Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 142 (2017) 2877–2883

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Global energy performance of residential buildings: the role of the urban climate

Michele Zinzi[a]*, Emiliano Carnielo[b]

[a]ENEA, Via Anguillarese 301, 00123 Rome, Italy
[b]University of Rome Tre, Engineering Department, Via della Vasca Navale, 00100 Rome, Italy

Abstract

The energy performance of buildings are strongly dependent on climatic conditions. Climatic data are acquired by measuring stations, generally located outside of the city, hence their reliability in reproducing the thermal conditions inside the urban environment should be carefully addressed. This paper deals with the analysis of the urban climate in Rome, city characterized by a composite urban texture and a high variability of the residential building stock. Air temperature and relative humidity were monitored in different neighborhoods of the city and in a microclimatic station placed in a countryside area for one year in 2015. The monitoring allowed to quantify relevant microclimatic indicators and to use the data as input to predict the impact on the energy performance of a reference building. It was found that UHI is uniform in winter, while it is zone dependent in summer. UHI hourly intensities reached 10.5 and 7.8°C in winter and summer, seasonal UHI reched 1.5°C in city centre. Urban cooling and heating degree days showed relevant variations up to 26% respect to the countryside area. In terms of predicted energy performance, UHI causes a winter reduction up to 36% and a summer increase up to 42%.

Keywords: Urban heat island, urban thermal monitoring, energy performance of buildings,

1. Introduction

The building sector accounts for the highest energy end uses and CO2 emissions in Europe, with a share of respectively 40% and 36%. Energy policies enforced in the past years aims at achieving relevant energy savings in the sector to accomplish environmental targets fixed at international and national level. The Energy Performance of Building Directive [1] and its successive 2010 recast set general framework for the energy performance of existing and new buildings, empowering the Member States to set actions and measures needed to fulfill the requirements. Most of the actions, in Italy as in other countries, were aimed at improving the energy performance for space heating, the most energy consuming service, implementing tight requirements for the building envelope insulation

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.
10.1016/j.egypro.2017.12.411

and the efficiency of heating generation system [2]. Conversely, cooling energy performances were not adequately addressed, in particular for two main issues: the impact of too tight and insulated envelope on the building thermal response, as well as the effect of global warming and the urban heat island (UHI). The latter is defined as the increase of the urban temperature respect to that of countryside surrounding the city, which is a function of different causes: urban texture and morphology, radiative properties, construction materials, local wind speed and direction, anthropogenic heat, presence of green areas and water [3, 4, 5]. UHI is the most intensive effect of climate change that can be observed in urban areas and it affects the response of the built environment at several levels, with a significant impact on the energy performances of the buildings, as well as on the thermal comfort and health of the occupants [6,7,8].

It emerges, as a consequence, the issue of the reliability of reference climatic data in reproducing the climatic conditions within the city boundaries. Such data are, in fact, often acquired outside of the city, generally by the airports, where microclimatic conditions can be significantly different from those observed in the urban environment, which a building effectively interacts with. Several studies demonstrated the impact of the local climate on the response of the built environment [9,10,11]. This issue is worth of investigation for two main issues: a reliable prediction of buildings energy performance in their effective microclimate and the use of realistic reference climatic datasets for the definition of the energy requirements in energy policies and standards.

2. Objectives and method

The first objective of this paper is the field monitoring and analysis of the spatial and time evolution of the urban temperatures in the city of Rome, through continuous measurements of the air temperature and relative humidity in selected neighborhoods. A second objective is to quantify the impact of the different temperature profiles on the global energy performance of residential buildings, where the term "global" refers to the climate dependent energy services: space heating and cooling.

Five microclimatic stations were installed to achieve the objective of the work: four in different neighborhoods inside the city belt and one in a nearby countryside area. The description of the selected zones and their aerial view are presented in Table 1. The reference station (RS) is outside the eastern border of the city, It is a countryside zone mainly dedicated to agriculture with small isolated residential or industrial areas. The environment is thus undisturbed respect to UHI.

The collected climatic data are analyzed for the winter and summer periods n the first phase, observing differences among zones in terms of temperature average, profiles and relevant climatic indicators. The dataset used for this analysis refer to year 2015. In the next phase, the measured data are used to set-up hourly datasets to be used as input for dynamic simulations, able to assess the global energy performance of a reference residential building, ideally located in the selected neighborhoods. Air temperature and relative humidity of the monitoring stations were used as input, while a single reference solar irradiation dataset was used for all the zones, being these quantity constant in the area taken into account for the numerical analyses.

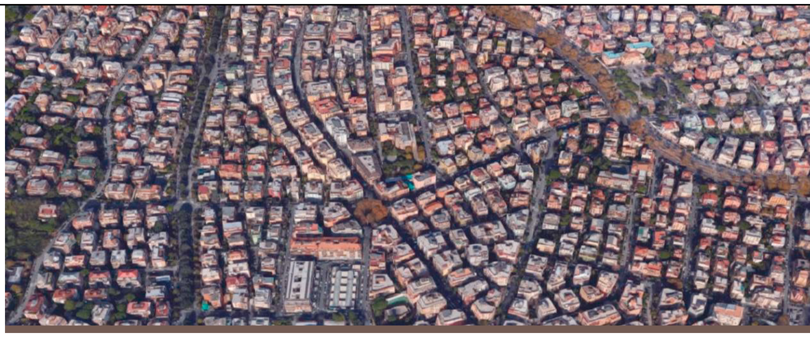
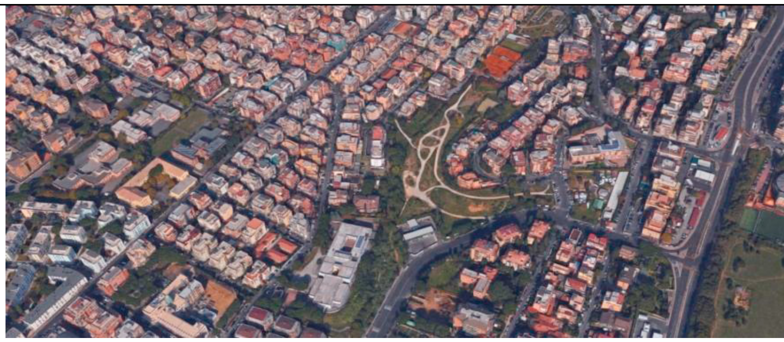
3. Urban climate monitoring

The study presented in this study refers to a wider monitoring campaign started in June 2014 and it is still going on. The microclimatic stations are mounted at 4-6 meters from the ground and under the canopy. Each station consists of a battery powered self-standing data logger and radiation shielded air temperature and solar humidity sensors, whose main characteristics are:

- 0.1°C temperature resolution in the -40 °C – 82 °C range;
- ±0.5 °C maximum temperature error in the -5 °C – 60 °C range;
- 0.1% humidity resolution in the 0-100% range
- ±5% maximum humidity error in the 10-100% range.

Measurements are acquired every 10 minute, different average time steps are used for the analyses and calculations following presented.

Table 1. Description of the urban monitoring stations

Zone	Description	View
CC	City centre. Densely built area with Middle Age to late 19th century massive buildings (height between 12-20 meters) and narrow streets (up to 10 meters), except few large boulevards. No vegetation, except few gardens belonging to historical mansions. Squares are without greenery and pavements made of basalt stone.	
MN	Monteverde neighborhood. Dating back to early 20th century, the neighborhood is densely built and characterized by 2-4 floors apartment blocks and narrow asphalt streets (8-10 meters). Limited presence of green area, mainly gardens annexed to the buildings and few boulevards with trees.	
ON	Ostiense neighborhood. Built in different decades of the 20th century, the prevalent typology consists of high rise buildings (30 meters). The spine of the area is a 60 meter wide boulevard with trees in between. Side streets are 10-20 meters large with no greenery. The area also characterized by small parks and large asphalted surfaces, used for common areas and parking lots.	
TN	Torrevecchia neighborhood. Peripheral area mainly built in the 40s and consisting of small apartment blocks (3-5 floors), most of them with small gardens around. The neighborhood has a composite texture: large boulevards alternates with narrow streets. Asphalt is used for pavements and there is a presence of extensive green areas around.	

4. Calculation

The numerical analysis was carried out using TRNSYS, a well-known and calibrated tool, able to model the thermal behavior of the building in transient regime [12]. TRSNYS operates through assembled calculation projects consisting of several objects, each of them with an assigned specific calculation task. The project implemented for the present study consists of the following tasks: weather data reader, filled with the climatic data acquired through the microclimatic stations; solar generator necessary to build the solar irradiation dataset,; several other tasks necessary for specific calculation tasks (exemplary cases: the calculation of the effective sky temperature and of the heat transfer through the ground); the building description routine, where all the building data are inputted; output of the main calculated quantities.

The building used for the study purpose is a four floors apartment block, representing one of the most recurring building typology in Italy. Each floor serves two apartments, all of them having three external façades. The main geometric data are: net floor area 89.7 m^2, net volume 242 m^3, windows area 13.6 m^2. Two envelope configurations are taken into account: without thermal insulation, representative of existing buildings, and insulated, representative of new or renovated buildings. U-values of the components are summarized in Table 2, values representative of typical construction technologies are selected for the non insulated configuration, while values for the insulated buildings refers to the national building code. Internal gains are set to 5 W/m^2 of sensible heat and 2.5 W/m^2 of latent heat according to Italian standard reference [13]. Windows are equipped with external solar protection devices, activated only during the cooling season and with a shading coefficient of 0.8.

Table 2. U-values of building components

Building configuration	U-roofs [W/m^2K]	U-wall [W/m^2K]	U-ground [W/m^2K]	U-window [W/m^2K]
Not insulated	0.99	0.96	1.14	5.68
Insulated	0.30	0.34	0.32	1.40

Simulations are carried out for the heating and cooling seasons: air temperature set-point is 20°C for the former; set-points of the latter are 26°C and 60% for respectively, the air temperature and the relative humidity. The energy performance calculations are carried out considering the space cooled/heated continuously and with 0.5 air exchange per hours, according to the national standards. In this study the net energy uses are calculated, which means only the energy needed to maintain the set-points without taking into account the installed energy system. This approach depended on the fact that the main objective was to compare the thermal response of the building construction under different microclimatic conditions, without introducing additional variants depending on energy sub-systems efficiencies.

5. Results

5.1. Urban thermal monitoring

The results here presented refer to 2015 and are separately discussed for the heating and cooling seasons: the former runs from January 1st until April 15th and from November 1st until December 31st, according to Italian laws; the latter is conventionally defined from June 1st until August 31st.

Figure 1 presents the hourly air temperatures in three of the selected zones, for cleanliness of representation: the city centre, centre, is the warmest neighborhood; Torrevecchhia neighborhood (TN), the most peripheral and the least affected by UH and the reference undisturbed monitoring station. The curves refer to five days in June, when temperature outside of the city ranges from 15 to 31°C. Some relevant findings: UHI is more intense at night, countryside temperatures steeply decrease in the evening while urban temperatures remain higher through the whole night and, thus, the air temperature differences reach the peak in early morning; the city centre air temperature is few degrees higher than that of the undisturbed zone during daytime, in peripheral neighborhood there are no significant air temperature differences respect to the reference station, which in some case result to be even higher. Similar trends are observed in winter as well, even if with different intensities and behaviors among the city neighborhoods.

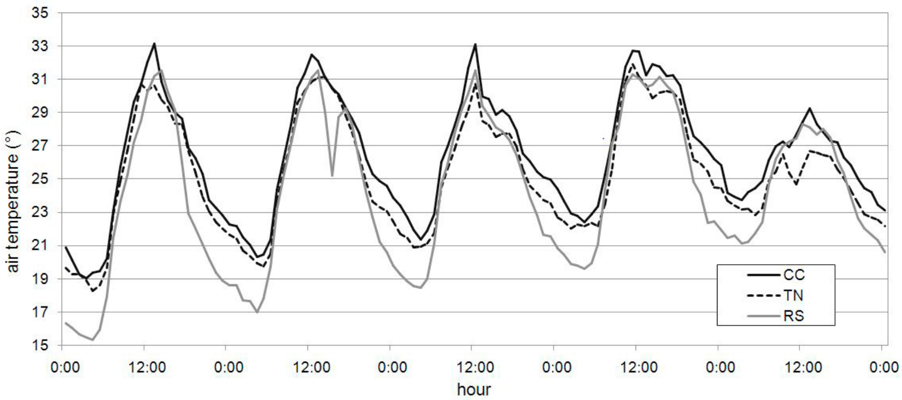


Fig. 1. Hourly air temperature in selected June days for three different station.

In terms of aggregated data, a first relevant issue is the impact of urban temperatures on the heating degree days (HDD), calculated in base 20°C, which is a relevant parameter to characterize the climate of a territory and address the energy performance of buildings. Heating and cooling degree days (CDD), the latter calculated in base 25°C, are presented in table 3, as well as the relative variations of urban neighborhoods values respect to the reference station. As expected, heating degree days in RS are higher than those in the urban stations. The HDD decrease ranges between 12.2 and 13.3%, indicating a different behavior between the countryside and the city, without significant variations within the different stations of the latter. CDD increase ranges between 26.4% in CC and 1.4% in the outskirts. The wider range is a function of smaller absolute CDD values, but also of a different response of different urban environments. To be noted that the maximum HDD difference is 19 among the city stations, while the CDD difference rises to 72.

Table 2. Heating and cooling degree days in monitoring stations and variations respect to the countryside station.

	RS	CC	MN	ON	TN
HDD (°Cday)	1635	1422	1416	1435	1434
HDD Relative decrease (%)	---	13	13.3	12.2	12.3
CDD (20°) (°Cday)	289	365	325	349	293
CDD Relative increase (%)	---	26.4	12.6	20.9	1.4

Table 3. Seasonal urban heat island and hours above selected values in the urban stations.

Zone	Average winter HUI (°C)	Winter UHI>1 (days)	Winter UHI>2 (days)	Average summer HUI (°C)	Summer UHI>1 (days)	Summer UHI>2 (days)
CC	1.4	126	14	1.8	122	33
MN	1.4	126	18	1.4	93	16
ON	1.3	125	7	1.5	113	18
TN	1.3	98	23	0.9	41	5

Concerning the UHI, maximum intensities of 10.5°C were monitored in ON in winter and 7.8°C in MN in summer. Table 4 summarizes the average UHI effect in winter and summer, as well as the number of days in which such value reached 1 and 2°C. It can be noted the urban heat island remains quite uniform across the city in winter, with seasonal spatial variation of 0.1°C. Conversely, summer UHI resulted to be strictly zone dependent, ranging from 0.9 in TN, in the outskirts, up to 1.8°C in the city centre, where the peak monthly UHI above 2°C was registered. Concerning the hours with UHI, it can be observed that absolute values are similar for the two season, even if winter hours are double of the summer ones. This result is of crucial relevance, since the phenomenon affects the energy, environment and health UHI associated risks, especially in summer.

5.2. Building energy performance

Figure 2 presents the results of the energy uses in the reference building, where the impact of the urban climate and of the thermal insulation can be easily inferred; figure 3 presents the relative variations of such energy uses respect to the reference station building. Trends are, however, different for heating and cooling performances. The city stations present similar heating uses in winter, since the variations are in 1.4 (3% respect to the average) and 0.5 (6% respect to the average) kWh/m^2 range for respectively the not insulated and insulated configurations. The effect of the urban climate is 22% and 35 % average reduction of heating use for respectively the existing and insulated building respect to RS. More scattered results are observed for the cooling season: variations are in 6.9 and 4.2 kWh/m^2 range for the existing and insulated configurations. The UHI causes an increase of the cooling use in the 20-42% range for the existing building and in the 15-29% range for the insulated building. This dispersion of the results depends on the higher irradiation levels in summer, which activate the UHI as a function of the driving forces as: solar absorption of construction materials, solar mask and shadowing effects due to the urban morphology and texture, urban greenery inside the zone.

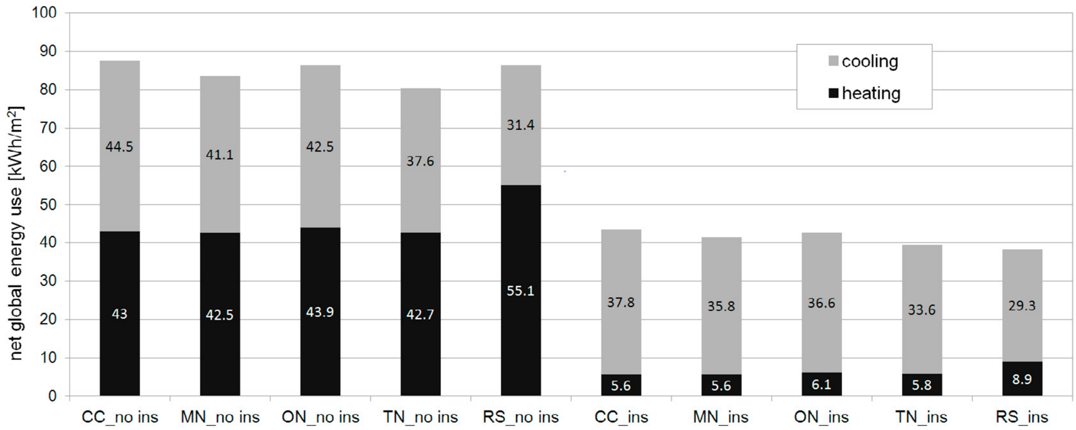


Fig. 2. Net energy for heating and cooling of the reference building in different neighborhood.

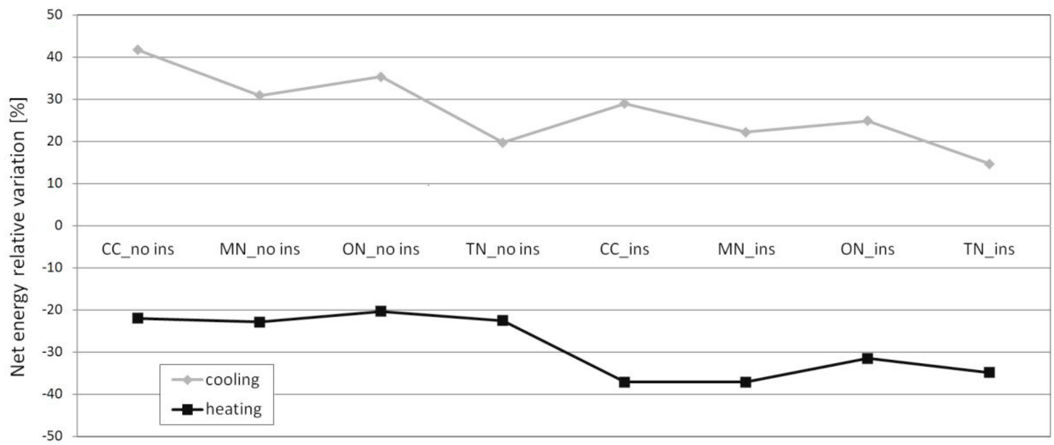


Fig. 3. Relative variation of heating and cooling of the reference building in different neighborhood respect to the reference station.

6. Conclusions

The urban environment is characterized by thermal levels different from those measured outside of the city. The monitoring carried out in Rome, showed significant differences of degree days, in particular decrease up to 13% in winter and increase up 26% in summer. Also the urban heat island effect was documented with seasonal values ranging between 0.9 and 1.5°C, and intensities up to 10°C. The simulations showed the impact of the local urban climate on the energy performance of buildings. Climate data acquired out of the city can overestimate the heating demand in the 22-37% average range, conversely cooling demand might be underestimated in the 15-42% average range. To be noted that the issue will be mainly critical for the summer season in the coming years, due to: UHI, climate changes and the very strict insulation performance of new buildings. It will be thus necessary implementing method and tools to duly take into account the specificity of the urban climate and build accurate datasets to predict the energy performance of buildings.

References

[1] European Parliament. Directive 2002/91/EC of The European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal of the European Union; 2002.

[2] Decreto del Ministero dello Sviluppo Economico del 26 giugno 2015. Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.

[3] Stewart D. A systematic review and scientific critique of methodology in modern urban heat island literature. International Journal of Climatology, Special Issue: ICUC-7 Urban Climate Meeting 201;, 31(2): 200–217.

[4] Arnfield AJ. Two decades of urban climate research: a review of turbulence,exchanges of energy and water, and the urban heat island, International Journal of Climatology 2003; 23: 1–26

[5] Papanastasiou DK, Kittas C. Maximum urban heat island intensity in a medium-sized coastal Mediterranean city, Theoretical and Applied Climatology 2012; 107 (3–4): 407–416.

[6] Santamouris M. On the energy impact of urban heat island and global warming on buildings, Energy and Buildings 2014; 82: 100-113.

[7] Santamouris M, Papanikolaou N, Livada I, Koronakis I, Georgakis C, Argiriou A, Assimakopoulos DN. On the impact of urban climate on the energy consumption of buildings. Solar Energy 2001; 70(3): 201–216.

[8] Akbari H, Konopacki S. Calculating energy-saving potentials of heat-island reduction strategies. Energy Policy 2005; 33(6): 721-756.

[9] Magli S, Lodi C, Lombroso L,, Muscio A, Teggi S. Analysis of the urban heatisland effects on building energy consumption. International Journal of Energy and Environmental Engineering 2014; 6: 91–99.

[10] Ihara T, Kikegawa Y, Asahi K, Genchi Y, Kondo H. Changes in year-round air temperature and annual energy consumption in office building areas by urban heat-island countermeasures and energy-saving measures. Applied Energy 2008; 85(1) 12–25.

[11] Paolini R, Zani A, MeshkinKiya M, Castaldo VL, Pisello AL, Antretter F, Poli T, Cotana F. The hygrothermal performance of residential buildings at urban and rural sites: Sensible and latent energy loads and indoor environmental conditions. Energy and Buildings, In press available on line 2016, http://doi.org/10.1016/j.enbuild.2016.11.018.

[12] TRNSYS 16. www.trnsys.com

[13] UNI/TS 11300: Parte 1 - Determinazione del fabbisogno di energia termica dell’edificio per la climatizzazione estiva ed invernale (Evaluation of energy need for space heating and cooling) 2014.