Renewable Energy xxx (2014) 1–8

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London

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ARTICLE INFO

Article history:
Received 20 February 2014
Accepted 17 June 2014
Available online xxx

Keywords:
Urban morphology
Solar potential
Renewable energy
Neighbourhood
London

ABSTRACT

Amongst academics and practitioners working in the fields of urban planning and design, there has been an on-going discussion regarding the relationships between urban morphology and environmental sustainability. A main focus of analysis has been to investigate whether the form of cities and neighbourhoods can be related to their energy efficiency, especially regarding the energy intensity of buildings and transportation. However, to analyse the overall energy performance of urban systems, both the consumption and the generation of resources need to be assessed. In terms of urban environmental sustainability, the potential to generate renewable energy within the city boundaries is a research topic of growing interest, being solar energy one of the main resources available.

This study uses neighbourhood-scale statistical models to explore the relationships between aggregated urban form descriptors and the potential to harvest solar energy within the city. Different possible scenarios of urban morphology in Greater London are analysed and variables of urban form are tested with the aim of increasing the solar energy potential of neighbourhoods. Results show that by optimising combinations of up to eight variables of urban form the solar irradiation of roofs could be increased by ca. 9%, while that of façades could increase by up to 45%. Furthermore, based on these results, a series of trade-offs needed for the optimisation of conflicting variables is unveiled. Finally, some recommendations for design strategies are offered with the aim of helping urban planners and designers improve the solar energy potential of new or existing urban areas.

1. Introduction

It is widely accepted that generating energy within the city boundaries can bring many advantages, a main one being the increase in efficiency due to the reduction of energy transmission losses. Amongst all possible sources of renewable energy available in the urban context, such as wind, geothermal and solar energy, the latter is probably the most popular and has been studied to great lengths. This paper reports on the results of a collaborative research effort aimed at developing a methodology of urban modelling for evaluating the solar renewable energy potential (REP) of cities, based on their urban morphology.

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http://dx.doi.org/10.1016/j.renene.2014.06.028

1.1. *Urban morphology and renewable energy potential of cities*

In the last decades there have been many examples of research looking at the solar potential of cities, including both passive solar gains and the potential of harvesting solar energy to heat water and to generate electricity. Back in 1997, Project ZED [1] used the RADIANCE ray-tracing software to investigate the solar exposure of cities and the environmental contributions from solar penetration in an urban area. Some years later the PRECis project [2] built upon the experience of Project ZED to assess the potential for renewable energy generation in cities, by exploring the relationships between urban form and the energy and environmental performances of buildings. Furthermore, Yun and Steemers [3] analysed the impact of urban settings on the potential for energy generation using façade-integrated photovoltaic (PV) panels.

Further on the relationship between urban morphology and solar potential, the SOLURBAN project [4] used the extraction of urban form descriptors from 3D models and built upon the results

Please cite this article in press as: Sarralde JJ, et al., Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London, Renewable Energy (2014), http://dx.doi.org/10.1016/j.renene.2014.06.028

of previous research [5,6] to evaluate the solar potential of three Swiss cities with different levels of building density. By comparing the results of the three cases, an inverse relationship was found between urban density (measured as plot ratio) and the potential for façade and roof mounted PV and solar thermal collectors. Other studies [7,8] followed up on these results and looked into more detail at the efficacy of using aggregated measures of urban form such as the height-to-width ratio of street canyons, site coverage, plot ratio, horizontal distribution, and vertical uniformity of buildings, amongst others, for calculating irradiation availability at district level. Meanwhile, more recently, further tools to perform neighbourhood-scale analysis of solar availability have been developed. SUNtool [9] and CitySIM [10] utilise complex computer modelling techniques to predict the performance of various energy generation technologies, including solar, within the city boundaries.

This paper builds upon the existing body of research to further expand the understanding of how this knowledge could influence urban planning and design to increase the solar potential of cities.

1.2. Aims of this study

The aim of this analysis is to test whether the knowledge obtained on the relationships between urban morphology and solar potential can help create cities that are more suited for harvesting solar energy. This is done by optimising certain parameters of urban morphology in order to increase the solar potential of buildings' roofs and façades. It is acknowledged that the variables of urban form involved in this analysis are not easily modified in the case of existing neighbourhoods. Hence, this parametrical exploration should be primarily considered as a theoretical exercise. However, it is expected that the insights gained through this research will be useful when briefing and designing new neighbourhoods or towns and to help guide planning policy in order to increase the solar REP of cities.

2. Methodology

This section offers a brief summary of the data and methods used in this study.

First, spatial data was used to characterise the urban morphology of neighbourhoods in London, UK, by computing a variety of aggregated urban form descriptors. The same data was then used to model the solar irradiation of building envelopes by means of computer simulation. The next step was to perform a statistical analysis to explore the interrelations between the aggregated descriptors of urban morphology and the solar irradiation of building envelopes. The outcome of this analysis was the creation of two separate models capable of predicting (to different degrees) the solar irradiation of roofs and facades, based on the urban form of a neighbourhood. These models are named *Roof-SolREP* and *Façade-SolREP*, respectively. Finally, the two models were used to test different scenarios of urban form. The aim of this was to explore whether the solar potential of building envelopes could be optimised by introducing changes to the urban morphology of neighbourhoods.

2.1. Urban form characterisation

Table 1 presents the data sources used for the calculation of 18 different aggregated descriptors of urban form. These were extracted from spatial data using computer code written in the Python programming language and linked to a Geographical Information Systems (GIS) platform (using the ArcGIS ArcMap 10.0 software). The 18 descriptors used were categorised in 5 groups and are listed in Table 2. Furthermore, all data was aggregated to the UK Census geographical division of Lower Layer Super Output Area (LSOA), which is the unit of analysis in this study and is assumed to represent a typical neighbourhood of Greater London, as illustrated in Fig. 1. By definition, each LSOA contains a population of ca. 1500 inhabitants. Therefore, different LSOA can show great variations in terms of area, building typologies, building use, and urban morphology.

Table 1
Data sources for the calculation of urban form descriptors.

Data set	Data source
UK census (2001), generalised land use database (GLUD, 2005)	Neighbourhood statistics: http://www.neighbourhood.statistics.gov.uk/
Ordnance survey mastermap: building heights & footprints	University of Edinburgh's EDINA, Digimap collections: http://edina.ac.uk/

Table 2
Data sources for the calculation of urban morphology descriptors.

Group	Descriptor	Units
Building typology	1) Share of detached houses	%
	2) Share of semi-detached houses	%
	3) Share of terraced houses	%
	4) Share of apartment blocks	%
Vertical & horizontal distribution	5) Average building height	m
	6) Standard deviation of building heights	m
	7) Average distance between buildings (nearest neighbours from centroids)	m
Land use	8) Share of area covered by domestic buildings	%
	9) Share of area covered by roads	%
	10) Share of area covered by private gardens	%
Building geometry	11) Average building volume	m^3
	12) Average building perimeter	m
	13) Average building orientation (variation between the main longitudinal angle of building footprint and due north)	°
Building density	14) Plot ratio (total floor area divided by total area of neighbourhood)	
	15) Site coverage (share of total built area)	%
	16) Total floor area	m^2
	17) Total area covered by buildings	m^2
	18) Total area of neighbourhood	1 K m^2

2.2. Modelling solar irradiation of buildings

The data on solar irradiation was obtained using computer simulations. For roofs, the analysis was carried out using the 'Area Solar Radiation' tool form the ArcGIS ArcMap 10.0 software package. This tool derives solar radiation from a raster surface, in this case from digital elevation models (DEM) based on the buildings of a LSOA, and produces an output raster showing radiation values in watts hours per square metre (Wh/m^2). The simulation was carried out on a dataset containing 4718 LSOA samples, which represent 77.8% of all LSOA in Greater London. The analysis of solar irradiation of façades was computed using the 'Solar Access Analysis' tool of the widely used Autodesk Ecotect Analysis 2011 software. This tool computes detailed shading masks for each building within a LSOA and simulates the solar irradiation of all vertical elements. The solar radiation was calculated using average daily values for each month of the year, using historic weather data for London. Because this analysis was much more computing intensive than the simulation of roofs, it was carried out for a smaller sample of 93 LSOA in the London Borough of Camden.

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