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Characterization of building thermal energy consumption at the urban scale

Guglielmina Mutani [a], Chiara Delmastro [a*], Maurizio Gargiulo [b], Stefano P. Corgnati [a]

[a]*DENERG, Politecnico di Torino, C.so Duca degli Abruzzi, 10124 Torino, Italy*
[b]*E4SMA, Via Livorno 60, ENVIRONMNET PARK, Torino, Italy*

Abstract

The ongoing urban transition toward decarbonized energy systems has raised the attention on local energy planning practices. Besides the multiple actors involved in the planning process, the complexity of the urban energy systems requires the elaboration of heterogeneous data. In such contest, the paper introduces and compares two GIS-based methodologies for supporting the spatial characterization of the local residential built environment in terms of building distribution and space heating energy consumption. Starting from the assessment of residential consumption, a third method for the characterization of non-residential building thermal energy consumption is proposed. From a bottom-up perspective, in both residential models all the buildings are geo-referenced and clustered according to their thermo-physical characteristics. From a top-down perspective, energy balance data are used to calibrate the bottom-up results and to match the total building loads. The procedure, tested on the city of Turin as case study, allows assessing the energy use of buildings and to create urban energy maps.
The energy spatial characterization of a territory is the basis for performing short and long-term scenarios analysis. Results of this method can be useful to: i. decision maker to understand the current state of the territorial energy consumption to identify critical energy intense areas; ii. citizens for visualising their energy consumption and iii. researchers for setting up the basis of further urban analysis.

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Keywords: building stock; urban; energy modeling; GIS; space heating

* Corresponding author. Tel.: +39.011.0902212.
E-mail address: chiara.delmastro@polito.it

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1. Introduction

Energy conservation in buildings is considered one of the key priorities for European low carbon transition. Many recent researches are focused on the investigation of procedures for assessing buildings energy consumption at different scales from single buildings to the whole building stock. Methodologies for the evaluation of energy consumption at single building level are currently well known and widely adopted by both architects and engineers [1]. The challenge is to improve the reliability of models results through occupant behavior analyses [2, 3]. On the contrary, the definition of standardized modeling procedures for the estimation of the energy consumption at the building stock level is still a challenging topic [4]. The large number of necessary information and data may lead to very time consuming and complex evaluations. Nevertheless, many studies have tried to define a procedure for large buildings stock energy consumption evaluations, mainly referred to the residential sector. First efforts used top-down data (e.g. energy statics) and current Standards and regulations for analytically defining the building distribution considering their primary energy consumption [5; 6]. By coupling building energy audit together with energy simulation, [7] proposed a methodology for classifying residential buildings according to the climatic zone, the construction period and the size. Moreover, the EPBD [8] required all the Member States to identify a set of reference buildings in order to create a common base for assessing the energy savings potential from building retrofitting at national or regional scale. The idea of Reference Buildings set has been thus created for defining representative buildings for modeling, in simplified way, existing and future performances of groups of buildings through buildings simulation [9; 10]. Starting from national/regional statistics and from building sample, the TABULA project [11] had the goal of creating a European common structure of building typologies and representative buildings. By this project, a preliminary evaluation of current energy consumption of the national building stock has been provided. Together with the development of computational tools, Geographic Information Systems (GIS) tools have supported local building stock analyses. A GIS- based procedure has been proposed and applied on the city of Milan by [4]: the approach uses statistical available data to evaluate the city buildings' energy performance and to define several scenarios for decreasing the energy consumption. By simplifying the methodology of the European Standard EN ISO 13790, urban energy maps have been created by [12] for historical centre of the city of Benevento, Italy. Mattinent et al. [13] proposed a calculation and visualization approach for energy use and greenhouse gas emissions estimation at the district level. Sample buildings and energy audits have been integrated with statistical data by [14] for assessing the energy performances of buildings of the Lombardia region (Italy). In the city of Ferrara (Italy), Fabbri et al. [15] highlighted how the creation of a GIS database of energy performance certificates may provide useful information about the building heritage and may support the identification of energy related indicators. In the city of New York, [16] estimated the building sector energy end-use intensity per unit of floor area for the different end-use services (space heating, space cooling, domestic hot water and electricity). They considered energy end-uses dependent on building destination function (office, residential etc.) and not from construction type and age of buildings. From all previous studies it results that a spatial explicit energy characterization of the stock represents a useful tool for the assessing cost-effective energy efficiency policies.

The choice of the approach it's clearly dependent on input data's availability and on the desired resolution of results. In this paper, a methodology for the assessment of urban residential space heating consumptions is proposed. The methodology allows choosing between two bottom-up GIS-based models that are proposed and compared. One model is related to the reference-building concept (Section 2.1) while the other assigns specific energy intensity to each building according to its compactness and construction period (Section 2.2). A last model, derived from non-residential building distribution and energy balance data is proposed for the characterization of non-residential buildings (Section 2.3). All the models are applied and validated on the city of Turin, Italy. Moreover, through top-down data (census data, energy statistics, Covenant of Major's data [17]) the urban non-residential building energy consumption is estimated and spatially distributed through the different census sections.

As a result, a methodological framework for comprehensively characterize the space heating energy profile of a city is provided.