Applying CO_2 reduction strategies to existing UK dwellings using GIS-based modelling: a case study in Oxford

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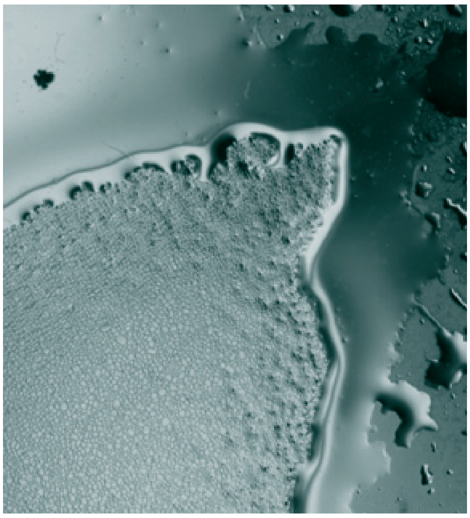

Sixty second summary

The 1990s was the warmest decade on record globally, with 1998 being the warmest year ever recorded over the 142 years in which global temperature records have been kept. Records over a longer period from other sources show a similar picture. Allowing this trend to continue brings with it the potential for catastrophic change, and the response to global warming will be one of the defining challenges that society, governments and industry face in the twenty-first century. In 2000, the UK government Royal Commission on Environmental Pollution called for a 60% cut in carbon dioxide (CO_2) emissions in the UK by 2050 and an 80% cut by 2100, relative to 1998 levels. This is a challenging target, and if they are to be achieved, then there is an immediate need to evaluate which are the most effective measures for reducing energy-related CO_2 emissions. For industrialised countries such as UK, buildings account for almost 50% of energy use, with consequent impact on climate change, and related CO_2 emissions that are driving climate change – they are an obvious area where we can seek to bring about change.

This research, carried out by Dr Rajat Gupta at Oxford Brookes University, has developed DECoRuM, a tool which brings together Geographic Information System (GIS) techniques and energy efficiency measures to identify and measure potential strategies to reduce CO_2 emissions in housing. Applying DECoRuM to a case study area in Oxford enabled the identification of those measures which are most cost-effective and which make the greatest contribution to reducing CO_2 emissions. It showed that it is possible to achieve cost-effective annual CO_2 savings of at least 45% of the baseline emissions, which increases to over 50% with the inclusion of solar systems. Local authorities could make great use of DECoRuM to more effectively plan their energy efficiency campaigns and to assess progress against targets. The adoption of DECoRuM could make a real difference to our ability to meet the challenging emissions reduction targets that are necessary if we are to respond to the challenge of climate change.

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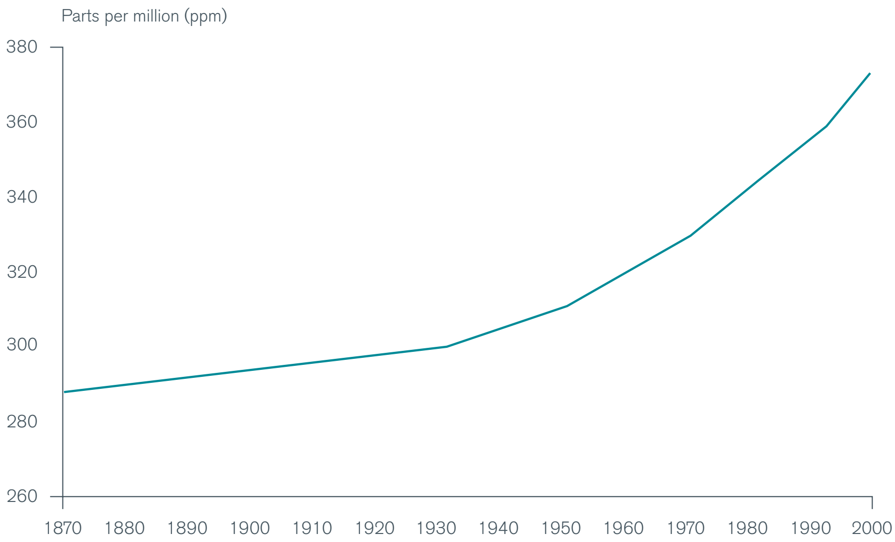
Introduction

Climate change has moved from being the concern of a few to a widely recognised threat to the natural environment and to humanity itself. Global temperature has increased by 0.6°C in the last 100 years, with about 0.4°C of this warming occurring since the 1970s. The 1990s were the warmest decade on record and ever-increasing atmospheric levels of greenhouse gases such as CO_2, could, if left unchecked, lead to serious consequences globally, including increased risks of droughts, floods and storms, disruption to agriculture, rising sea levels and spread of disease. Figure 1 shows the global trend in CO_2 levels in the atmosphere from 1870 to 2000 – the trend is clear.

The contribution of CO_2 emissions resulting from human activity is now recognised as the principal cause of the atmospheric changes that drive these climate trends. On an international level immediate and long term targets recognise the need to drastically cut the emissions of CO_2 to stabilise its atmospheric concentrations in order to avoid the worst impacts of climate change.

Globally, energy use in buildings is the largest source of indirect CO_2 emissions. In most industrialised countries, including the UK, the energy use in the housing sector contributes substantially to national CO_2 emissions and is directly responsible for just under 30% of the UK's total CO_2 emissions. If we are to achieve a reduction in CO_2 emissions, then the housing sector is a good place to look – cuts in housing sector CO_2 emissions are both achievable and necessary. However, CO_2 emissions vary greatly from area to area and, indeed, house to house. A study carried out in February 2006 by Best Foot Forward for British Gas highlighted the huge variation – houses in Uttlesford, Essex produce 8 092 kg of CO_2 each year, making them the highest producers of CO_2 in the UK – and more than double the figure for houses in Camden in London, which on average produce just 3 255 kg of CO_2.

Figure 1 Global atmospheric concentration of CO_2



Sources: Mauna Loa Observatory, Hawaii, T P Whorf, Scripps Institution of Oceanography, University of California, La Jolla, 1999

This dramatic variation could be explained by different housing types in the two areas. This raises a key question – how can we best target our efforts? This is a particularly important question for local authorities in trying to implement and monitor energy saving initiatives at the town and city level. This research aimed to develop a model to assist local authorities in identifying and evaluating the most effective measures for reducing energy-related CO_2 emissions from the existing UK housing stock. The focus was on existing housing, as they will still form 75% of the UK housing stock in 2050. The main energy-saving measures identified were:

1. Roof insulation.
2. Cavity wall insulation.
3. Solid wall insulation.
4. Hot water tank insulation.
5. Draught-proofing.
6. Low-energy double-glazing.
7. Condensing boilers.
8. Solar hot water systems.
9. Solar PV systems.

The first step in using the model is to calculate the baseline energy consumption of houses, in order to provide the benchmark against which the effect of these energy efficiency measures and solar energy technologies can be compared.

Related urban energy models

There have been a number of initiatives to predict energy use in houses – these are summarised in Table 1. Most of these use either a monthly or an annual version of the BRE Domestic Energy Model (BREDEM), a de facto industry standard.

Table 1 A summary of key characteristics of the urban energy models.

	BREHOMES[1]	DREAM[2] -city	EEP[3] model	NHER[4] software	CCP[5] model	SEP[6] system
Area of application	UK	City	Postcode area within city for the domestic sub-model	Stock analysis down to individual buildings	City	Individual dwellings aggregated to city level
Energy use sectors	Domestic	Domestic, Non-domestic, Industry, Transport	Domestic, Non-domestic, Industry, Transport	Domestic	Domestic, Non-domestic, Industry, Transport	Domestic
Data sources	National statistics	Regional statistics	Map-derived data, rapid site surveys, defaults based on global assumptions	National statistics, rules of thumb, questionnaires, rapid/detailed site surveys	City-level data from utility companies	Map-derived data, rapid site-surveys, defaults from national statistics
Outputs	Annual: energy use	Monthly: energy use, fuel use, CO_2 emissions	Annual: energy use, SAP ratings, CO_2 emissions, running costs	Annual: energy use, CO2 emissions, SAP, NHER, running costs	Annual: energy use, CO_2 emissions	Monthly: energy use, CO_2 emissions
Use of GIS	None	None	Yes, MapInfo	None	None	Yes, MapInfo
Developer	BRE	Energy & Environment Research Unit, Open University	Welsh School of Architecture, Cardiff University	National Energy Services Limited	Torrie Smith Associates	Institute of Energy & Sustainable Development, DeMontfort University
Users	Department for Food, Environment & Rural Affairs	Local Authorities – Leicester, Milton Keynes	Welsh local authorities – Neath Port	Local authorities	24 UK local authorities	Development just completed
Solar energy technologies	None	None	None	None	None	Passive solar, SHW and PV
Energy efficiency	None	None	Some	Some	None	None

1 Building Research Establishment Housing Model for Energy Studies
2 Dynamic Regional Energy Analysis Model
3 Energy and Environmental Prediction
4 National Home Energy Rating
5 Cities for Climate Protection
6 Solar Energy Planning

A key problem in urban energy modelling is data collection, and each model addresses this issue in a different way. The NHER and SEP models are the only ones that allow energy use to be predicted at various levels of data input. The model developed in this research needed to be able to use the data reduction techniques of these models to derive input data from a range of sources, such as national and city-wide statistical data. Primary data collected through walk-by surveys is needed only for the most sensitive input parameters. It was important to develop the model so that it could use detailed data from individual property surveys where possible. It should also include a package of energy efficiency as well as solar technologies, with their cost benefits, since this aspect has not been addressed holistically by any existing urban energy model.

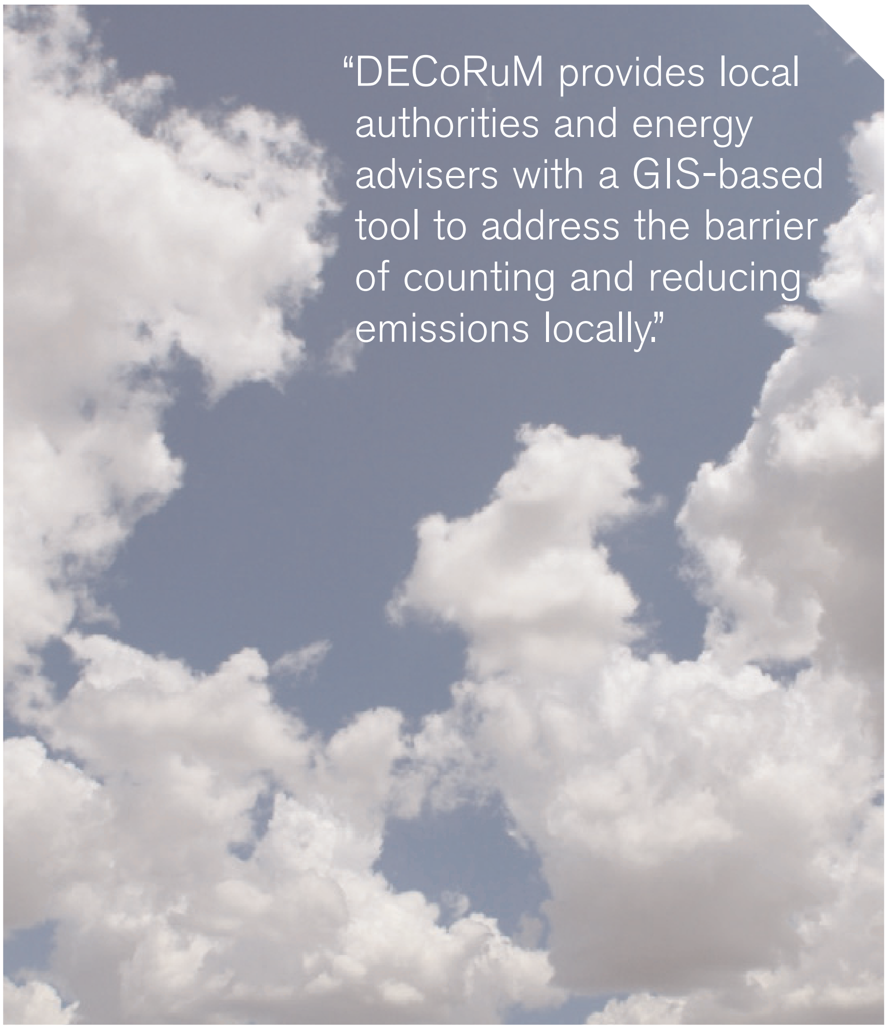
The DECoRuM tool

This research has developed the DECoRuM Model – the Domestic Energy, Carbon Counting and Carbon Reduction model. What is new about DECoRuM? The key innovative feature of DECoRuM is its capability to estimate baseline CO_2 emissions from individual dwellings using a combination of locally-relevant approach and well-established methodologies, to ensure credibility. It can then aggregate these to an urban scale – street, district or city level. This enables DECoRuM 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. A mapping tool within DECoRuM represents the baseline domestic CO_2 emissions and potential reductions. An additional and unique feature is that DECoRuM assesses the cost-benefits of individual CO_2 reduction measures and puts a financial cost to CO_2 emission reduction. As Rajat Gupta says, "DECoRuM provides local authorities and energy advisers with a GIS-based tool to address the barrier of counting and reducing emissions locally."

DECoRuM uses the annual version of the Building Research Establishment Domestic Energy Model (BREDEM-12) linked to Standard Assessment Procedure (SAP) to estimate annual energy use, running costs and CO_2 emissions from space heating, water heating, cooking, lights and appliances.

In DECoRuM, data reduction techniques have been developed to enable most of the dwelling-related data required by the underlying energy model to be supplied from traceable sources. The data that is needed is broken down into five categories, according to the source of data:

1. Data common for all dwellings.
2. Data derived from built form of the dwelling.
3. Data derived from age of the dwelling
4. Primary data collected for individual dwellings.
5. Data collected for estimating the solar potential.



The data sources include a GIS urban map, authoritative reports by BRE, English House Condition Survey 2001, standard default values and a walk-by survey. The model then generates thematic maps in MapInfo GIS, in order to display the results of energy use, CO_2 emissions, running costs and an energy rating for every dwelling. This helps to pinpoint hot spots of energy use and CO_2 emissions. 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. It is then possible to create comparisons with other models, such as the NHER evaluator, using data sets for ten different dwellings. There only seem to be minor difference in the results, which suggest that the results from the DECoRuM model are reliable.

This, then, tells us the current energy use and CO_2 emissions. The next step is to identify what scope for improvement exists, looking at the various options available. Of course, not every option makes sense in every house – the model uses filtering criteria to select the most suitable houses and discard the most unpromising candidates. For instance, in case of solar hot water systems, houses with roofs that face south (plus or minus 45°), a roof pitch between 0° and 60° and roof area greater than 9 m^2 are selected. The model then displays the results in GIS in the form of thematic maps.

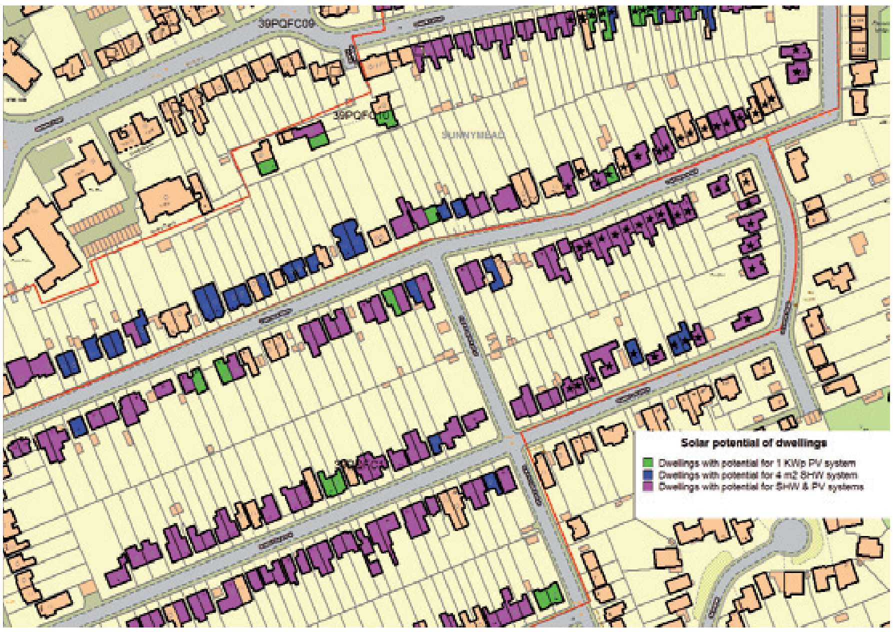
Potential for CO_2 reduction: Oxford case study area

What does the model reveal? The researchers applied it to a representative case study area in Oxford, containing 318 dwellings. The data for the individual dwellings is derived from GIS urban maps, local authority records and walk-by surveys. The DECoRuM tool then calculates the baseline energy consumption and associated CO_2 emissions for all 318 dwelling in the case study area and adds them to give a total baseline energy consumption figure of 49 699 GigaJouoles per year and total CO_2 emissions of 3 026 tonnes per year. A thematic map is then created in MapInfo GIS, which shows the predicted baseline total annual energy consumption for every dwelling. This is shown in figure 2.

These estimates of energy use, CO_2 emissions and running costs for the houses in the case study area vary with the dwelling age and built form, with older dwellings having a much higher energy use while less exposed built forms such as mid-terrace have the least energy use. The researchers compared the figures produced by DECoRuM for baseline energy use with city-level and national statistics, and similar patterns are observed – it seems that the DECoRuM model is accurate. Estimates from DECoRuM also show that almost 72% of dwellings in the case study district in Oxford are suitable for installing 4m^2 solar hot water systems, while 75% are suitable for a 1kWp solar PV system. Figure 3 shows an example of the output maps produced by DECoRuM, this one indicating the solar potential of buildings in the case study area.

Figure 2 Total annual CO2 emissions from dwellings in the Oxford case study area

Figure 3 Solar potential of dwellings in the Oxford case study area



Once the baseline energy and emissions figures have been calculated, it is then possible to apply the various CO_2 reduction strategies. This allows meaningful comparisons to be made between different measures in terms of CO_2 savings and cost-effectiveness.

So, what seem to be the best measures? It seems that hot water cylinder insulation appears to be the most cost-effective measure, followed by cavity wall insulation and condensing boilers. Even topping-up roof insulation, low-e double-glazing and full draught proofing seem to be cost-effective. By contrast, solar hot water and solar photovoltaic systems seem – in isolation – to be quite expensive technologies despite the large savings in CO_2 emissions. Solid wall insulation saves the most CO_2 emissions, followed by condensing boilers. An interesting finding is that measures which are the most cost-effective do not necessarily save the most CO_2 emissions. The total cost-effective CO_2 reductions are about 1 361 tonnes per year, or a saving of 45% of the baseline figure.

If all the CO_2 reduction measures (including energy efficiency and solar systems) considered in the research were applied in the Oxford case study district, a total annual energy saving over the baseline figures of 26 844 GJ/year and CO_2 reductions of 1 504 tonnes/year are possible. This implies a CO_2 emission reduction of almost 50% over baseline emissions. The total capital cost for installing all the measures is calculated to be around £1.8 million to £3 million.

Conclusion

The DECoRuM tool can be used to investigate the potential for domestic CO_2 emission reductions. Applying the DECoRuM tool to the case study area has enabled us to identify the measures which are most cost-effective, and those that are most effective in reducing CO_2 emissions. The following measures seem to be cost-effective in both low and high capital cost scenarios:

- Hot water cylinder insulation
- Cavity wall insulation
- Replacement condensing boilers
- Low-e double glazing (in comparison with single glazing)
- Roof insulation: top-up from 50/75mm to 250 mm.

Based on the case study area, it is possible to make cost-effective annual CO_2 savings of about 1 300 tonnes of CO_2 corresponding to a 45% reduction over baseline emissions. This increases to over 50% with the inclusion of solar systems. Although solar hot water and PV systems are not cost-effective at present, the policy should be to install solar systems in tandem with energy efficiency measures to bring down capital costs and reduce CO_2 emissions. This is going a long way to achieving our targets. It could provide a GIS-based toolkit to enable local authorities to develop a carbon reductions planning capability:

- to develop GIS-based housing stock energy databases containing a unique record for every dwelling in the stock, with details of its energy efficiency and energy ratings
- to assess the energy efficiency of the whole or part of their housing stock and set targets for improvements and to monitor progress towards those targets
- to estimate baseline energy and potential CO_2 emission reductions from an individual dwelling, a street, a suburban area, a city or a region.

Applying the DECoRuM tool to the case study area has enabled us to identify the measures which are most cost-effective, and those that are most effective in reducing CO_2 emissions

About the study

Dr Rajat Gupta from Oxford Brookes University undertook this research as part of his doctorate which was awarded in May 2005. The project was supervised by Professor Susan Roaf, Professor John Raftery and Professor Fergus Nicol from Oxford Brookes University. The RICS Education Trust supported it financially, with additional support from Pilkington Energy Efficiency Trust and Oxford Brookes University.

Further reading

The full results of the DECoRuM work can be found in:

Gupta, R. (2005). Investigating the potential for local carbon emission reductions: Developing a GIS-based Domestic Energy, Carbon counting and Reduction Model (DECoRuM). Proceedings of the 2005 Solar World Congress. 6-12 August 2005, Orlando, Florida, USA.

Gupta, R. and Roaf, S (forthcoming). Developing locally-relevant domestic carbon emission reduction planning scenarios, Environment and Planning B.

Gupta, R., Raftery, J and Roaf, S (forthcoming). Using GIS-based modelling to estimate baseline energy use and CO2 emissions from UK dwellings on an urban scale. Energy and Buildings.

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