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Modelling household spatial energy intensity consumption patters for building envelopes, heating systems and temperature controls in cities

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HIGHLIGHTS

- Local area essentials systematically establish energy baseline consumption in cities.
- Variation in internal temperature is the most sensitive element in energy demand.
- Boiler type, heating controls and the tenure type follows a spatial distribution.
- An area-based approach allows more houses to be targeted for inefficient elements.

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ABSTRACT

This paper explore the benefits of a bottom-up spatially enabled engineering building-based energy framework in identifying neighbourhoods, and community's building aggregated areas with spatial patters. We argue that an area-based approach allows more houses to be targeted in places where local area characteristics show inefficient elements, and may therefore potentially capture a greater number of households per unit of cost, compared to the existing self-referral methods. We propose a spatial method to show the extent of building envelopes, heating systems and temperature controls. Heating controls, which are not recorded in the United Kingdom Homes Energy Efficiency Database (HEED), but we believe would be considered good practice to maintain balanced temperatures around the house, and also potentially reduce the complexity in modelling the thermal zones. Additionally, heating controls are seen as compulsory in new building regulations, an eligible measure in Green Deal and Energy Company Obligations, and in the United Kingdom Department of Energy and Climate Change (DECC) heat strategy. This paper has taught us that the emerging picture surrounding local energy modelling and that, for example, singularities such as group heating and district heating (decentralised energy supply) have a great impact on final energy consumption calculations.

1. Introduction

The first reason for researching energy use in cities is that it is rapidly increasing. Cities use a significant proportion of the world's energy and because urban population and economic activities within the city are also increasing, the urban energy use is also projected to grow. The Organisation for Economic Co-operation and Development [1, p. 137] argues that by 2008 half of the world's population lived in cities, and by 2030 cities will house 60% of the worlds population, equivalent to the total global population in 1987. Detailed analysis from the International Energy Agency [2, p. 44] shows that global energy use in the residential sector increased 19% between 1990 and 2005. The second reason is that the Local Authorities (LAs) [3] play a key role in the achievement of the energy and climate objectives through formal commitment to be achieved by the implementation of Sustainable Energy Action Plans. This stems from their direct energy use in the building stock, but also because they act as planners, and have the authority to regulate various activities (e.g., community energy services). Cities are also producers and suppliers of energy (e.g., district heating schemes), and most importantly have experience in translating international and national policies (e.g., [4] on the energy performance of buildings) into local actions.

In the last five years, there has been interesting domestic energy research in cities using the spatial approach. This review will provide a useful understanding of current efforts made by energy modellers to provide a solution for the urban energy consumption patterns planning.

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Nomenclature

AECI	the Annual Energy Consumption (use) Intensity (density)
BREDEM	The Building Research Establishment Domestic Energy Model
CHM	Cambridge Housing Model
CHP	Cogeneration of electricity and heat
DA	Data aggregators
DECC	United Kingdom Department of Energy and Climate Change
DFEE	the Dwelling Fabric Energy Efficiency Methodology
DUKES	Digest of UK energy statistics
EED	Energy Efficiency Directive
EHS	English Housing Survey
HEED	United Kingdom Homes Energy Efficiency Database
LAs	Local Authorities
LLSOAs	Lower Layer Super Output Areas
MLSOAs	Middle Layer Super Output Areas
MPAN	Meter Point Administration Number
NCRM	Newcastle Carbon Route Map
NCRF	Newcastle Carbon Route Framework
NEED	National Energy Efficiency Data-Framework
SAP	The Standard Assessment Procedure
SCU	whole building self-contained unit
SEAPs	Sustainable Energy Action Plans
TVRs	Thermostatic Radiator Valves
YHN	Your Homes Newcastle

Examples include: [5], who addressed the scale of the modelling by proposing a 'whole building' self-contained unit (SCU) as a physically meaningful unit that has its own energy metering and its relationship to buildings. This approach allows city-scale modelling based on the characteristics of an individual building in Leicester. Ref. [6] used a three-dimensional digital model of the city of London to make a series of geometrical measures: building volume, exposed surface area and plan depth. Ref. [6] found a strong correlation between the exposed surface area with the combined energy consumption, and the plan depth and the electricity consumption.

From the literature review, it is clear that spatial modelling is an important aspect of energy consumption; also local energy consumption patterns are important to alleviate fuel poverty [7] and for micro-generation supply [8]. This paper attempts to address some of these issues - or shortcomings for other models - and also the important impact on policies [9] in sub-city areas. Our work is one of the first modelling exercises to be undertaken within the city limits that are set in the context of a unique identification of Local Land and Property Gazetteer in a spatially enabled database to explore similar patterns of energy consumption and identify building aggregated areas with spatial expression patterns most similar to a given parameter within the building energy profile. The National Land and Property Gazetteer is updated on a continual basis by the local authorities in England.

Furthermore, the literature review has highlighted the benefits arising from a spatially enabled approach. From the spatial analysis, our paper show that it is possible to use operators and develop queries that enable: the representation of key energy estimators, a comparison of the effect of using different local area characteristics on the patterns extracted, which are potentially useful for measures below local authorities in sub-city areas. Our paper links secondary sources either by Unique Property Reference Number (UPRN) code, Topographic Identification (TOID) and/or address, instead of using a grossing methodology that adjusts national dwellings to totals by region. The secondary information is generally available in some form to many, if not all, local authorities.

Using a case study from the United Kingdom [10], we develop a bottom-up spatial local energy end-use framework [11] that sets out the sub-city energy aggregated planning direction, the Newcastle Carbon-Route Framework (NCRF), and establishes the single dwelling as our unit of detail. NCRF is a spatially referenced parameterised per-dwelling domestic energy framework developed with the purpose of estimating the energy (electricity and gas) consumption of sub-city areas. Elsewhere, [12] analysed holistically the residential energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland. In the United States, [13] analysed patterns of direct fuel consumption for on-road transportation and in buildings and industry in urban counties.

The aim of this paper is to use the NCRF spatially enabled model and rich thematic database facilities in developing queries that enable spatial analysis, i.e., a comparison of the effect of using different local area characteristics on the patterns extracted, which we argue are potentially useful to inform the design of energy efficiency policies in sub-city areas.

This paper is structured as follows: Section 2 explains the data formation and assumption of the NCRF. Section 3 reviews the key Energy Efficiency directive (EED) and the Energy Performance. Section 4 analyses the spatial characteristics of the energy consumption patterns of building envelopes, heating systems and temperature controls. Section 5 discusses these findings, and finally, Section 6 makes suggestions concerning the relevance of these findings.

2. Domestic energy model framework

This section describes the assumptions within the developed of NCRF and how these affect the analysis of the results. Fig. 1 shows the NCRF energy intensity estimation. As can be seen in Fig. 1, the NCRF framework is comprised of the Newcastle Carbon Route Map (NCRM) data sets [14], energy modelling aggregation, validation method and energy spatial patterning.

Four classes of data sets were used to build NCRM: dwelling domestic stock data, building physics data, household data and climate data, and each one is described in turn here. The assumptions in the modelling methods are described in Sections 2.1 and 2.3 and DECC and NEED data is used to assess the performance of the framework is in Section 2.4.

The NCRM has two data sets at the resolution of the individual dwelling, with one data set of rough approximations of household occupancy and three average regional scale landscape and climatic data sets. The NCRM individualized data sets are the dwellings' domestic stock data and building physics data. The coverage of both data sets is different; whilst the domestic stock data have 100% coverage, the building's physical data do not. The spatial interpolation strategies are used to complete the missing survey data. Framework assumptions are presented in three sections: Section 2.1 on using Cambridge Housing Model in the framework, Section 2.2 on applying interpolation and imputation methods to NCRM for building a full SAP record, and Section 2.3 on the number of thermal zones for a building. Assumptions on using DECC and the National Energy Efficiency Data-Framework (NEED) as a validator data set are given in Section 2.4.

2.1. The Cambridge Housing Model (CHM)

The CHM is the basis for the per-dwelling energy estimates. However, there are a number of assumptions built into the model that potentially impact on the results of the Energy Modelling Framework. The main assumptions in using the CHM in the framework concern the use of averages for climate data and occupancy.

The CHM [15] relies on regional and monthly climate data as part of