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A model for mapping the energy consumption of buildings, transport and outdoor lighting of neighbourhoods

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ABSTRACT

Energy consumption of urban areas is a relevant theme for sustainable spatial planning. Through the integration of energy and urban planning issues, it can be identified a suitable strategy to face climate change. This study aims to evaluate overall energy demand of existing urban neighbourhoods, considering the most energy intensive sectors within a city. Using GIS software, the method provides energy mapping of neighbourhoods, allowing to improve the insight of energy demand of cities and to develop a preliminary assessment for future scenarios. The method has been applied to a neighbourhood of the municipality of Catania in southern Italy. Methodology and earliest results are discussed in this paper.

1. Introduction

Climate change represents one of the major challenges of the 21st century. The change of the climate system has been correlated to human activity with 95% of confidence (IPCC V report, 2013). Its major effects, such as increasing global temperatures, require immediate actions since adapting to impacts in the future will be more difficult and costly (UNEP, 2010).

Substantial action has to occur at the city level where half of world population lives (Gossop, 2011) and 75% of the world's primary energy is used, producing about 60% of all GHG (UNHabitat, 2014 on http://unhabitat.org/urban-themes/energy). In addition, urban areas have the potential to reduce CO_{2eq} emissions significantly, as part of the energy system (Rutter & Keirstead, 2012). For this reason cities have been defined as part of both problem and solution (Lindseth, 2004).

Cities are complex systems (Batty, 2012), where urban energy flows arise from sub-systems such as buildings, transport, human activities and green areas (Kellet et al., 2013, Ascione et al., 2013) and their interactions. Within cities, relationships and interactions occur through different land uses, infrastructure systems and built environment at a range of scales from individual buildings to the city (Walsh et al., 2011). Energy demand resulting from each system varies widely according to urban and climate characteristics.

Urban planning and energy policies were traditionally separate approaches. Consequently, in the last decades, energy issues have been almost neglected in both urban planning strategies and building processes. Yet, recently European energy policy has concentrated also on the contribution of cities on overall energy demand. Therefore, the need for an approach to integrate energy action planning and urban planning has arisen.

While in literature, the assessment of energy consumption is mostly developed with sectoral approaches, frequently focusing on building sector (Ascione et al., 2013; Dall'O, Galante, and Torri, 2012; Fracastoro & Serraino, 2011; Caputo, Costa and Ferrari, 2013; Aksoezen, Daniel, Hassler, & Kohler, 2015; Theodoridou, Papadopoulos and Hegger, 2012), this paper aims to assess and map global energy consumption, integrating three components of urban systems: buildings, transport and outdoor lighting. The model provided by this study is an analytical tool that allows evaluating global energy demand of existing urban neighbourhoods regardless of reliable data availability. The applicability to urban neighbourhoods makes the model suitable for spatial planning applications. District level is widely considered the right scale for the implementation of energy and planning actions in sustainable town planning (Special EU, 2014, Kellet et al., 2013). Neighbourhoods represent the intermediate scale between individual buildings and the whole city and embrace much of the most influencing factors of carbon emissions. Energy maps are provided to represent results, allowing the identification of both energy intensive areas and influencing factors.

The model may be further applied to configure urban energy scenarios through GIS modelling. Geographic information systems are suitable and convenient tools to represent urban issues and to develop advanced

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Nomenclature

EP	energy performance index for winter heating (kWh/m^2 year)
Q	thermal need (kWh)
S_f	windows surface (m^2)
S_{UTot}	sum of surface of floors of buildings (m^2)
S_d	dispersion surface (m^2)
H	heat transfer coefficient (W/K)
U	transmittance value (W/m^2 K)
B	correction factor
ACH	air change rate (1/h)
A_{pav}	net overall floor area of a building (m^2)
S/V	surface to volume ratio (1/m)
B_{uild} E_{el}	electric Consumption indicator
Eel	average electric energy per inhabitant
Z	total transport energy
o_i	workers living in zone i
d_i	workplaces in zone i
c_{ij}	energy consumed travelling from zone i to zone j by the selected transport mode
t_{od}	number of trips from zone o to zone d to minimise Z
l_{od}	shortest distance between zone o and zone d (km)
LF_v	load factor
Ev	unit energy consumption of the transport mode chosen (MJ/km)
nlamps	number of lamps
P	power of lamps (kW)
h_{el}	number of hours of power
Il	lighting index (kWh/m^2 y)
$E_{(th\_B)}$	total thermal Energy of buildings (kWh/y)
Cv	capacity of the vehicle (spaces)
Ol	outdoor lighting energy consumption (kWh/y)
E_j	neighbourhood energy consumption (TOE)

Abbreviations and acronymon

DD	degree-days (°C days)
ISTAT	Istituto Nazionale di Statistica
OD	origin destination
TED	transport energy dependence
SEAP	sustainable energy action plan
BRT	bus rapid transit
TOE	tonne of oil equivalent
GIS	geographic information system
GHG	greenhouse gases
ISO	International Standards Organization
UNI	Italian National Unification
DM	ministerial decree
inhab	inhabitants
PAX	passenger

Greek letters and symbols

η_g	global efficiency of the heating system
ρ_a	air density (kg/m^3)
θ_{end}	average internal gain rates(W/m^2)

Subscripts

TR	transmission
VE	ventilation
End	endogenous
Sol	solar
Nd	need
Pav	floor
H	heating

spatial planning analysis with energy concerns (Fistola, 2009). Energy mapping at urban scale, developed in GIS, allows the integration between energy evaluations and spatial planning for neighbourhoods and the assembling of several data. Combining urban energy mapping and scenario analysis allows one to determine integrated planning — energy strategies and to support sustainable political choices on existent urban areas.

The paper first presents a brief review of the literature relating to existing energy models and then the following section describes the proposed energy model. The application of the method to an Italian city is described in Section 3 and, finally, Section 4 summarises the main results and discusses further options of research to improve and reproduce the model.

1.1. State of the art

While energy consumption of individual buildings is a widespread topic, the analysis of energy consumption at the neighbourhood level and the mapping of results have been recently developed with a plurality of approaches. Both sectoral and integrated models are performed, the former regarding either residential or transport sector, the latter aggregating components of energy consumption.

Two approaches for the energy modelling techniques of residential sector are identified by Swan & Ugursal (2009) through a complete analytical classification of residential energy models reported in literature. The main difference between the approaches relies on the use of different parameters, the levels of input information and the calculation techniques (Swan & Ugursal, 2009). Bottom up models are structured from lower levels of disaggregated data towards high level of general output. From the definitions given by Swan & Ugursal (2009) the model developed in this paper is a bottom up model. Despite classifications, models rarely fall into a unique category completely.

Pereira & Assis (2013) developed a model to quantify the energy consumption of the residential sector of the city of Belo Horizonte in Brazil. The methodology is based on the combination of a variety of data drawn from census surveys and statistical studies. The energy consumption of urban areas is shown on maps for planners and decision makers.

Dall'O et al. (2012) developed a model for the evaluation of the energy performance of existing building stock, applied in Carugate, Italy. The model can be classified as a mixed method integrating aggregated statistical and individual building approaches. Data are collected from energy audits on sample statistically selected buildings and are managed in a GIS platform. By data processing, linear regressions correlating EP_H and S/V ratio for different periods are constructed.

Ascione et al. (2013) performed a model to assess the energy demand of buildings for both winter and summer. The energy demand of urban areas is mapped, setting the Urban Energy Maps for the historical centre of Benevento. The method determines the energy performance of buildings by simplifying the national standard procedure.

Howard et al. (2012) implemented a model to estimate the energy end-use intensity for space heating, domestic hot water, electricity for space cooling and electricity for non-space cooling of buildings in New York City. The energy intensities are regulated using ZIP code level electricity and fuel use data.

Filogamo, Peri, Rizzo, and Giaccone (2014) proposed a method with a differentiated approach to assess the energy consumption of the existing building stock. Virtual buildings are identified to represent classes of buildings in an energy perspective. The methodology has a regional scale and has been implemented to the residential sector of Sicily, Italy. Among integrated models, Jones, Williams, and Lannon (2000) developed the Energy and Environment Prediction Model (EEPM), an analytical tool to assess energy use and carbon emissions for different sectors in urban areas. Separate sub-models for each sector of the built environment have been created to quantify specific energy