need to be collected for individual dwellings in a case study, and only one-tenth are to be collected by a walk-by survey. Results of energy use, CO_2 emissions, fuel costs and SAP energy ratings can be displayed in the form of thematic maps in MapInfo GIS, with an individual dwelling displayed as the basic unit of resolution. This helps to pinpoint hot spots of energy use and CO_2 emissions. Also, in the GIS map, through *hot links,* digital images of street-facing façades of dwellings can be presented to get an idea of their construction (Figure 3).

Validation of BREDEM models in DECoRuM

Tests were required to show that the enhanced BREDEM-12 and SAP models in DECoRuM were producing results identical to those obtained using the equations given in the BREDEM-12 and SAP documents (Anderson et al., 2002). These should demonstrate whether DECoRuM was a faithful interpretation of the algebraic formulation, and give confidence in the results generated by DECoRuM. The ability of BREDEM-12 equations to estimate accurately the energy consumption of real dwellings was not of primary concern, since validation exercises aimed at proving the absolute accuracy of BREDEM-12 in relation to dynamic simulation models and real dwellings have been discussed elsewhere (Dickson et al., 1996).

Table 2 Comparison of present annual energy use estimated by DECoRuM and NHER Evaluator for a 1930s semi-detached house

	DECoRuM	**NHER EVALUATOR**
	Annual energy use (GJ/year)	
Space heating	68.12	70.5
Water heating	20.98	21.0
Lights and appliances	11.10	6.5
Cooking	4.78	8.5
TOTAL	**104.98**	**106.5**
Difference (from NHER)	*-1.5%*	
Mean temperature in zone 1	18.52°C	18.5°C
Mean temperature in zone 2	16.89°C	16.9°C
SAP rating	51	52

It should be noted that at each stage of the incorporation of BREDEM-12 and SAP into DECoRuM, the algorithms were checked with the BREDEM-12 and SAP 2005 documents. Subsequently, in order to test the correctness of the enhanced BREDEM-12 and SAP 2005 versions in DECoRuM, inter-model comparisons were made between results obtained from DECoRuM, and those from BREDEM-12 in NHER Evaluator (version 3.3), software used widely by local authorities to produce energy ratings for dwellings. Identical data sets for ten different dwellings (covering a range of built forms, insulation levels, heating systems and heating regimes) were entered into the calculation models. The average agreement for the ten dwellings is 3 GJ of energy consumption or +2%. One of the comparisons for a 1930s semi-detached house is shown in detail in Table 2.

In Table 2, the estimate of total annual energy consumption for the 1930s semi-detached dwelling by DECoRuM is 1.5% less than estimated with the NHER Evaluator. This is because the version of the NHER Evaluator used for validation is based on the BREDEM-12 model developed in 1996, whereas the BREDEM-12 version in DECoRuM is based on the most up-to-date BREDEM-12 model, released in 2001. However, there is almost no difference between the mean internal temperatures of zones 1 and 2 obtained from DECoRuM and those from the NHER Evaluator.

However this type of test has the disadvantage that the whole model is tested; it is possible that good agreement could be obtained although cancelling errors are present. This is why further confidence in the correctness of the BREDEM-12 version in DECoRuM was sought and achieved by performing sensitivity tests on specific data input parameters. This second type of test has the advantage that particular aspects of a model's performance can be checked, thereby addressing the possibility of cancelling errors. Thus the two types of test complement one another, and together provide a balanced approach to assessing the performance of the model (Dickson et al., 1996, p. 135). As part of the sensitivity tests, changes to the key parameters of element U-values, space and water heating system efficiencies, zone demand temperatures and heating regimes all produced the expected effects. Fabric U-values of a typical UK dwelling (1930s semi-detached) were improved theoretically to good practice, best practice and advanced energy efficient standards.

Similarly, using a more efficient gas-condensing boiler reduced the total energy consumption by reducing space and hot water heating energy uses. Increasing the zone demand temperatures by 2°C increased overall energy consumption and specifically space heating energy use. Although these comparisons do not test correctness of every equation, they build further confidence in the overall estimates obtained from DECoRuM. Therefore, given these results, it was concluded that the BREDEM-12 and SAP versions in DECoRuM are acceptably accurate for use in this study.

DECoRuM CO_2 reduction and cost-benefit model

A wide range of literature was reviewed and the following measures were identified for reducing domestic CO_2 emissions on the demand and supply side of energy. These CO_2 reduction measures are listed in Table 3.

TABLE 3 List of measures embedded in DECoRuM to reduce domestic CO_2 emissions

DEMAND SIDE MEASURES	SUPPLY SIDE MEASURES
Roof insulation	Ground-source heat pumps
Cavity wall insulation	
Solid wall insulation: internal	Domestic micro-CHP units
Solid wall insulation: external	
Floor insulation: 100 mm	Passive solar: conservatory
Low-e double glazing	
Full draught proofing	Solar hot water systems
Hot water cylinder insulation	
Primary pipe-work insulation	Solar PV systems (1 kWp)
Draught lobby	
Condensing boilers	Green tariff electricity
Improved heating controls	
Energy efficient lighting	
Energy efficient refrigerators	
Energy efficient fridge/freezers	
Energy efficient freezers	
Efficient washing machines	
Energy efficient tumble dryers	
Energy efficient dishwashers	
Energy efficient televisions	

For these measures to be incorporated in DECoRuM, the baseline energy model is used to filter suitable dwellings for every CO_2 reduction measure by use of appropriate criteria. Subsequently, for the 'passed' dwellings, the measure is incorporated in their baseline energy models using appropriate procedures to quantify the energy savings and reductions in CO_2 emissions that occur on an individual dwelling level, and also aggregated to an urban scale. This approach developed in DECoRuM is presented in Figure 1.

Depending upon the measure, the filtering criteria and procedures are derived from field trials, laboratory experiments, theoretical calculations, or from a realistic mixture of these (Shorrock et al., 2001). For instance, in case of solar hot water systems, dwellings with roof orientation lying between ±45° of south (Northern Hemisphere), roof inclination lying between 0^o and 60^o and roof area $>3.9m^2$ are selected. When insulation-related energy efficiency measures are run in DECoRuM, the procedure is to change the appropriate U-values and ventilation rate; a more detailed calculation is performed to quantify the potential for solar hot water yield of the selected dwellings (BRE, 2004, p. 46). The results are displayed in GIS in the form of thematic maps.

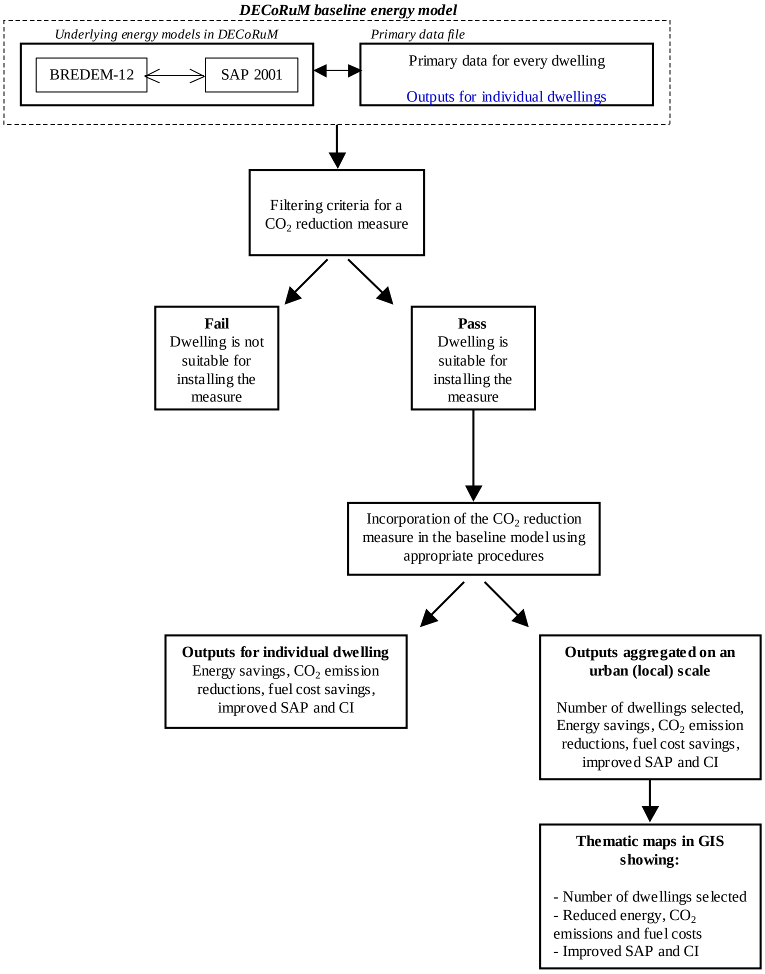

Figure 1 Approach for assessing CO_2 reductions in DECoRuM

The net annual cost (NAC) methodology is incorporated in DECoRuM as the cost-benefit model to assess the cost-effectiveness of individual CO_2 reduction measures. The cost-effectiveness is assessed for high and low capital costs, with the expectation that in most circumstances, the real figure would lie somewhere between them. This cost-benefit model requires standard input parameters relating to typical capital costs per dwelling for installing a measure, lifetime of the measure, the cost and CO_2 emission factor of the fuel displaced, as well as case-study-specific parameters. One of the key results of using the DECoRuM cost-benefit model is that the *net annual cost per tonne of CO_2 emissions saved* can be derived, and used to assess the cost-effectiveness of that measure. A measure is taken to be cost-effective if the NAC is negative; the larger its absolute value, the more cost-effective that measure is. The DECoRuM cost-benefit model also gives the *cost for reducing a tonne of lifetime CO_2 emissions* by using one or a combination of measures.

APPLYING DECORUM TO OXFORD CASE STUDY

DECoRuM was applied to a case study area in Oxford city covering approximately 318 dwellings, to demonstrate and validate its capabilities. The case study dwellings contained all the built forms and age-bands present in UK housing, although in different proportions from those of the national stock. Data for individual dwellings was derived from GIS urban map, local authority records and walk-by surveys.

The DECoRuM model calculated the baseline energy consumption and associated CO_2 emissions for every dwelling in the case study area (318 dwellings) and aggregated them together to give a total baseline energy consumption figure of 49,699 GJ/year and total CO_2 emissions of 3,026 tonnes/year. A thematic map is created in MapInfo GIS, showing the estimate of baseline total annual CO_2 emissions from every dwelling (Figure 2). The dwelling footprints in red and pink indicate hotpots of CO_2 emissions.

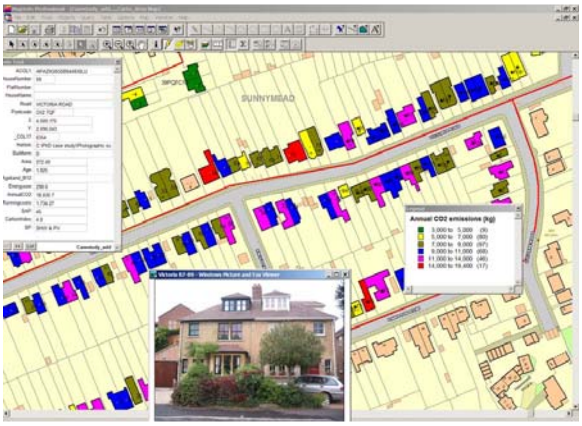

Figure 2 Thematic map showing total annual CO2 emissions from the Oxford case study dwellings.

As expected, space heating consumed the most energy (61%), producing 55% of the total CO_2 emissions, and was responsible for 44% of the total running costs. The breakdown of baseline results according to the different built forms showed that mid-terraced dwellings in the case study had the highest average SAP rating at 47.9 and the lowest average fuel cost of £657/year, while bungalows (open from all 4 sides) had the lowest SAP rating of 36.3.

When the baseline figures of the case study were broken down by age group, as expected, dwellings built between 1996 to 2002 had the highest average SAP rating of 90.3 and the lowest running costs of £676/year. On the other hand, pre-1930 dwellings have the lowest average SAP rating. Furthermore, SAP ratings increased as the dwellings got more recent (Figure 3).

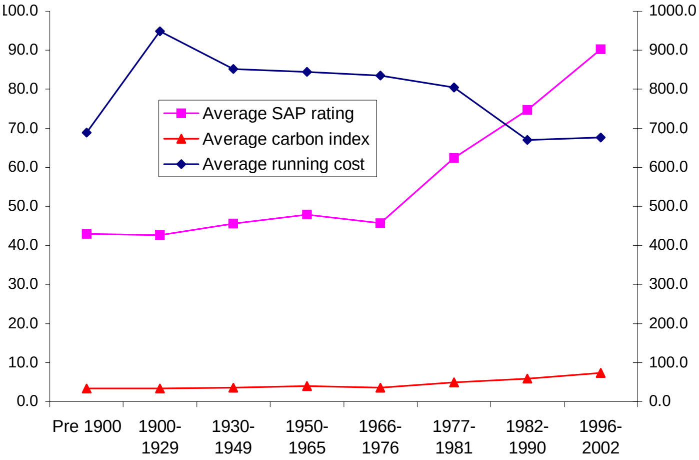

Figure 3 Distribution of SAP rating and annual running cost by age band in the Oxford case study

These results were extensively validated by comparisons with national and city-level statistics, as well as with case-study-specific databases. This instilled confidence in the predictions from DECoRuM, and built the case for extrapolation of findings from the case study to the national level. Each CO_2 reduction measure embedded in DECoRuM was then applied individually in the case study, using appropriate filtering criteria to select the most suitable dwellings (Figure 4). The corresponding savings in total annual energy use, total annual CO_2 emissions, fuel costs, and improvement in SAP ratings were calculated.

Figure 4 Estimating the solar potential of dwellings in North Oxford using DECoRuM

Results indicated that external solid wall insulation saved the most energy, CO_2 emissions and fuel costs in the case study dwellings. The cost-benefits of applying these measures were evaluated at 2001 fuel prices, and it was shown that measures which were the most cost-effective did not necessarily save the most CO_2 emissions. Energy-efficient appliances, for instance, have considerable savings in expenditure only when installed collectively. However, hot water cylinder insulation, replacement with condensing boilers, roof insulation and cavity wall insulation appeared to be cost-effective in any circumstance (low capital cost and high capital cost scenario), and this justifies the wide promotion they have received over the years. While domestic micro-CHP units appeared to be cost-effective in any circumstance, GSHP systems emerged as cost-effective only when government grants were included. Solar hot water and solar photovoltaic (PV) systems were not cost-effective at current prices. Although the simple payback period for a 1-kWp solar PV system reduced to 30 years from 95 years if government grants were included and if it was assumed that domestic PV systems qualified for selling Renewable Obligation Certificates (ROCs) to energy suppliers.

The overall potential for reducing CO_2 emissions from the case study dwellings was then predicted. Five alternative packages were developed, using a combination of energy efficiency measures, low carbon technologies, solar energy systems and green tariff electricity.

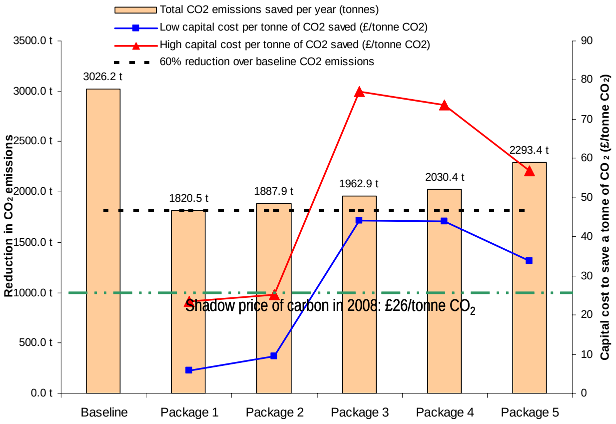

Figure 5 Estimating the solar potential of dwellings in North Oxford using DECoRuM

The analyses showed that reductions in excess of 60% were possible from the case study dwellings at a cost of between £6/tonne of CO_2 - £77/tonne of CO_2 emissions saved. This cost depended upon the package of measures used, and the scenario of capital costs (low or high) employed. These figures compared favourably with the UK's estimated social cost of CO_2 emissions (£26/tCO_2). Cost-effective savings of 2,044 tonnes of CO_2 emissions per year were estimated for the case study dwellings. This is equivalent to 67.5% reductions of CO_2 emissions over baseline if green tariff electricity is included and 57% if it is not. This indicated a total expenditure of between £0.4 million and £1 million as currently necessary to install all the cost-effective CO_2 emission reduction measures in all the case study dwellings. The DECoRuM model was then used in Oxford to undertake targeted marketing to increase the uptake of the energy efficiency measures and solar energy installations (Roaf et al., 2002).

In DECoRuM, the investigation of potential CO_2 emission reductions is based on static analysis. This means that it is assumed that all the measures could be applied to the selected dwellings immediately, without considering a time dimension or uptake rates. This may indicate overall savings higher than could be achieved in practice, due to the time taken to reach a particular policy goal. However, it does permit meaningful comparisons to be made between measures, allowing them to be ranked according to potential CO_2 emission savings and cost-effectiveness, important for policy decision-making. This is particularly important in selecting measures that local authorities could promote for maximising CO_2 emission reductions.

EXTRAPOLATION TO UK HOUSING STOCK

The extrapolation of CO_2 emission savings from the case study dwellings to the UK housing stock, taking into account the different proportions of dwelling built-forms in the case study and UK housing stock, showed that there was a large potential for CO_2 savings. Overall, a potential for saving about 92MtCO2 or 25MtC per year was identified. This is equivalent to a reduction of 66% relative to UK housing stock CO_2 emissions in 2000, at a capital cost of £150 billion to £234 billion Although the cost of reducing emissions from the UK housing stock in the near future seems considerable, it seems preferable to the damage from climate change that will otherwise be incurred at a more distant date, estimated to cost around £200 billion of assets as a result of flooding and coastal erosion (EST, 2004). Therefore, though it is indeed important to put a financial cost to emission reductions, it is essential that CO_2 emissions be reduced to help avoid the worst impacts of climate change for the survival of the mankind itself.

CONCLUSIONS

This paper has described the development, demonstration and validation of a domestic energy model. The model is likely to be of significant use to planners in local authorities and energy advisers for evaluating energy consumption in, and CO_2 emissions from, the UK housing stock and the cost of a range of measures to reduce both. DECoRuM could be in applied to any city in the UK, and the principles of data reduction for urban energy modelling could be extended overseas too.

In fact further development of DECoRuM model has been funded as a 'proof of concept' to be used as a toolkit for carbon emission reduction planning for use by UK local authorities to report, monitor and improve the energy efficiency of both public and private housing (see: www.decorum-model.org.uk).

Principles of DECoRuM model have been applied to non-domestic buildings (University Campuses) and discussions are ongoing to set up a formal partnership with an aerial digital image provider to carbon map the entire UK housing stock using DECoRuM.

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REFERENCES

Anderson, B. R., Chapman, P. F., Cutland, N. G., Dickson, C. M., Henderson, G., Henderson, J. H., Iles, P. J., Kosmina, L. & Shorrock, L. D. (2002) *BREDEM-12 model description,* Watford, Building Research Establishment.

Bre (2004) *The Government's Standard Assessment Procedure for energy rating of dwellings. Draft 2005 edition,* Watford, Published on behalf of DEFRA by BRECSU, Building Research Establishment.

Commission of the European Communities (2006) *Action Plan for Energy Efficiency: realising the Potential,* Brussels, European Commission.

Decc (2009a) *Community energy saving programme (CESP),* Consultation, London, Department of Energy & Climate Change

Decc (2009b) *Heat and energy saving strategy,* Consultation, London, Department of Energy & Climate Change

Dickson, C. M., Dunster, J. E., Lafferty, S. Z. & Shorrock, L. D. (1996) Testing monthly and seasonal versions against measurements and against detailed simulation models. *Building Services Engineering Research & Technology,* 17**,** 135-140.

Est (2004) *Forecasting the future: changing climate changing behaviour,* London, Energy saving Trust.

Foresight Sustainable Energy Management and the Built Environment Project (2008) *Powering our lives: sustainable energy management and the built environment,* Final Project Report, London, The Government Office for Science.

Gadsden, S., Rylatt, M. & Lomas, K. (2003a) Putting solar energy on the urban map: a new GIS-based approach for dwellings. *Solar Energy,* 74**,** 397-407.

Gadsden, S., Rylatt, M., Lomas, K. & Robinson, D. (2003b) Predicting the urban solar fraction: a methodology for energy advisers and planners based on GIS. *Energy and Buildings,* 35**,** 37-48.

Gupta, R. (2007) A review of initiatives to reduce energy-related CO2 emissions from the city of Oxford: Past, Present and Future. *ECEEE 2007 Summer study proceedings volume 1.* Côte d'Azur, France, 4-9 June 2007, ECEEE.

Ipcc (2007) *Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Geneva, IPCC.

Jones, P., Williams, J. & Lannon, S. (2000) Planning for a sustainable city: an energy and environment prediction model. *Journal of Evironmental Planning and Management,* 43**,** 855-872.

Roaf, S., Fuentes, M. & Gupta, R. (2002) Solar Cities: The Solar Oxford Initiative. *Creating Sustainable Urban Environments: future forms for city living.* Christ Church College, Oxford, Oxford Centre for Sustainable Development, Oxford Brookes University.

Rylatt, M., Gadsden, S. & Lomas, K. (2003) Using GIS to estimate the replacement potential of solar energy for urban dwellings. *Environment and Planning B: Planning and Design,* 30**,** 51-68.

Shackley, S., Fleming, P. & Bulkeley, H. (2002) *Low carbon spaces area-based carbon emission reduction: a scoping study,* A report to the Sustainable Development Commission prepared by the Tyndall Centre for Climate Change Research.

Shorrock, L. D. & Dunster, J. E. (1997) The physically based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioixde emissions of the UK housing stock. *Energy Policy,* 25**,** 1027-1037.

Shorrock, L. D., Henderson, G., Utley, J. I. & Walters, G. A. (2001) *Carbon emission reductions from energy efficiency improvements to the UK housing stock,* Watford, Building Research Establishment and Department for Environment, Food and Rural Affairs.

Stern, N. (2006) *The Economics of Climate Change,* The Stern Review, Cambridge, Cambridge University Press.

Urge-Vorsatz, D., Harvey, L. D. D., Mirasgedis, S. & Levine, M. D. (2007) Mitigating CO2 emissions from energy use in the world's buildings. *Building Research and Information,* 35(4)**,** 379-398.