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Metrics of urban morphology and their impact on energy consumption: A case study in the United Kingdom

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ABSTRACT

Energy policies implemented by local authorities and targeted at the domestic sector have focussed on interventions, which are usually selected after an optimisation procedure. This paper identifies differences and similarities between three Medium Layer Super Output Area (MLSOA) districts in the United Kingdom (UK) and draws conclusions which prove to be useful to interpret other districts in the city and provide general rules for energy efficiency measures and distributed supply interventions in Newcastle upon Tyne, UK, and potentially beyond. The core argument aims at provide an important link between the energy-reducing and energy-increasing effects of four urban morphology characteristics in 'place-specific' neighbourhoods. Our methodology explores the potential application of the close relation between four urban morphological characteristics and the spatial aggregated building energy end-use in the roll-out strategy of interventions. Our findings first indicate that the combination of shape and size of continuous building classes (in a building class the main residential buildings are grouped by their age and building type) and their extent using patch areas potentially simplify retrofit campaigns. We argue that the whole continuous building class influences the building's thermal mass (the building massing) and their extent (the patch area or patch in short) and these are better descriptors for the energy use in the occupational phase of a building. Second, the building massing and the plot ratio (the ratio of the building floor area to the land area in a given territory) are a better descriptors of building density/mixing of land use and built form leading to the potential use of adequate distributed energy supply. Third, the way in which social and economic factors interact to shape area-based of household energy consumption leads to a possible better spatially-enabled policies for low income families; and fourth, the layout and orientation design of the neighbourhood may identify municipal sites for potential renewable energy projects. The use of the building massing and patch areas as spatial cluster operators simplify the complexity of aggregated building energy consumption by representing its spatial incidence through a smooth continuous surface. Additionally, building classes and its patch area extent show notable differences across different sub-city areas. Furthermore, the greater the number of building classes, the more diverse is the socio-economic make-up of a sub-city area.

1. The spatial energy end-use in cites

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 Cooperation and Development (OECD)[1] argues that by 2008 half of the world's population lived in cities, and by 2030 cities will house 60% of the world's population – equivalent to the total global population in 1987 [26,p. 137]. Detailed analysis from the International

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[1] The OECD is an international economic organisation of 34 countries, and was founded in 1961 to stimulate economic progress and world trade.

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Energy Agency[2] [19,p. 44] shows that global energy use in the residential sector increased 19% between 1990 and 2005. The second reason is that the LAs 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 (SEAPs) [10]. 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. the Directive 2010/31/EU [14] on the energy performance of buildings) into local actions.

In the United Kingdom, the Department of Energy and Climate Change (DECC), as part of the implementation and monitoring of local energy strategies, reports estimates of electricity and gas consumption data at various scales below local authority (LA) level. DECC reports individual dwelling energy consumption in the National Energy Efficiency Database (NEED) as part of the energy efficiency statistics, and aggregated dwelling energy consumption in the sub-national energy consumption statistics. Aggregated data are in two geographic areas: Middle Layer Super Output Area (MLSOA) and Lower Layer Super Output Area (LLSOA).[3]

Our work supports analysts working on distributed energy supply programmes in sub-city areas where DECC published data does not geographically match policy and energy needs through the use of common values for the Unique Property Reference Number (UPRN), the address, and the building Topographic Identifier (TOID). In the UK, the UPRN identifies a Basic Land and Property unit (BLPU) whereas a TOID is a unique reference identifier associated with every building within Ordnance Survey's large scale topographic mapping. UPRN, address and TOID have made possible the use of different combinations of thematic and spatial resolutions and their interaction with the aggregated domestic energy consumption estimation. Our work investigates how the energy consumption changes at different aggregates of domestic homes according to different local area characteristics. Energy planning at decentralised level would be to prepare an area-based Distributed Target Scenarios (DTS) to meet energy needs using a bottom-up approach and disaggregated data [18,p. 735].

The energy and carbon saving potential varies between cities, reflecting their particular landscape, the physical characteristics of the building stock, the heating supply systems, and the household's real characteristics. These differences need to be understood via a domestic energy model; one common characteristic of cities is that the local area's aggregated demand for energy use provides economies of scale (less infrastructure unit cost per capita) as well as additional energy savings due to minimised distribution losses. However, one key activity often overlooked when quantifying interventions in DTSs is the implementation of the roll-out strategy. This paper explores the relations between aggregated building's energy consumption and a possible roll-out strategies using four characteristics of the urban morphology in building aggregates covering spatially contiguous sub-city areas. In cities, the concept of spatially enabled database allows data integration to ensure multi-sourced thematic data and interoperability. Thematic information may be integrated through key identifiers (UPRN and TOID) and the result is a comprehensive, spatially enabled database embedded in the building energy estimations.

[2] IEA is an autonomous intergovernmental organisation established in the framework of the Organisation for Economic Co-operation and Development (OECD) in 1974, serving as an information source on statistics on the international oil and energy sector.

[3] These statistics are experimental.

Component Matrix[a]		
	Component	
	1	2
age	-.156	.823
number of floors	.879	-.006
dwelling size	-.693	-.073
wall construction	.193	.824
building form	.888	-.080
heating	.337	-.015
Extraction Method: Principal Component Analysis.		
a. 2 components extracted.		

Fig. 1. Principal component analysis matrix.

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	2,217	37	37
2	1,369	23	60

Fig. 2. Factor analysis total variance explained.

Using a case study from the United Kingdom, Calderón et al. [4] developed a bottom-up spatial area-based local energy end-use framework that sets out the sub-city energy aggregated planning direction, the Newcastle CarbonRoute Framework (NCRF). NCRF utilises Newcastle CarbonRoute Map (NCRM) [3] and adds on the energy modelling aspect through linking with the English House Survey (EHS) as input to the Cambridge Housing Model (CHM). This provides the means to produce building level energy consumption estimates which in turn can be analysed both spatially and aspatially (e.g. by building type). NCRF establishes the single dwelling as the unit of detail. CHM Outputs are also adjusted to match the Digest of UK Energy Statistics (DUKES) data for gas and electricity use each year. This means that effectively it also includes a weather-adjustment [29,p. 3]. The key modification in CHM is the use of 19 °C (292 K) as the baseline demand temperature for the living area for all dwellings – SAP uses 21 °C.

The dwelling definition includes a dwelling-house and a flat. In general, a dwelling-house does not include a flat or a building containing a flat. However, dwelling-houses do include single storey bungalows. The bottom-up spatially enabled database provides information not only on the magnitude but also the extent of neighbourhood variations [6] i.e. indicating a significant correlation between dwellings with similar energy profiles in neighbourhoods in which these dwellings are in close proximity to each other. Bahu et al. [1] argue that the introduction of the spatial dimension to our understanding of all aspects in the energy model involves a 'paradigm shift'[4] that extends the traditional tabular energy consumption aggregates to a modern spatially enabled energy model.

Results from our component matrix show higher correlation (association) between dwelling size, building form and number of floors (principal component one PC_1); and between age and wall construction (principal component two PC_2) as seen in Fig. 1. The total variance table informs the cumulative proportion of variance criteria that can be met with two components. Also, PC_1 and PC_2 satisfy the criteria of explaining almost 60% or more of the total variance (see Fig. 2).

The urban morphology, which refers to the spatial configuration of urban land use within an urban area, has profound influences on

[4] A fundamental change in approach.