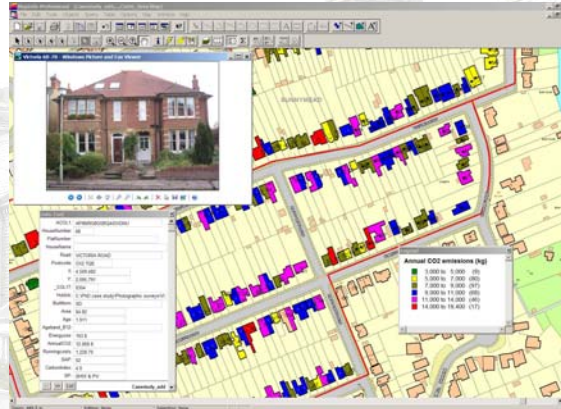


## Reducing carbon emissions: A GIS-based approach



Green retrofit for housing: make the most of what you've got

RIBA South East conference, 11<sup>th</sup> November 2008, Brighton

Dr Rajat Gupta, Reader

Department of Architecture, Oxford Brookes University  
rgupta@brookes.ac.uk



## Contents

Background to the study

Overview of DECoRuM®

DECoRuM: estimating baseline energy and CO<sub>2</sub> emissions

DECoRuM: predicting CO<sub>2</sub> emission reductions and cost-benefits

Application of DECoRuM to a case study in Oxford

Extrapolation to UK housing stock.

Benefits and applications of DECoRuM.



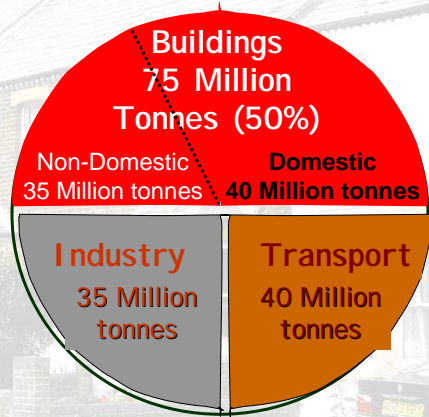


Recent paper: *Target CO<sub>2</sub>: Where should humanity aim?*

- 'Climate change - faster stronger sooner' than forecast by IPCC 2007 reports.
- NASA's Dr. James Hansen's et al. recent paper, ([http://www.columbia.edu/~jeh1/2008/TargetCO2\\_20080317.pdf](http://www.columbia.edu/~jeh1/2008/TargetCO2_20080317.pdf))
- Bar for acceptable levels of CO<sub>2</sub> in the atmosphere should be lowered to 350ppm, possibly lower, if we are to avert catastrophic climate change.
- We are currently at 385 ppmv and increasing at about 2 ppmv annually.

Buildings are a large part of the problem:  
decade on decade they use more energy

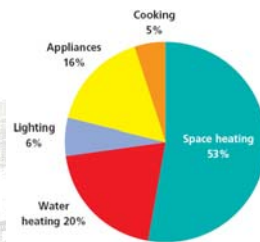
*Buildings can also rapidly  
change without pain!*



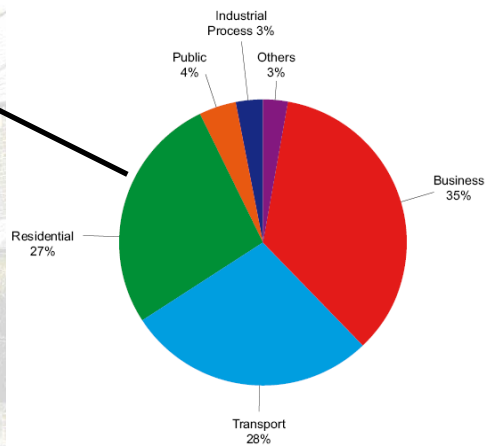
UK carbon emissions in 2000: 150 MtC

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CO<sub>2</sub> emissions from the UK housing sector are significant...



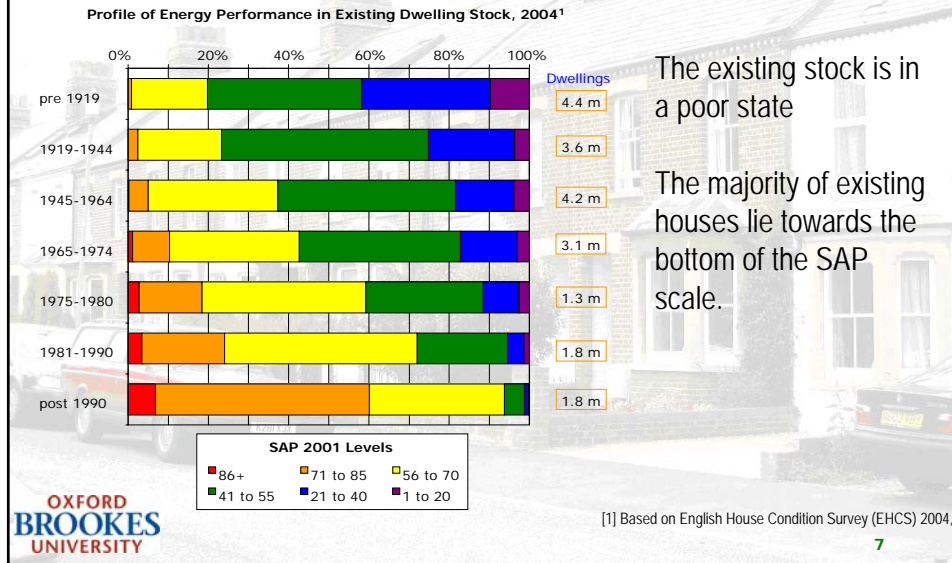
73% of household emissions  
arise from space and water  
heating, and 27% from lighting,  
appliances and cooking.



2006 CO<sub>2</sub> emissions by final user  
(Source: DEFRA (2008). 'e-Digest Statistics about: Climate Change')

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## Three-quarters of the housing stock was built before 1975 and has poor energy efficiency



## And since it is accepted that:

- Three-fourth of the domestic stock existing today will be present by 2050.
- Targeting new buildings (added <1% a year) will only limit the increase of CO<sub>2</sub>.
- Average existing house uses 4 times more energy to heat than a new-build home.



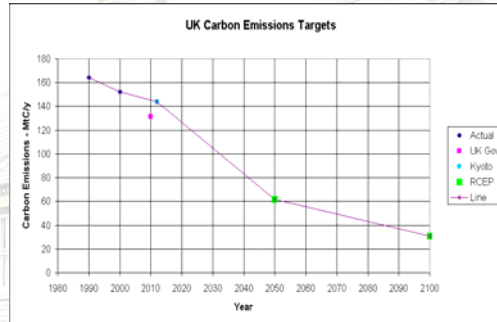
To reduce current levels of CO<sub>2</sub> emissions in the short or long term, existing domestic buildings need to be targeted first!

Domestic sector can also realistically accommodate radical reductions in emissions.

## Tougher targets ahead...

### UK's 80% target

On 28 October 2008, the UK Government approved a bill that includes a requirement to cut CO<sub>2</sub> emissions to 80% below 1990 levels by 2050. (Increased from 60%)



### UK Renewable energy target:

- EU energy policy - mandates that 15% of UK energy be sourced from renewables by 2020.
- RE is used in three sectors: heating and cooling, transport and electricity.
- Critical to meeting the UK's renewable energy targets will be the widespread deployment of micro-generation installations in housing.

UK CO<sub>2</sub> emission reduction targets

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## Targets for the UK housing stock

Government's National Energy Efficiency Action Plan – sets a target to reduce emissions from the UK's housing stock by 31% on 1990 levels by 2020. (Source: DEFRA, 2007, Energy efficiency action plan)

Recent UKGBC report explores how emissions could be reduced by 80% in the existing housing stock by 2050.

To feed into Government's 'Low Carbon Homes strategy': due in spring 2009.

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Report

October 2008

Low carbon existing homes



This report is a compilation of key messages and feedback from a wide range of expert stakeholders. It is designed to inform the development of Government's Low Carbon Homes strategy.

Supported by



CAMPAIGN FOR A SUSTAINABLE BUILT ENVIRONMENT

## Environmental Sustainability: National Indicators

Following consultation in 2007, the Government has issued a national indicator set (198) against which local councils will begin to report their performance from April 2008.

**NI 185**                      **Percentage CO<sub>2</sub> reduction from LA operations**

**NI 186**                      **Per capita CO<sub>2</sub> emissions in the LA area**

**NI 187**                      **Tackling fuel poverty - % of people receiving income based benefits living in homes with a low energy efficiency rating**

**NI 188**                      **Planning to Adapt to Climate Change**

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## Moreover Acts such as HECA 1995

- All UK local authorities to report annually about the energy efficiency of all housing stock and consider energy efficiency strategies.
- Success of HECA = identify individual properties which could benefit from energy efficiency measures, in addition to making citywide estimates.
- A consultation in 2007 on the future of HECA set out the Government's preference for the Act to be repealed.
- However a final decision on the future of HECA will be taken by autumn 2008.
- **PROBLEM:** In reporting and monitoring effectiveness of energy efficiency measures there is a lack of consistent, publicly available tools and methods for calculating the potential carbon savings.

+

**Growing need to estimate the potential for using low/zero carbon systems on a citywide scale.**

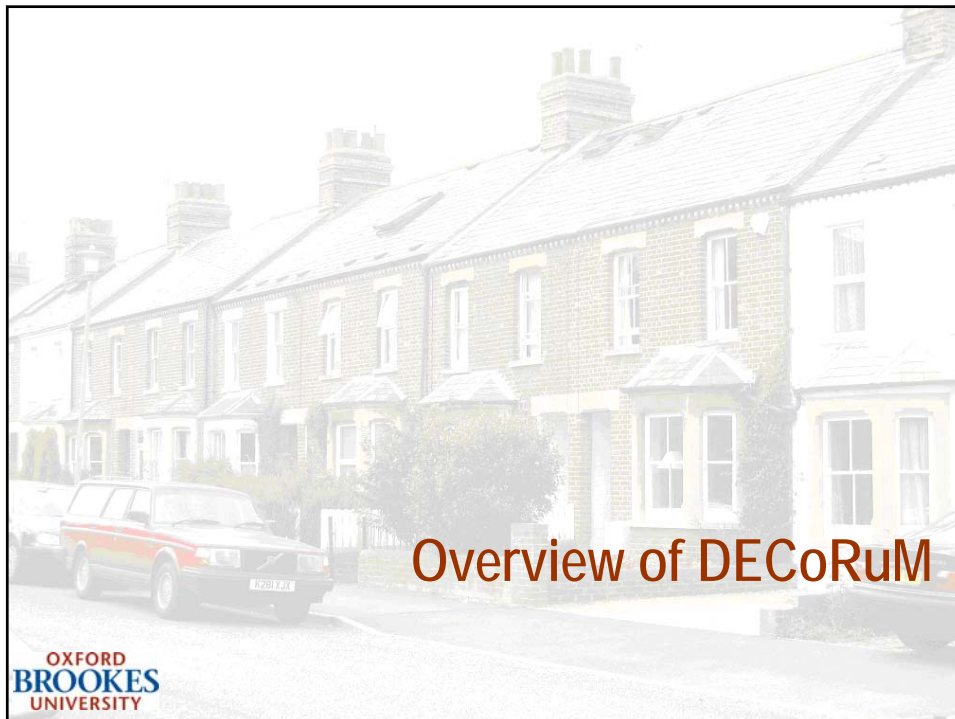
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Actions at the local to regional scale are needed to deliver extensive carbon emission reductions (SDC report, 2002).



It is within this context that the DECoRuM model has been developed!

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Overview of DECoRuM

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## DECoRuM: a next generation domestic energy model

Capability to estimate baseline CO<sub>2</sub> emissions from individual dwellings using a locally-relevant approach, and well-established methodologies to ensure credibility.

Aggregates these to an urban scale – street, district or city level.

This enables it to evaluate the potential for domestic CO<sub>2</sub> emission reductions from a whole range of measures on both the demand and supply sides of energy.

An additional and unique feature of assessing the cost-benefits of individual CO<sub>2</sub> reduction measures and putting a financial cost to CO<sub>2</sub> emission reduction.

A mapping tool for representing domestic CO<sub>2</sub> emissions and reductions.

DECoRuM provides local authorities and energy advisers with a tool to address the barrier of counting and reducing emissions locally.

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## Core methodologies used in DECoRuM

Methodology used	Details of methodology	Outputs	
Building Research Establishment Domestic Energy Model (BREDEM) -12	Industry standard to calculate energy use for different dwelling types in UK.	Annual energy use (GJ/year)	Underlying physically-based energy models: BREDEM -12 linked to SAP 2005.
	Estimates annual energy requirement for space heating, water heating, lights & appliances and cooking	Annual CO <sub>2</sub> emissions (kg/year) Running costs (£s/year)	
Standard Assessment Procedure (SAP) 2005	Government's recommended system for home energy rating based on energy costs for space and water heating.	SAP rating (scale of 1-100)	
Net annual cost method	Used by BRE to assess cost-effectiveness of energy efficiency measures.	Net annual cost/tonne of CO <sub>2</sub> saved	Cost-benefit analysis approach

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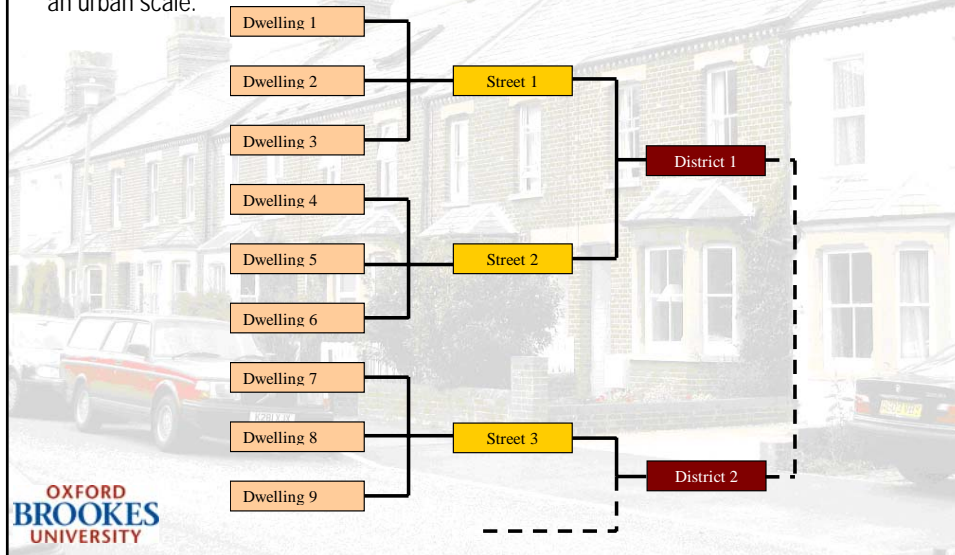
## Outputs from DECoRuM

	Outputs	Expressed as
Energy use	Total annual energy use	kWh/year kWh/m <sup>2</sup> /year
	Annual energy use by end use	kWh/year
CO <sub>2</sub> emissions	Total annual CO <sub>2</sub> emissions	kgCO <sub>2</sub> /year kgCO <sub>2</sub> /m <sup>2</sup> /year
	Annual CO <sub>2</sub> emissions by end use	kgCO <sub>2</sub> /year
Fuel costs	Total annual running (fuel) costs	£/year
	Annual running (fuel) costs by end use	£/year
Energy rating	SAP rating	Scale of 1 to 100

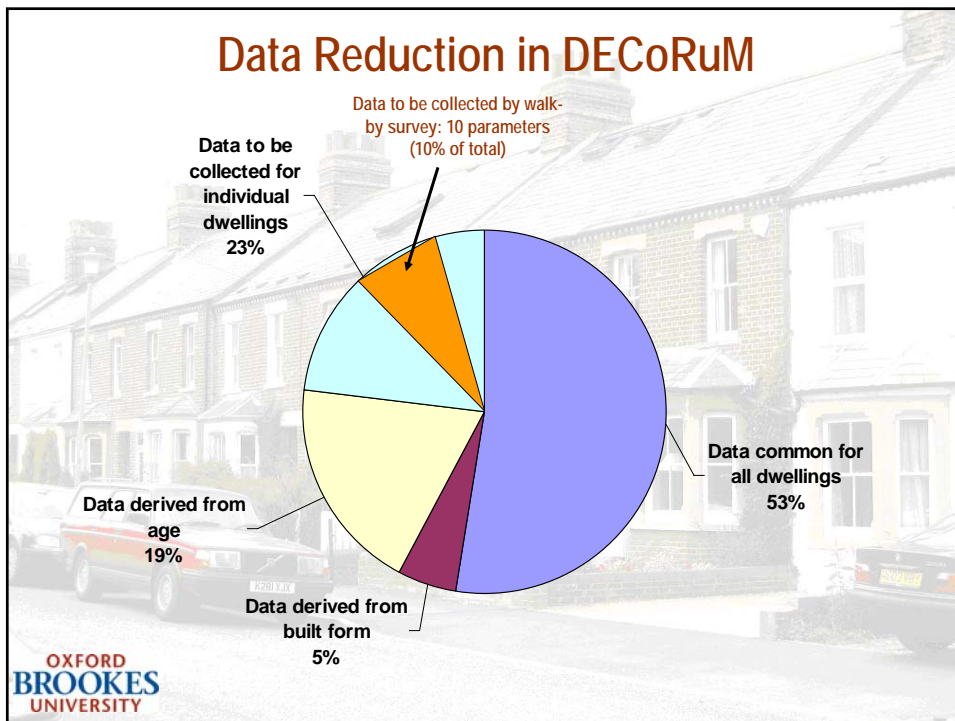
DECoRuM: estimating baseline energy and CO<sub>2</sub> emissions

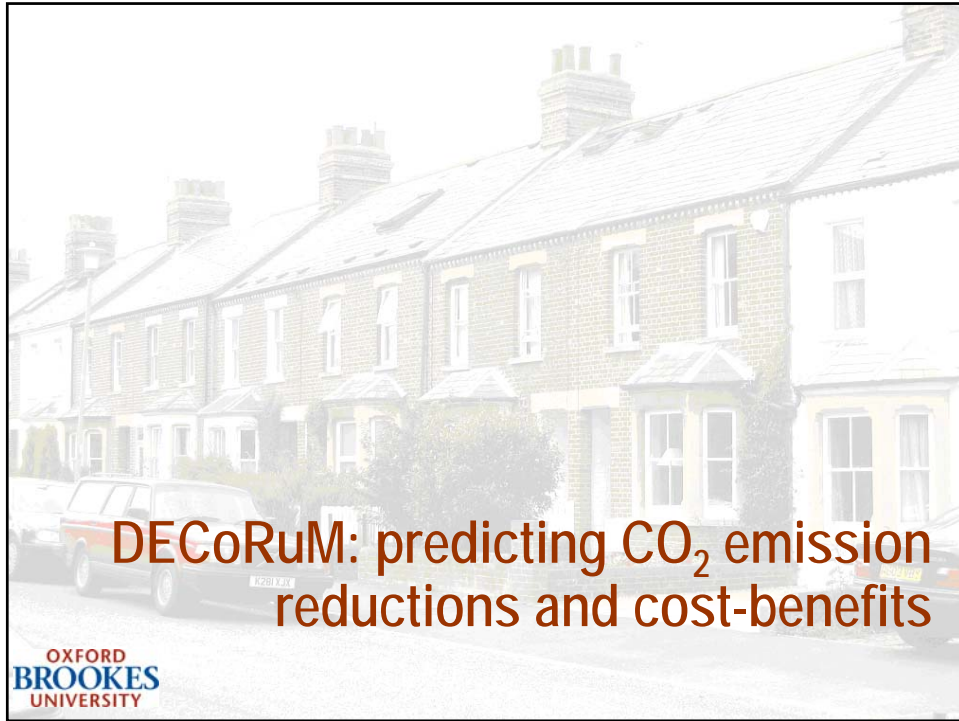
## Framework for baseline predictions

DECoRuM baseline energy model estimates energy consumption and CO<sub>2</sub> emissions of individual dwellings as the basic component for calculation, and then aggregates these to an urban scale.



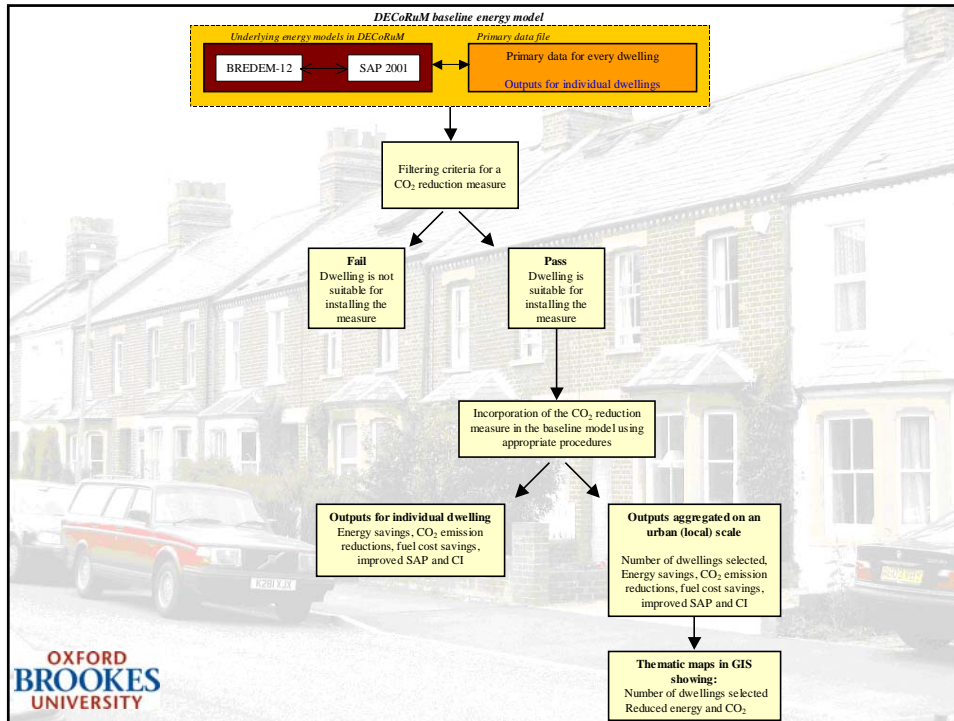
## Data Reduction in DECoRuM





### DECoRuM: 30 CO<sub>2</sub> reduction strategies

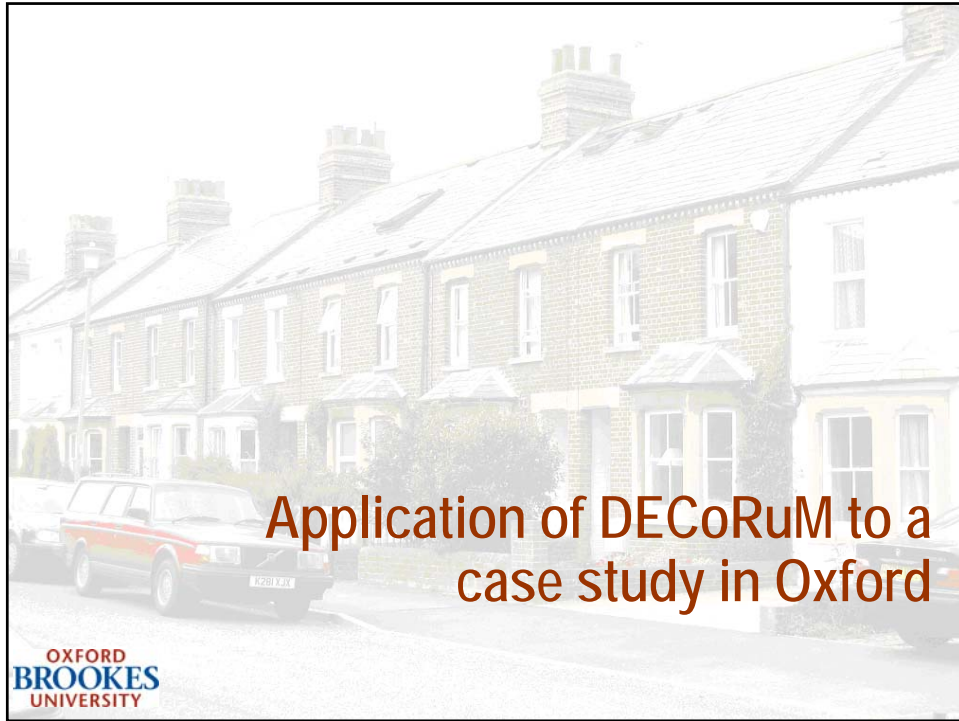
Strategies for CO <sub>2</sub> reduction	END-USES OF ENERGY IN A TYPICAL UK DWELLING				
	Space heating	Water heating	Lighting	Appliances	
Energy use in 20001	60 %	23 %		12 %	
CO <sub>2</sub> emissions 2000 <sup>23</sup>	54 %	21 %		20 %	
Fuel used	Mostly gas	Mostly gas		Electricity	
DEMAND SIDE OF ENERGY	Energy efficient measures	<i>Insulation</i>		<i>Low energy lighting</i>	<i>Energy efficient appliances</i>
		Roof insulation	Hot water tank insulation	CFLs	
		Cavity wall insulation	Primary hot water pipe insulation	Energy efficient fittings	
		Solid wall insulation: internal			
Solid wall insulation: external					
Floor insulation					
Low-e double glazing					
Draught stripping					
Draught lobby					
	<i>Heating system</i>				
	Installation of a condensing boiler				
	Improved heating controls				
SUPPLY SIDE OF ENERGY	Low carbon technologies	Micro-CHP			
		Ground source domestic heat pumps			
	Solar energy systems	<i>Passive solar</i>		<i>Active solar</i>	
		Conservatory	Solar hot water system		Solar PV
Fuel switching				Green-tariff electricity	



## DECoRuM: cost-benefit methodology

Use	Outputs (Low capital cost high capital cost scenarios)
To assess the cost-effectiveness of deploying various CO <sub>2</sub> reduction measures.	<i>Net annual cost</i> is divided by the annual CO <sub>2</sub> saving to give the <i>net annual cost per tonne of CO<sub>2</sub> saved</i>
To determine the capital cost of reducing a tonne of CO <sub>2</sub> , using a single or a combination of measures on an urban scale.	<i>Cost for reducing a tonne of lifetime CO<sub>2</sub> emissions</i>
To be widely used and understood.	Simple payback period


Helps to compare the *cost of eliminating a tonne of CO<sub>2</sub>* by using energy efficiency measures with low carbon technologies and solar energy systems.



### Oxford case study (318 dwellings)

This case study area was chosen because:

- Naturally fell within 2 enumeration districts.
- Number of dwellings in case study area was 318, comparable to other studies by researchers.
- Householders environmentally aware as realised from a survey done as part of the Oxford Solar Initiative project.

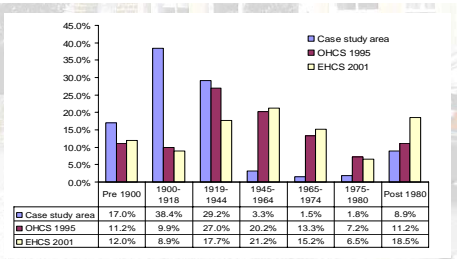
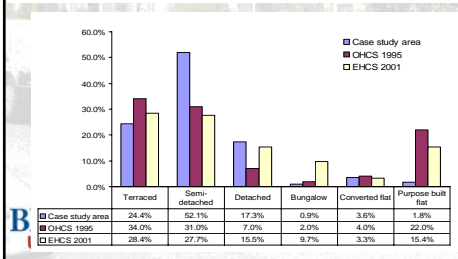
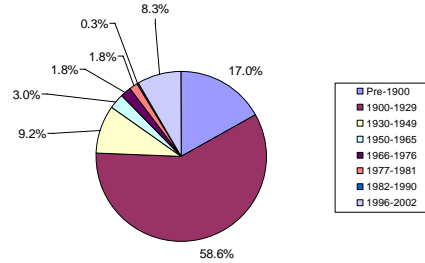
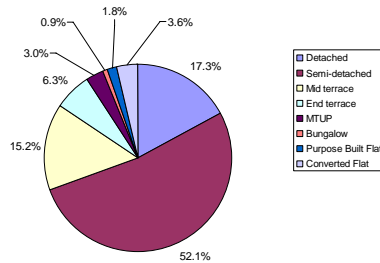


Aerial image of the case study area in North Oxford, UK

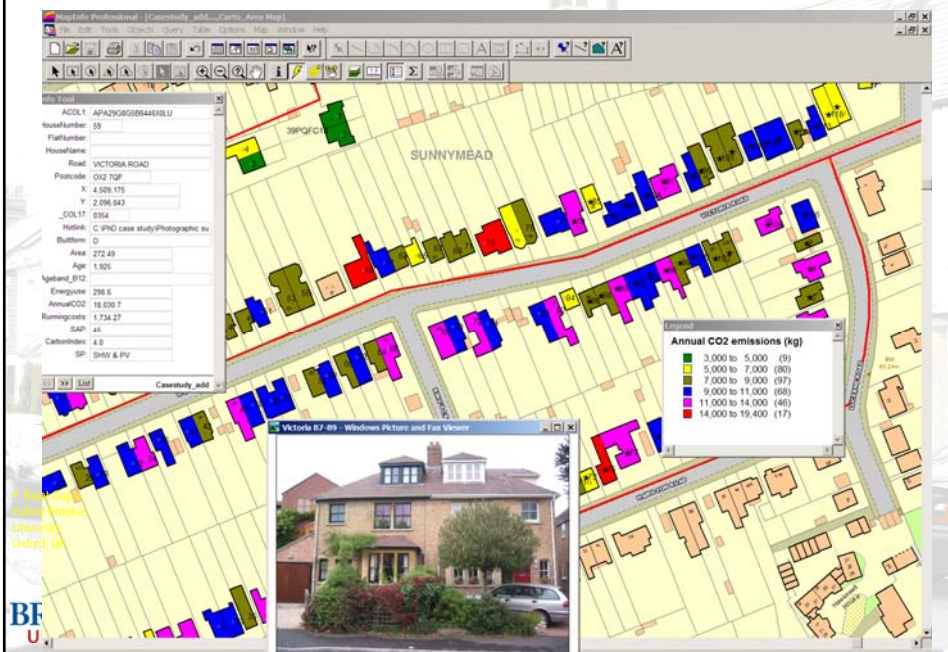
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## Oxford case study (318 dwellings)

All the built forms and age groups of dwellings defined in DECoRuM, EHCS and OHCS, are present in the case study area.



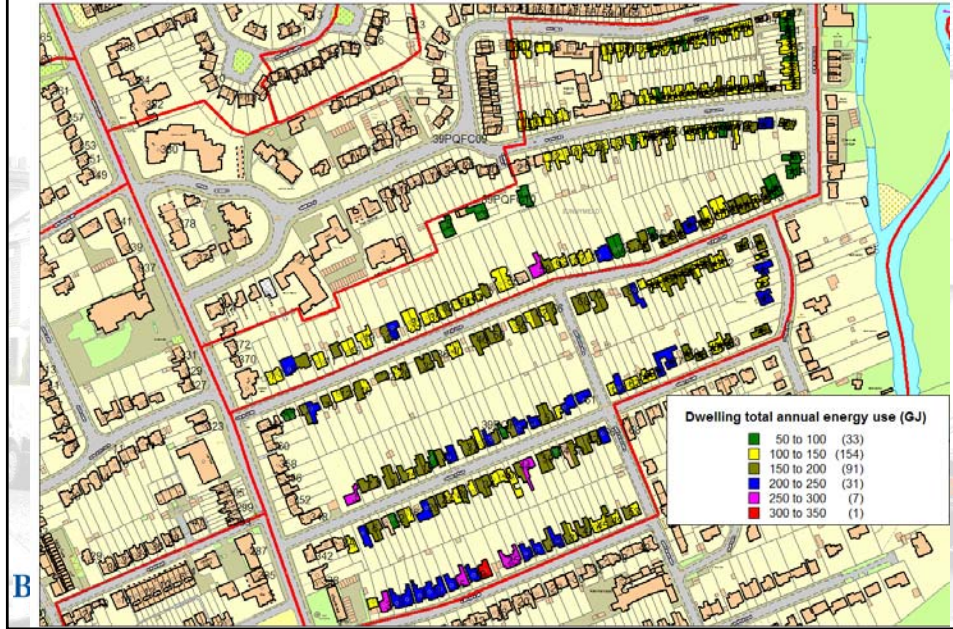
## Oxford case study: DECoRuM baseline energy & CO<sub>2</sub> model



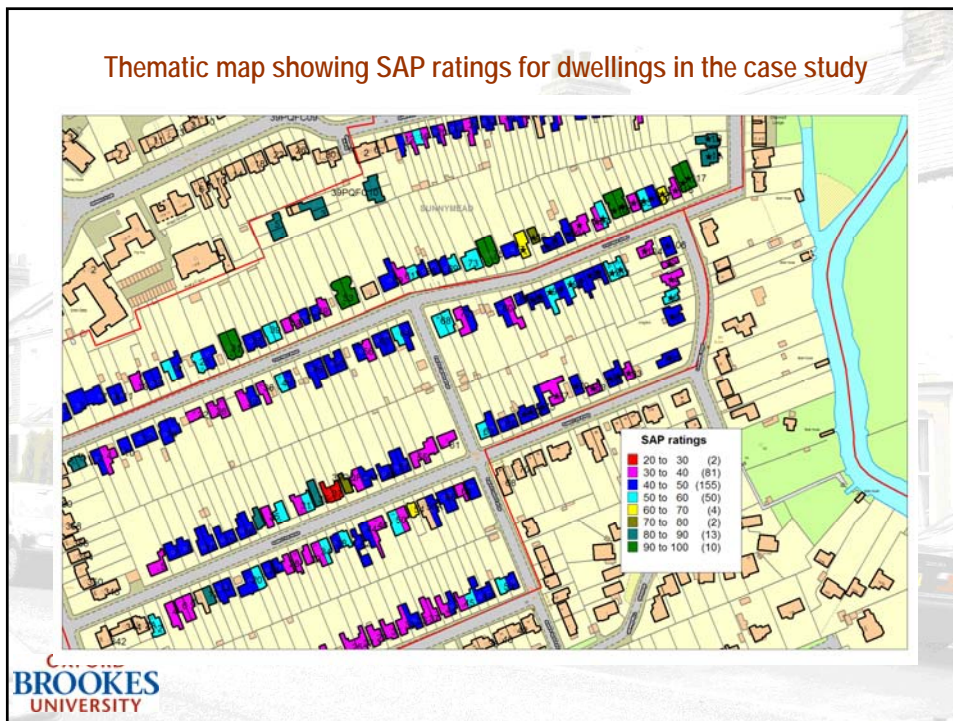
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Oxford, UK

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Thematic map showing estimate of total annual energy consumption in the case study dwellings



Thematic map showing SAP ratings for dwellings in the case study



Thematic map of dwellings in the case study showing annual fuel costs



Oxford case study: Results from DECoRuM baseline energy model

End uses	Energy consumption (GJ/year)	Percentage of total	CO <sub>2</sub> emissions (tonnes/year)	Percentage of total	Fuel costs (£s/year)	Percentage of total
Space heating	30,252.5	60.9%	1,664.2	55.0%	120,500.8	43.9%
Water heating	12,655.8	25.5%	683.4	22.6%	47,332.7	17.2%
Lights and appliances	5,113.8	10.3%	588.1	19.4%	100,691.7	36.6%
Cooking	1,676.9	3.4%	90.6	3.0%	6,271.8	2.3%
<b>Total</b>	<b>49,699.1 GJ</b>	<b>100.0%</b>	<b>3,026.2 t</b>	<b>100.0%</b>	<b>£274,797.0</b>	<b>100.0%</b>

Mean energy use for a dwelling is 368kWh/m<sup>2</sup>/year

CO<sub>2</sub> emissions are 80 kgCO<sub>2</sub>/m<sup>2</sup>/year.

Average SAP rating was estimated as 45

Carbon Index: 3.4

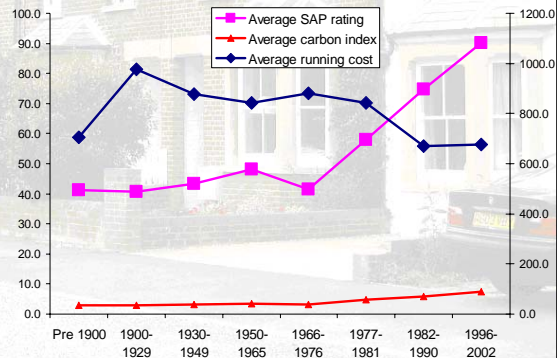
Average annual fuel (running) cost per year per dwelling: £892

## Results from DECoRuM baseline model: by built form and age groups

Built form	Number of dwellings	Annual energy use	Annual CO <sub>2</sub>	Running costs	SAP	Carbon Index
		(GJ)	(tonnes CO <sub>2</sub> /year)	(£/year)	Average	Average
		Total	Total	Average	Average	Average
Detached	58	10985.2	669.1	1074.2	43.2	3.2
Semidetached	175	27774.5	1698.5	916.2	46.4	3.5
End-terrace	21	2902.8	173.0	747.6	39.5	2.8
Mid-terrace	51	5958.8	359.2	656.9	47.9	3.6
MT-UP	10	1563.6	95.3	897.2	41.2	3.0
Bungalow	3	514.2	31.2	961.7	36.3	2.7
<b>TOTAL</b>	<b>318</b>	<b>49,699.1 GJ</b>	<b>3,026.2 t</b>	<b>£892.1</b>	<b>45.4</b>	<b>3.4</b>

Breakdown of energy use, CO<sub>2</sub> emissions, running costs, SAP rating and carbon index as per built forms of dwellings in the case study

Distribution of SAP rating, carbon index and running cost by age-band in case study area



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## DECoRuM CO<sub>2</sub> reduction model: estimating solar potential

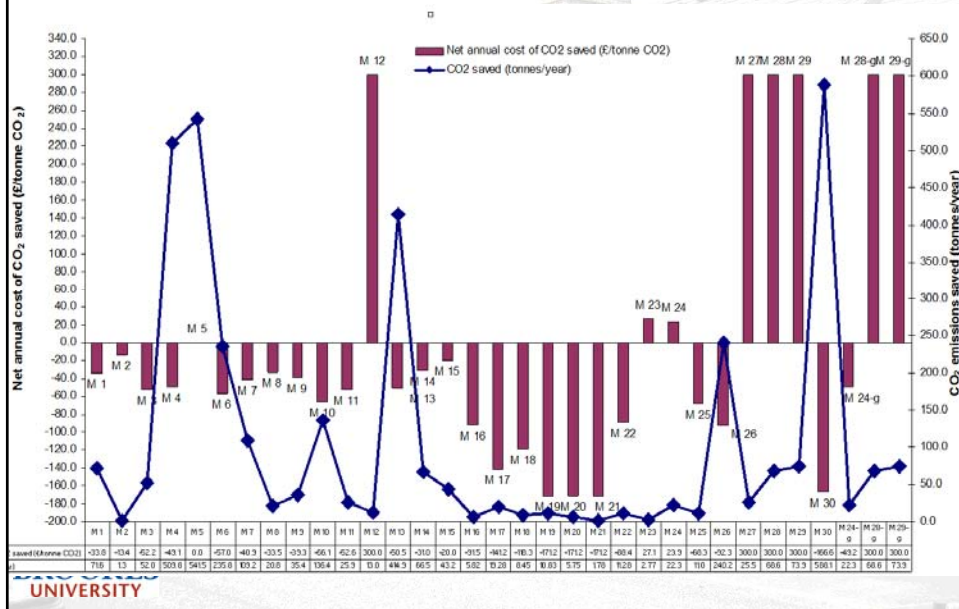
87% of the dwellings in the case study were suitable for installing either a SHW or a PV system or both.

Dwellings with potential for	Number of dwellings	Percentage
4 m <sup>2</sup> flat plate SHW (available roof area: 4.0 m <sup>2</sup> - 9.9 m <sup>2</sup> )	38	11.9%
PV (available roof area: 10.0 m <sup>2</sup> -13.9 m <sup>2</sup> )	46	14.5%
SHW & PV (available roof area: >13.9 m <sup>2</sup> )	192	60.4%
None	42	13.2%
<b>TOTAL</b>	<b>318</b>	<b>100.0%</b>

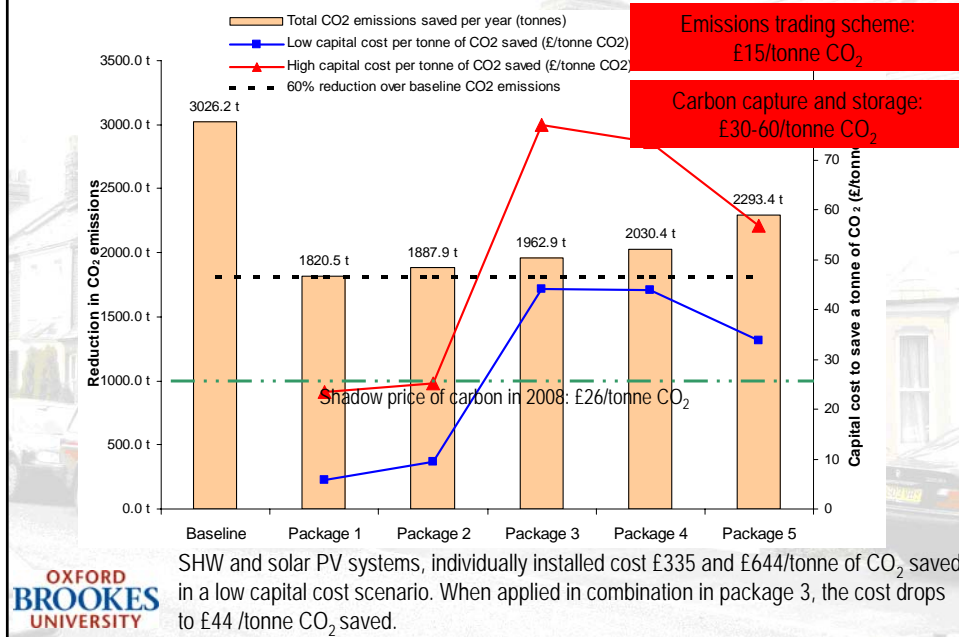


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### Cost-effectiveness of various CO<sub>2</sub> reduction measures versus potential CO<sub>2</sub> savings in the Oxford case study area (Low capital cost scenario)



### Potential for CO<sub>2</sub> emission reductions above 60%



## Potential for CO<sub>2</sub> emission reductions from UK housing stock

S.No. of measure	Strategy/Measure	UK LEVEL (24.27 MILLION DWELLINGS)								
		Average CO <sub>2</sub> emission saved per year per dwelling (tonnes CO <sub>2</sub> )	Number of dwellings selected in UK	CO <sub>2</sub> Emissions saved/year (Mtonnes CO <sub>2</sub> /year)	Lifetime CO <sub>2</sub> Emissions saved (Mtonnes CO <sub>2</sub> )	Total cost for selected dwellings (£s in Million)		Pounds spent to save a tonne of CO <sub>2</sub> (£/tonne CO <sub>2</sub> )		
						Low cost	High cost	Low cost	High cost	
<b>ENERGY EFFICIENCY MEASURES</b>										
M 1	Roof insulation: top-up from 50/75mm to 250 mm	0.24	4 911 000	1.2	35.9	466.5	726.8	13.0	20.3	
M 2	Roof insulation: top-up from 150 mm to 250 mm	0.06	6 187 000	0.3	10.4	216.5	544.5	20.9	52.6	
M 3	Cavity wall insulation	1.44	8 696 000	12.6	502.3	2504.4	3330.6	5.0	6.6	
M 5	Solid wall insulation: external	2.16	10 615 000	22.9	687.0	0.0	15922.5	0.0	23.2	
M 8	Low-e double glazing (in comparison with double glazing)	0.15	11 190 000	1.6	32.6	559.5	1678.5	17.2	51.5	
M 9	Full draught proofing (currently with none or some)	0.11	24 193 000	2.7	27.0	532.2	1983.8	19.7	73.5	
M 10	Hot water cylinder insulation (currently with none or some)	0.47	5 017 000	2.3	23.4	50.2	175.6	2.1	7.5	
M 13	Replacement condensing boilers	1.41	5 720 095	8.1	96.9	1144.2	2860.4	11.8	29.5	
M 14	Improved heating controls: room thermostat & cylinder thermostat	0.21	2 510 000	0.5	6.3	150.6	338.9	23.9	53.8	
M 15	Energy-efficient lighting (new CFLs and new fittings)	0.14	24 195 000	3.3	39.4	967.8	2225.9	24.6	56.5	
M 16	Energy-efficient refrigerators	0.04	10 404 000	0.4	5.8	280.9	364.1	48.3	62.6	
M 17	Energy-efficient fridge/freezers	0.10	15 348 000	1.5	26.6	414.4	1028.3	15.6	38.6	
M 18	Energy-efficient freezers	0.06	10 544 000	0.6	9.2	284.7	727.5	30.9	78.9	
M 19	Energy-efficient washing machines	0.04	22 317 000	0.6	10.1	0.0	2544.1	0.0	292.3	
M 20	Energy-efficient tumble dryers	0.04	12 390 000	0.4	6.4	0.0	371.7	0.0	58.0	
M 21	Energy-efficient dishwashers	0.02	5 814 000	0.1	2.4	0.0	180.2	0.0	75.9	
M 22	Energy-efficient televisions	0.02	42 769 000	0.9	7.3	427.7	427.7	58.5	58.5	
M 23	Energy-efficient videos	0.01	23 855 000	0.2	1.7	238.6	238.6	143.0	143.0	
<b>LOW CARBON TECHNOLOGIES</b>										
M 24	Ground-source heat pump systems	0.89	1 908 097	1.7	42.5	2919.4	3434.6	68.7	80.8	
M 25	Domestic micro-CHP units (small unit: 1 kW <sub>e</sub> / 6 kW <sub>t</sub> )	0.69	1 221 182	0.8	12.6	519.0	610.6	41.3	48.5	
M 26	Domestic micro-CHP units (large unit: 3 kW <sub>e</sub> / 9 kW <sub>t</sub> )	1.85	9 922 107	18.3	275.0	12650.7	14883.2	46.0	54.1	
<b>SOLAR ENERGY SYSTEMS</b>										
M 29	Solar hot water (4m <sup>2</sup> flat plate system)	0.30	17 554 497	5.2	104.7	35109.0	49152.6	335.4	469.5	
M 30	Solar PV (1 kW <sub>p</sub> system)	0.31	16 165 068	5.6	141.0	90825.4	130788.6	644.1	927.5	
				<b>TOTAL</b>	<b>92.3</b>	<b>2,106</b>	<b>150,262</b>	<b>234,639</b>	<b>71.3</b>	<b>111.3</b>
				Equal to	<b>25.2</b>	<b>MTC</b>				
Potential for each measure at UK level extracted from BRE report										
Potential for each measure at UK level extrapolated from the application of DECoRuM to the case study in Oxford										
				<b>UK domestic CO<sub>2</sub> emissions in 2000 (Domestic energy fact file)</b>	<b>38.2</b>	<b>MTC</b>				
				<b>CO<sub>2</sub> reduction achieved</b>	<b>66%</b>					

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## DECoRuM: Key drivers

National Indicators: environmental sustainability

Decent Homes Standard

All social housing and vulnerable households in the private sector to be made decent by 2010: efficient heating and effective insulation.

Fuel poverty

To end fuel poverty by 2010 amongst vulnerable households.

Home Information pack: EU Building Energy Directive

Home Condition Report containing SAP energy rating and measures for improving energy efficiency.

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## DECoRuM: Benefits

- Individual dwelling is represented as the base level of resolution but results can be displayed up to a street, district and city level.
- Pollution hotspots can be spatially located and targeted for improvement.
- Assessment requires no access to the property.
- A robust data filtering process provides accurate and reliable results.
- Cost-benefits analysis enables cost comparison of different measures.
- Helps to estimate the potential for citywide application of solar energy systems.
- A useful visual aid when encouraging householders to install energy efficiency measures

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## Applications: Local Authorities and DECoRuM

Provides a GIS-based toolkit to enable LAs to develop a carbon foot-printing capability to :

- Assess and map the current carbon emissions of their housing stock.
- Benchmark baseline emissions against typical and good-practice standards.
- Identify 'hotpots' of pollution.
- Establish carbon emission reduction targets.
- Evaluate strategies and technologies to achieve those targets in terms of carbon reduction and cost-benefits.
- Verify and monitor the reductions achieved.
- Help to develop guidelines (solar legislation, solar rights, and building energy standards) to restrict the housing stock's carbon emissions to good practice benchmarks.

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## RIBA President's medal for outstanding research 2006

The screenshot shows a Microsoft Internet Explorer browser window displaying the Oxford Brookes University website. The page is titled "RIBA Research Award 2006". The main content area contains the following text:

The Royal Institute of British Architects (RIBA) is pleased to announce that Dr Riqat Gagle from Oxford Brookes University (Oxford, United Kingdom) has been awarded the RIBA President's Research award for 2006 - outstanding PhD.

This award was made on 6 December 2006 at the prestigious President's Medal ceremony held at the RIBA, 66 Portland Place, London.

The judges' citation for the winner of the Outstanding PhD is as follows:

This PhD research describes the development and validation of a domestic energy, carbon-counting and carbon-reduction model (DECoRuM) for urban scale assessments of the cost benefits of a wide range of energy efficient and renewable energy options. The thesis deftly handles the complex and contentious literature on climate change. The novelty of the approach lies in the ability to reliably aggregate results for individual houses up to an urban scale. This is an extremely impressive study both in terms of its scope and detail. It is also very timely, and should be taken up by local authorities and housing agencies around the country. This is an issue of widespread importance and interest to many architects, and one which the RIBA champions.

**Judging panel:**

- Jane Rendell - chair of judges - Director of Architectural Research at the Bartlett School of Architecture UCL
- Richard Coyne - Edinburgh University, Architecture Department
- Andrew Ballarthyne - University of Newcastle, School of Architecture
- Brian Ford - Head of School of the Built Environment, Director of the Institute of Architecture, University of Nottingham
- Simon Allford - ARBM, and RIBA Vice President for Education

On the left side of the page, there is a "Business and employers" sidebar with a "Making list" section containing links to "RIBA Research Award 2006" and "Business and Employers".

The screenshot shows the Oxford Brookes University website page for the DECoRuM model. The main content area contains the following text:

**DECoRuM**

DECoRuM is a GIS-based toolkit for carbon emission reduction planning with the capability to estimate current energy-related CO<sub>2</sub> emissions from existing UK dwellings, aggregating them to a street, district, sub-urban, and city level. This enables DECoRuM to evaluate the potential and financial costs for domestic CO<sub>2</sub> emission reductions by deploying a whole range of best practice energy efficiency measures, low carbon systems and renewable energy technologies.

The DECoRuM model is able to clearly point out and identify sources of domestic emissions, so that pollution hotspots can be targeted. It performs calculations of carbon emissions based on more readily available secondary data such as SAP ratings analyses of domestic properties.

DECoRuM has an in-built cost-benefit analysis model. Furthermore it has a facility to employ robust filtering criteria to select suitable dwellings before predicting the effect of applying various low carbon measures.

The main target users for the DECoRuM model include planners in local authorities, energy advisers in Energy Efficiency Advice Centres, building surveyors as well as real estate professionals.

On the right side of the page, there is a "DECoRuM" sidebar with a "Making list" section containing links to "Background", "About DECoRuM", "Usage features", "Potential users", "Peer-reviewed publications", "Services we offer", and "People involved in the research".

At the bottom of the page, the URL [www.decorum-model.org.uk/](http://www.decorum-model.org.uk/) is displayed.

