Calderon C, James P, McCloughlin A, Urquizo J. An area-based GIS energy model for cities and neighbourhoods. ***In: 21st GIS Research UK conference (GISRUK 2013)*****. 3-5 April 2013, Liverpool.**

An area-based GIS Energy Model for cities and neighbourhoods

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KEYWORDS: Urban Energy, GIS, Planning, Spatial analysis

1. Introduction

Planning energy infrastructure at local level is the key to addressing some of the most difficult challenges in climate change and energy policy planning (i.e. fuel poverty) and to unlock the transformative potential of distributed energy technologies. The scientific field of urban energy and carbon modelling is becoming a fundamental instrument to estimate a carbon baseline at a point in time and to quantify the impact that policy-driven technological interventions that could have on the overall carbon footprint of a city. This capability enables an evidence-based approach in which the economic case towards a low-carbon economy can be made.

Research in domestic energy consumption has mainly focused on what are the factors influencing energy consumption or how behaviour change can lead to reduced household energy consumption (Zhang, Siebers & Aickelin 2012). As a result, in the last two decades, a myriad of disaggregated, national level, energy demand models have been developed. They vary considerably in their data requirements, disaggregated levels, socio-economic assumptions and the types of scenarios or predictions that can be made (Kavgic et al. 2010). Energy consumption modelling approaches can be classified into two broad concepts; top-down and bottom-up methods. Top-down modelling approaches work at an aggregated level, fitting a historical time series of national energy consumption or CO_2 emission data (Kavgic et al. 2010). A Bottom-up approach extrapolates the estimated energy consumption of a representative set of individual homes to regional and national levels (Swan & Ugursal 2009).

Transformative local distributed energy technologies such as CHP or district heating have a strong spatial component due to a need identify synergies with adjacent properties or heating loads. Currently available domestic building energy models often do not take into account spatial information. Most available models are based on housing survey data at national level and run the model from regional to national scales. Only a few studies have investigated applying Geographical Information System (GIS) techniques to see how spatial analytical tools can be used to derive predictors from digital maps (Heiple & Sailor 2008) (Lomas et al. 2011). Accessing geo-referenced data for energy modelling can also be particularly useful as validated outputs (i.e. heating and electricity loads, energy profiles) can be mapped using spatial modelling techniques that help to easily identify high and low energy consumption areas and potential synergies in local energy infrastructure planning

At Newcastle University, jointly with the City Council, we are currently undertaking an ambitious exercise to develop a spatially referenced domestic energy demand model for the city and neighbourhoods of Newcastle upon Tyne: a Carbon Route Model (CRM). Our spatial database has been designed to provide complete coverage of all the domestic building stock in the city of Newcastle upon Tyne (139257 residences) so as to ensure the Local Authority has a spatially referenced energy profile of each individual domestic building and property.

2. Data sources

Our Carbon Route Model utilises an Address Base UPRN approach to spatially reference building level data, obtained via comprehensive surveys at city level such as WarmZone (see Table 1). CRM has been designed to incorporate data from a variety of sources and to provide an extensible collection of attributes, information and metadata for each residential building. The dataset is per building such that the underlying geometry of the building footprint encompasses the physical structure of the building itself. The dataset is designed to augment and link to existing datasets through common identifiers such as the Unique Property Reference Number (UPRN), part of the National Land and Property Gazetteer (NLPG) or the Topographic ID (TOID) that is part of the underlying geometry maintained and developed by the Ordnance Survey (OS), the UK's national mapping agency. In the UK a LA is mandated to collect and maintain data about properties that feed into the NLPG and other national datasets. They typically also maintain a number of property databases for operational purposes that may augment the mandatory databases. The NLPG stores information about building usage against a domain of classes defined in the Building Land and Property Unit (BLPU) (NLPG 2006) classification. This classification is hierarchical in nature. Classification R subtype D includes dwellings and a basic classification of residential building types. A large number of data holders were approached to evaluate and, where possible, incorporate their data holdings. The main datasets are detailed in Table

Table 1: Details of major datasets identified by CarbonRouteMap

Dataset	Description	Data Owner
Ordnance Survey MasterMap (OS MasterMap)	Continuous, themed, polygonal coverage. Contains polygonal geometry of building outlines.	Ordnance Survey. (Licensed through NCC).
Ordnance Survey Addresspoint (OS	Location of postal addresses in the UK (point dataset)	Ordnance Survey/Royal Mail. (Licensed through Newcastle City

AddressPoint)		Council)
Newcastle City Council Gazetteer (NCC Gazetteer)	The gazetteer is based on the OS MasterMap dataset and contains property parcels referenced using the Unique Property reference Number (UPRN) which is the basis for the NLPG. It classifies all property in the authority using the Basic Land and Property Unit classification scheme (BLPU)	Newcastle City Council
WarmZone property audits (WarmZone)	The WarmZone database uses UPRN to identify properties and contains the results of a detailed questionnaire completed by a surveyor during a visit to the property. The dataset contains information on interventions, housing type, age, space and water heating arrangements.	WarmZone is a not for profit company that administers schemes for providing energy audits for domestic properties and grants for interventions.
Cities Revealed Building Classification Data (CR)	Detailed building type and age information compatible with Ordnance Survey Mastermap data	The Geoinformation Group
Scorchio Classifications	Classifications of building type from Scorchio project (Triantakonstantis & Barr 2009)	Newcastle University
Your Homes Newcastle data	Age and type of construction keyed on UPRN. Also historical records of LA housing stock released to private owners.	Your Homes Newcastle is the primary provider of social housing in Newcastle.
Registered Social Landlords	A range of information from registered social landlords	Newcastle City Council
Right to Buy data	Information on social housing stock sold under the right to buy scheme.	Your Homes Newcastle
Thermal Imagery	Thermal imagery of Newcastle City	Newcastle City Council/Newcastle University
Lidar	0.5m Resolution Lidar for Newcastle City	Newcastle City Council/Newcastle University

3. Modelling

Underpinning the database is the Cambridge Housing Model (CHM) used by DECC (Hughes 2011), a domestic energy model based on SAP 2009 (i.e. a standardised approach for calculating energy performance of specific dwellings) that estimates energy use and CO^2 emissions by use and by fuel type. At the core of the CHM is a BREDEM validated building physics model for calculating energy consumption of space and water heating, electrical appliances, cooking and lighting. Key inputs to the model are climate data, building physics parameters and housing data from the English Housing Survey. In fact, CHM is designed to generate estimates of energy use for the Department of Energy and Climate Change (DECC)

Housing Energy Fact File (HEFF) (Cooper & Palmer 2011)and the associated Energy Consumption in the UK (ECUK) domestic data tables. The primary source of input data for the CHM is the English Housing Survey (EHS): a dataset which provides data on 16,150 representative English dwellings (cases) (DECC 2010). Each case, in turn, represents a quantity of dwellings in England.

In our work we have adapted the CHM to develop spatially referenced energy profiles and technology driven scenario generation. This process of adaption was based on two key steps: 1) linking our CRM to the EHS via eight key factors. These eight factors such as dwelling size and age have the greatest impact of energy consumption according to the literature (Cooper & Palmer 2011); 2) development of spatial interpolation procedures as to fill in the missing gaps in our original sample. In short, in CRM we possess approximately 67,000 records which contain the eight key factors harvested from the existing database. For the other 60,000+ properties spatial interpolation was used to essentially copy the values from properties with matched records to similar properties close by. A variety of spatial interpolation methods including nearest neighbour, IDW and kriging were used to match properties. The success of each interpolation technique depended on the spatial heterogeneity of the area in question.

4. Results

To validate the model once complete the CHM energy profiles were computed for each residence in CRM in an MLSOA and LLSOA and compared to DECC's energy consumption figures (DECC 2009). Table 2 shows CRM figures for South Heaton MLSOA against the DECC consumption figures for the same area. Gas values agree to within 2% and Electricity agree within 8%.

Table 2 South Heaton MLSOA CRM and DECC consumption figures 2009/2010

CRM figures	DECC figures	Difference
GAS: 60,075,526	61,412,232 KWh	-2.2%
15,267,453 KWh	14,228,799 KWh	+7.3%

5. Discussion

Our results suggest that area based spatial energy modelling using aggregates of individual buildings can provide an evidence base to ascertain the likely impact of energy saving measures. We see this type of models are a first and necessary step towards facilitating local energy planning infrastructure of, for instance, decentralised low carbon heat technologies.

References

Cooper, I. & Palmer, J. 2011. Great Britain's housing energy fact file.

DECC 2010. English Housing Survey.

DECC 2009. MLSOA electricity and gas: 2009 - Department of Energy and Climate Change. Available at: http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/mlsoa_llsoa/mlsoa_2009/mlsoa_2009.aspx [Accessed November 15, 2012].

Heiple, S. & Sailor, D.J. 2008. Using building energy simulation and geospatial modeling techniques to determine high resolution building sector energy consumption profiles. *Energy and Buildings*, **40**(8), pp.1426–1436.

Hughes, M. 2011. A Guide to The Cambridge Housing Model. , (November).

Kavgic, M. et al. 2010. A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment*, **45**, pp.1683–1697.

Lomas, K.J. et al. 2011. The Carbon Footprint of UK Cities 4M: measurement, modelling, mapping and management in *ISOCARP Review 06 International Society of City and Regional Planners*.

NLPG 2006. National Land and Property Gazetteer data transfer format.

Swan, L.G. & Ugursal, V.I. 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, **13**(8), pp.1819–1835.

Triantakonstantis, D. & Barr, S. 2009. A Spatial Structural and Statistical Approach to Building Classification of Residential Function for City-Scale Impact Assessment Studies Computational Science and Its Applications – ICCSA 2009 in O. Gervasi et al. eds., Springer Berlin / Heidelberg, pp. 221–236.

Zhang, T., Siebers, P.-O. & Aickelin, U. 2012. A three-dimensional model of residential energy consumer archetypes for local energy policy design in the UK. *Energy Policy*, **47**(0), pp.102–110.

Biographies

Phil James is a Senior Lecturer in GIS. He is interested in applying spatial data and techniques to the solution of engineering problems and the integration of disparate data sources using space and location as the key.

Carlos Calderon is a qualified Civil engineer with a PhD in applied computer science and a lecturer in the School of Architecture. He is researching the area of energy and carbon modelling in cities.

Javier Urquizo is a PhD candidate. His Research interests are in the area of spatial energy analysis, particularly in relation to renewable energy and sustainability.