A spatial domestic energy framework for sub-city areas: a case study from the United Kingdom

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ABSTRACT

This research focuses on spatial domestic energy modelling of sub-city areas in the United Kingdom using Newcastle upon Tyne as a case study. The model estimates the energy end-use at the single dwelling level on three aggregate scales: district, neighbourhood and community.

The model uses two aggregation approaches, one using an approximated prototype-cluster of similar dwellings at the district scale and the other using a novel, detailed modelling of building and its micro-cohesive energy structures in neighbourhoods and communities. The results of a property type based model are also introduced. Besides estimating energy consumption, the property type model could play an interesting role in developing strategies for energy efficiency at various scales.

The validation strategy is used to compare the modelled gas and electricity values in three representative districts against the 2009 DECC values in two aggregate hierarchical areas for electricity and gas: the DECC Medium Layer Super Output Area (MLSOA), and the Lower Layer Super Output Area (LLSOA). A collection of test samples of property type were devised and compared with statistics in the National Energy Efficiency Data set framework (NEED).

The spatially enabled energy model and rich thematic database enables integrated mapping practices, such as updating authoritative data with secondary data sets which may possibly reduce their production costs. A spatially enabled database also provides the precise spatial extent of the energy consumption in sub-city areas and enables a query procedure that allows the identification of building aggregated areas with spatial expression patterns most similar to a given parameter within the building energy profile.

Although all sources of uncertainties affect confidence in the domestic energy model estimation, this research only considers the sources that can be subject to quantitative characterization. The key uncertainties in the energy model are identified in a three dimensional taxonomy originally used in the medical field. The dimensions identify sources, issues and the nature of the uncertainties. The final objective is to extend traditional sensitivity analysis in order to deconstruct the uncertainty of inputs and uncertainty in the pathway, as uncertainty flows through the model to inform data gathering and information collection activities.

AIM

The aim of this research, therefore, is to develop a spatially enabled framework to estimate energy consumption in a multi-scale approach

OBJECTIVES

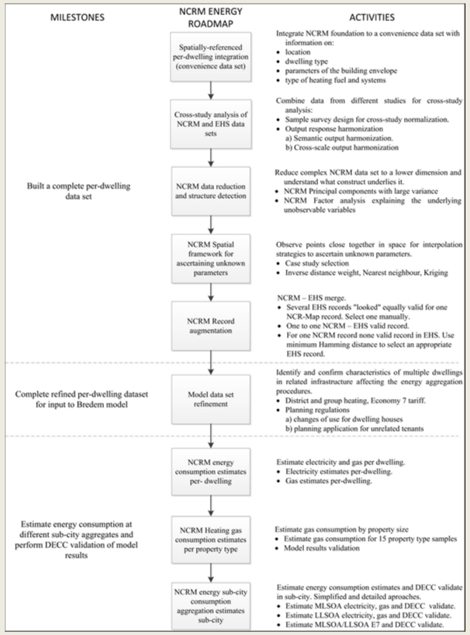
- ✓ Identify and review literature on the modelling approaches that could be used to estimate domestic energy use in cities, and undertake a critical analysis of the domestic energy use data availability in United Kingdom cities.
- ✓ Develop a domestic energy (gas and electricity) model in Newcastle upon Tyne that is capable of explaining the local area characteristics as drivers of energy use at three scales:
  - ✓ Simplified district model –Geographic Area: Medium Layer Super Output Area MLSOA
  - ✓ Detailed neighbourhood model –Geographic Area: Lower Layer Super Output Area LLSOA
  - ✓ Detailed community retrofitting model –Geographic Area: from a single dwelling to community.
- ✓ Develop a spatially enabled database to provide the precise spatial extent of the energy consumption in sub-city areas and enable a query procedure that allows the identification of building aggregated areas that have spatial expression patterns most similar to a given parameter within the building energy profile.
- ✓ Assess the efficacy of the energy model with respect to uncertainty.
- ✓ Analyse and discuss the results obtained from modelling energy in sub-city areas and the illustrative measures of energy reduction.
- ✓ Formulate recommendations for future research.

MODELLING

What this research has shown is that at the scale of districts and larger areas up to a city scale, a few key variables are reasonable surrogates to estimate the energy consumption. The simplified model at this scale uses six categorical variables (dwelling age, wall construction, building form, dwelling size, heating and number of storeys). The three variables of building form, wall construction and heating are composite variables. More variables could increase the odds that the cluster groups are no longer dissimilar, i.e. they are not sufficiently unique to identify distinct domestic energy segments.

The simplified (cluster) model uses six dwelling archetype prototypes in every cluster to capture the mean effects in the interaction between the physical variables as the individual effect will cancel out at this scale. In every cluster prototype there are assumed regional weather characteristics and standard occupancy values. The cluster centre (mean) is the prototype of the cluster. In this research we want the centre (mean) in each cluster to be one particular dwelling. This was the reason why the six medoids were utilised to replace the six mean values in each cluster.

As the scale decreases the local area characteristics are more important. Model estimates in the detail model are improved in neighbourhoods by taking into consideration ten variables (usable floor area, dwelling type, construction date, number of floors above ground, predominant type of wall structure, cavity wall insulation, main heating fuel, primary heating system, boiler group and tenure) and local micro-cohesive structures like micro-cohesive energy supply structures (district and group heating), dwelling in electricity time-of-use tariff (E7) and planned permission granted for converting houses to HMOs and houses and flats having sharing amenities. The reason for the increased number of variables is to get a better insight into the effect of uncertainties in the aggregated process by generating a more complete representation of the dwelling. In the case of dwellings using the Economy 7 tariff, an increase to 12 variables is needed to provide a better description for the dwelling (the hot water heating system and the tank insulation are the new variables).



RESULTS

1.- SIMPLIFIED (CLUSTER) MODEL

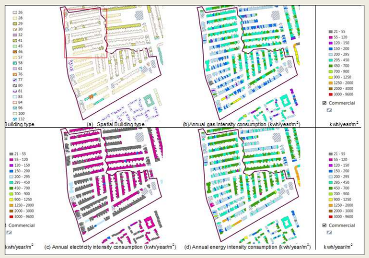
The cluster composition reflects the 2009 energy efficiency of the stock. Secondly, the cluster sizes (in percentage) are indicative of the potential impact in terms of energy reduction that certain retrofitting measures will have in the city. Finally, pair-wise cluster proximity can be inferred for example between clusters 1 and 2, and between clusters 7 and 8, due to the principal component analysis

Cluster (Share of Newcastle stock)	Energy archetype profiles
Cluster 1 (18.24% of the stock)	Mixed ages; mixed wall construction except cavity insulation; Flat semi-detached, end-terraced; house detached, end-terraced; maisonette semi-detached; mixed areas; Electric room heaters and gas boilers with increased efficiency (until gas condensing boiler); up to 6 storeys
Cluster 2 (0.20% of the stock)	Mixed ages; mixed wall construction, except solid insulated; flat semi-detached, mid-terraced, end-terraced, enclosed; house enclosed, end-terraced; maisonette semi- detached; bungalow mid-terraced; mixed sizes; electric warm air, standard boiler, combinational boiler, room heater, liquid petroleum gas, coal; up to 4 storeys
Cluster 3 (1.71% of the stock)	Mixed ages; uninsulated and timber insulated; flat semi-detached, mid-terraced, end-terraced, enclosed; house detached, end-terraced, maisonette semi-detached, enclosed, bungalow mid-terraced; mixed sizes; gas warm air, condensing, condensing combinational and all types of communal; mixed storeys
Cluster 4 (9.98% of the stock)	Mixed ages; uninsulated; flat semi-detached, mid-terraced, end-terraced, enclosed; house detached, enclosed, end-terraced; maisonette semi-detached, enclosed; bungalow mid-terraced; mixed sizes; fuel heat coal, all oil, all E7 fuel types; all gas boilers except condensing combinational and communal; up to 3 storeys
Cluster 5 (30.98% of the stock)	Mixed ages; uninsulated and timber insulated; maisonette detached, semi-detached, end-terraced; flat detached; house end-terraced, semi-detached; all bungalows except mid-terraced; mixed sizes; electric room heaters; fuel heat coal, oil, E7, all gas boilers; up to 9 storeys, except 5 and 7 storeys
Cluster 6 (12.18% of the stock)	Mixed ages; all insulated; maisonette mid-terraced, flat end-terraced, semi-detached, mid-terraced, enclosed; house mid-terraced, detached, enclosed; bungalow mid-terraced; mixed sizes; electric room heaters, all coal, all oil, all E7, all gas boilers; up to 5 storeys
Cluster 7 (22.67% of the stock)	After 1837; mixed walls except timber uninsulated; maisonette detached, semi-detached, end-terraced; flat detached; house end-terraced, semi-detached; all bungalows except mid-terraced; mixed sizes; mixed heating systems except electric warm air and electric combinational boiler; up to 4 storeys
Cluster 8 (4.04% of the stock)	After 1870 except interwar; mixed walls except timber; flat semi-detached, mid-terraced and enclosed; more than 200 square meters; all gas fuel and head systems except condensing boilers and E7; ground floor

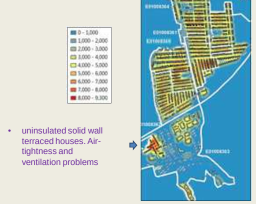
2.- DETAILED (DWELLING) MODEL

The detailed model provides estimation of energy and gas consumption at the LLSOA level. It takes into account the exact characteristics of each dwelling in contrast to the cluster based approach, which uses a single prototype for each cluster. The aggregating strategy was by building, by block, and by LLSOA, and a further aggregation was made to the MLSOA level for comparison purposes

South Heaton LLSOA 8362



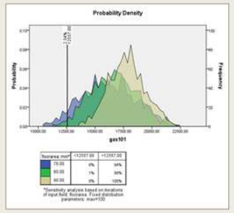
South Heaton spatial distribution of energy intensity (Annual energy per sqm)



Low terraces in Byker

South Heaton spatial patterns (Tyneside flats)

Sensitivity analysis



- Castle Bungalows (local area Bungalows) are of bigger floor area than the North East England (regional Bungalows).

CONCLUSION

A new spatially-enabled approach for modelling energy consumption in sub-city areas is proposed. Previous modelling approaches adopted a number of house archetypes which together represent all dwellings in the stock. This research identifies individual dwellings' energy profiles to estimate individual and aggregated energy consumption. The simplified model uses six categorical variables (dwelling age, wall construction, building form, dwelling size, heating and number of storeys) to capture the mean effects in the interaction between the physical variables in districts as the individual effect will cancel out at this scale. The model estimates in the detail model are improved in neighbourhoods by taking into consideration ten variables (usable floor area, dwelling type, construction date, number of floors above ground, predominant type of wall structure, cavity wall insulation, main heating fuel, primary heating system, boiler group and tenure) and local micro-cohesive structures. The reason for the increased number of variables is to obtain a better insight into the effect of uncertainties of the aggregated process by generating a more complete representation of the dwelling.

This research has shown that the theoretical cases for domestic energy models therefore need to be revisited in order to further understand the interactions between urban form, climate, buildings (fabric and heating supply systems) and household real characteristics in modelling the domestic energy consumption

CONTACTS

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.

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