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Effects of urban compactness on the building energy performance in Mediterranean climate

Agnese Salvati[a,b,*], Helena Coch[a], Michele Morganti[a,b]

[a]Architecture and Energy Research Group - School of Architecture of Barcelona,UPC, Av. Diagonal 649, 08028 Barcelona, Spain
[b]SosUrban_lab - DICEA department, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

Abstract

This work explores the double effect of urban compactness on building energy performance in a Mediterranean climate, namely the increase of urban heat island (UHI) intensity and the decrease of solar radiation availability on building façades. The energy demand of a test apartment has been calculated under varying conditions of UHI intensity and solar radiation for different urban textures. Results show robust relationships between the energy demand and the 'site coverage ratio' of the buildings. This demonstrates that compact urban textures are more energy efficient than less dense urban patterns in a Mediterranean climate.

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Keywords: Urban compactness; Mediterranean climate; Heat island; Solar radiation; Heating demand, Cooling demand, Urban energy modelling

1. Introduction

Urban areas are the main source of emissions responsible for climate change, the major part of which is due to the energy consumption for heating and cooling needs of buildings. The challenge of reducing the environmental impact

* Corresponding author. Tel.: +39 -06-44585665; fax: +39-06-44585186.
E-mail address: agnese.salvati@uniroma1.it

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of the built environment has thus boosted research into the modelling of building energy consumption at the urban scale [1,2], considering the energy phenomena that affect the energy performance of buildings in urban environments. This is aimed at developing urban analysis tools able to inform decision makers on the most effective policies and design strategies to improve the performance of the built environment at urban scale, instead of focusing on retrofitting the single building.

This paper contributes to this wider aim through the assessment of the impact of urban compactness on the energy performance of buildings in a Mediterranean climate. Urban compactness modifies building energy demand in two ways; on the one hand, it may contribute to the increase of the UHI effect [3,4], which entails an indirect impact on the energy demand. On the other hand, it modifies the solar radiation availability on the building façade, which is a key variable of energy demand in a Mediterranean context [5].

Several studies have investigated the relationship between compactness and solar access in urban textures [6–11] highlighting the possibility of enhancing solar collection on the building's envelope through the optimization of urban form. Many other studies have analysed the relationship between urban compactness and heat island intensity, using both experimental data and modelling tools [4,12–15]. According to these results, it is generally agreed that an increase of urban compactness entails a decrease of solar energy availability within the urban texture and an increase of heat island intensity in the urban area, especially at night.

Notwithstanding the extensive knowledge developed on this topic, a quantitative analysis of the global impact of urban compactness on building energy performance is still lacking. Urban compactness may have contrasting outcomes as regards the energy performance of buildings, especially in a Mediterranean climate, where cooling and heating demand are equally significant. The increase of urban compactness enhances the UHI intensity, which is positive for the heating and negative for the cooling; conversely, the decrease of solar radiation due to the increase of urban compactness has a positive impact on the cooling demand but is detrimental to the heating demand [5].

It is generally accepted that the UHI effect causes an overall increase of the energy demand in both hot and temperate climates [15–19], however the combined effect of increased UHI intensity and decreased solar gains has not yet been investigated. This paper aims at filling this gap, presenting an analysis of the global impact of urban compactness on the annual energy demand of residential buildings in a Mediterranean urban context.

2. Materials and method

The analysis is based on calculations of the energy demand for heating and cooling of a test apartment in different urban contexts, considering both the solar obstructions and the heat island intensity determined by the compactness of the urban structure.

A sample of urban textures was identified in Rome (Italy) and Barcelona (Spain) to represent the range of urban compactness in Mediterranean urban areas. The reference textures are: Borrel y Soler, Gracia and Raval in Barcelona and Centocelle and Don Bosco in Rome (Figure 1).

The compactness of the textures was measured using the 'Site Coverage Ratio' (ρ_{bld}), given by the ratio of the ground surface occupied by buildings to the total site area.

A normalised model was built for each urban texture; the normalised models are theoretical homogenous textures composed of simplified urban blocks repeated in a regular urban structure [20], with the same values of 'site coverage ratio' of the real urban textures. The simplified textures were modelled in Design Builder in order to perform energy simulation of the test apartment with EnergyPlus (v 8.1) as follows:

1) without urban context and using the standard weather file of Rome-Ciampino
2) within the different urban textures and using a specific weather file for each texture

The first simulation is representative of an apartment in a rural environment; the second takes into account the solar radiation obstruction and the UHI intensity determined by the urban context. To carry out the latter set of simulations, an urban weather file was created for each urban texture using the Urban Weather Generator (UWG) model [21,22]. The calculation of UWG model is based on a rural weather file (Rome-Ciampino in this case) and a parametric description of the urban area, which considers the morphological features of the fabric. Therefore, different urban weather files have been created using constant average values for all the urban parameters except the morphological ones, which were changed according to the different urban textures [5].