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ScienceDirect

Procedia Engineering 180 (2017) 433 – 442

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

How can a multi-scale analysis guide smart urban energy demand management? An example from London City Westminster Borough

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Abstract

The study of urban-scale energy consumption due to buildings follows the archetype approach where samples of representative buildings are analysed and then results are extrapolated across the city. Lack of reliable data has so far been the main reason hindering different approaches; nevertheless, significant improvements have been achieved recently. In this work we use the Westminster Borough of London City, as a case study to illustrate how a dynamic high-resolution dataset for the energy demands of the whole area can be analyzed using the Multi-Resolution Analysis (MRA) to provide insights into the urban- and sub-urban (e.g. district) scale energy demand and therefore suggest how such an analysis can be exploited to guide smart urban energy-demand management. Specifically, we analyze full-day (24-hr) evolutions of the urban-scale energy heating/cooling demands together with high-resolution information on the building density, height and the population. By introducing the scale-adaptive approach, our analysis provides suggestions for e.g. peak hour identification and localization, as well as the identification for example of best-neighboring candidate zone area for extra energy supply in case of power failures.

Peer-review under responsibility of the organizing committee iHBE 2016

Keywords: Urban-scale energy analysis; Multi-resolution analysis; building energy consumption; London Westminster

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Peer-review under responsibility of the organizing committee iHBE 2016
doi:10.1016/j.proeng.2017.04.202

1. Introduction

More than 54% of the world's population resides nowadays in urban areas (United Nations, World Urbanization Prospects: The 2014 Revision, (ST/ESA/SER.A/366).), leading to an unprecedented rise on the energy demands associated to retain and improve urban life quality standards. Specifically, the average energy consumption by the building sector only currently accounts approximately for the 30% of the worldwide energy consumption (Swan and Ugursal, 2009). This rise in urban energy consumption is also causing a steep increase on emissions of greenhouse and other pollutant gases which in turn results to severe impacts on urban climate and public health. This is of particular concern to governmental agencies and regulatory authorities who seek to develop strategies for efficient and sustainable use of energy within the building sector as well as overall. For this purpose, a number of multi-criteria analyses and models are being sought to help decision-makers to establish such sustainable energy management strategies (Swan and Ugursal, 2009). So far, the study of urban energy consumption has been considered at the level of an individual building. Most studies to date follow the archetype approach where few representative buildings are analyzed and then results are exploited across the stock (Tian et al, 2015). A complete dataset has recently emerged from the Energy Efficient Cities Initiative (EECi) (http://www.eeci.cam.ac.uk/) where a range of urban information including building heights, population and energy consumption for heating and cooling is included; the data also cover an entire calendar year thus enabling distinguishing between different seasons.

The aim of this paper is to provide new insights into urban energy consumption and thus urban energy management using a novel Multi-Resolution Analysis (MRA) in order to surface out the multiscale nature that can be embodied in the urban energy management and planning. MRA has been used so far for its scale-adaptive and spatially-varying characterization capacity in the atmospheric urban boundary layer characterization and parametrization (Mouzourides et al., 2013; 2014) as well as in the context of urban data use for weather and climate modelling (Ching, 2012; Ching et al., 2014). In this paper we illustrate the insights that an MRA analysis on the energy data can surface out, and therefore elucidate and enrich urban energy management and planning. For this purpose, we make use of the urban-building and energy demand dataset from the London Westminster Borough derived from EECi.

2. Urban Energy Data Analysis: MRA based methodology

2.1. Dataset for urban building energy demands

A complete dataset has recently emerged from the EECi (http://www.eeci.cam.ac.uk/) where a range of urban information including building heights, population and energy consumption for heating and cooling is included. Specifically, data of urban-building energy demand, building heights and population has been obtained for the London Westminster City Borough. In particular, the raw data on building energy consumption has been further processed using building energy models simulations in order to derive the corresponding consumptions for building heating and cooling. The data was derived for an entire calendar year and it also provides the diurnal variations for typical days in different seasons. The data on urban building heights has also been further processed in order to derive the planar packing density information of the city, that is the ratio of the built area over the total surrounding planar area, a parameter that in building science and urban physics is linked to air flow ventilation capacity of the city and therefore to the corresponding energy demands for heating and cooling in different seasons.

In Fig 1shows the spatial visualization of the Westminster's Borough data as derived for (i) the building heights across the city, (ii) packing density (λ_p) and (iii) population density. The dataset concerns the central business district (CBD) of Westminster City, with an approximate coverage area size of $6000 \times 7000 m^2$ at an initial (highest) resolution of 10mx10m per pixel. As noted from Fig 1 b, that tallest buildings of Westminster Borough are located centrally and eastward, where most of the buildings are designated as offices and retail stores (Tian et al, 2015). On the other hand, most of the population is located mainly in the south and northwest areas (Fig 1 d).
In this paper, we investigate the associations of building height, packing density (λ_p) and population density with energy demand, as we note from observations that these parameters are expected to have high impact on energy demand (e.g. Choudhary and Tian, 2014).

High spatial resolution data from Geographic Information Services (GIS) related to building and land use of the entire building stock, were used as input to dynamic energy simulation models. The energy consumption for a set of representative buildings of the area was computed and the simulation output extrapolated to all buildings which have