Which climate for each urban context? A preliminary comparative study on urban climate prediction and measurement in different districts in Rome and Barcelona.

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Abstract

The research progress in building energy modeling and simulation has led to the widespread diffusion of more and more sophisticated software. By contrast, there aren't such effective results when it comes to the urban-scale climate modeling, whose geometric, morphological, material and anthropogenic features clearly distinguishes it from a rural context. The clearest effect of these differences is the Heat Island phenomenon. Despite that, the weather files currently used for energy simulations practice refer to measurements gauged in out-of-town weather stations, as like airports, causing the results to be unreliable and inaccurate.

The aim of this study is to prove that, despite referring to the same region, latitude or city, quite different microclimates may occur depending on urban local features. To this purpose, temperature data available in urban weather stations located in Rome and Barcelona are inspected and compared to the rural reference station, in order to evaluate the difference of Heat Island intensity in different urban context. The experimental verification is then used to evaluate a recently developed method for generating urban weather files from a rural station, the Urban Weather Generator (UWG). The experimental verification shows a maximum intensity of Urban heat island in Barcelona in July, with a Dt of 4.7° C at 18:00 local time. In the case of Rome there is a maximum Dt of 5° C in August at 17:00 local time. The comparison between measured data and calculate data show that the reliability of the UWG calculation strongly depends on the location of the urban site within the city and on its features. The temperature discrepancies decrease when the urban site is located in a fairly central position and in a rather homogeneous urban fabric. There is a systematic error during the central hours of the day which suggests an underestimation of the effect of radiation and radiative trapping.

Keywords : urban heat island, micro-climate, experimental verification, urban simulation

1.Introduction

Active and passive renewable energy systems are, nowadays, more and more widespread and applied to architecture. Furthermore the availability of detailed building energy models allow to simulate and predict with precision their effectiveness in energy saving. Despite their high computing capability, such energy models do not take into adequate account the urban context in which is located the building. The urban environment can significantly alter the local microclimate, as proved by the wide scientific literature on "Urban Heat Island"[1,3,4,6]. To date, however, the simulation tools developed in the field of urban climatology aren't suitable for a direct application in building engineering and architectural design, because of its high complexity and computational cost. This means that the major limitations for an adequate prediction of the energy demand in urban area and the performance of alternative energy production is the availability of reliable urban climate data. This study aims to highlight the importance of the local context properties for the proper valuation of the microclimate of an urban area, by analyzing four case studies in Rome and Barcelona. It is interesting to compare the behavior of the two cities, since they share the same latitude and belong to the same Mediterranean climate. This paper also evaluates a tool called "Urban Weather Generator" [2] recently developed by Bueno. B et al for generating urban weather files from a rural station, accounting for the reciprocal interactions between building and the urban climate. This method can be useful for engineers and architects, because its computational cost has been intentionally kept at the same order of magnitude as annual building energy simulations and the output weather file is compatible with the most popular building energy simulation models. So this study first analyzes the intensity of the heat island in winter and summer for two urban sites placed in each of the two reference cities. Then is applied the UWG method using as input the temperatures of rural stations. Finally, it concludes with recommendations for a proper use of the tool and its applicability.

2. Methodology and case studies

Rome and Barcelona are classified in the map of Köppen-Geiger as a temperate climate, with hot and dry summers. They are located at a very close latitude, respectively to 41.9 ° N Rome and 41.4 ° N Barcelona; this properties lead to an average daily temperatures trend very similar in the two cities . Barcelona is a coastal city, so its climate is affected by the ventilation and by the thermoregulatory effect of the sea. The geographical conformation characterized by the sea to the south, and the mountains to the north, has contributed to a very compact urban development. Rome is located at a distance of about 20 km from the coast and has daily temperature range larger than the Catalan city; has a less compact and much broader spatial development, with large green parks into the city and a less marked limit between town and country. The reference rural sites are the airports of each city, respectively Barcelona El Prat Airport for Barcelona and Rome-Ciampino GB Pastine Airport for Rome. Actually, these sites do not conform the definition of rural site, given the presence of the sea in Barcelona's airport and the presence of surrounding urbanization in both cases. However, standard TMY climate data, for any cities, are basically extracted from weather stations at the airports; it is therefore interesting to assess how much urban temperatures differ from those that normally are used as reference for energy simulations [7]. The case studies has been elected on the basis of urban meteorological data availability and to enhance the microclimate differences found within the same city. For Barcelona the study refers to data available in meteo.cat , the meteorological service for Catalunya, and to the network of personal weather station (PWS) of the town, whose data are published in wunderground.com. Meteorological data refer to 2013.For Rome has been used the data supplied by ARPA, the Regional Environmental Protection Agency for Lazio, which refer to 2003.

2.1 Urban Heat Island intensity in Barcelona:

For a correct interpretation of the results, first it has to pay attention to the urban characteristics of the two selected sites: Raval and Gracia. Raval is located in the district of Ciutat Vella, in the south of the city center, near the harbor. It is an extremely dense and compact urban fabric, composed of irregular blocks and a network of small size streets, mostly pedestrian. The average H/W ratio of the urban canyon is 3.9. There is a few presence of trees and vegetation. The intended use is primarily residential, with the exception

Figure 1 From left to right: Urban fabric in Gracia District; Urban fabric in Raval District; Urban stations location within the city and respect to the Airport

of the northern area, where are located some university facilities and museums. The district is very close to the sea, just 1.3 km from the port, and 11.6 km away from the airport. The weather station is located on the top of the building of Faculty of Geography and History (at 33m above sea level). Referring to Oke's Urban Climatic Zone classification [9], the district matches the UCZ 2. The Gracia district is located just to the north of the city centre. It is characterized by a quite regular street pattern, composed of smaller blocks, clearly recognizable in respect to the predominant structure of the city set by Cerdà's urban plan. The average ratio H/W of the canyon is quite high, about 2.25. It is a dense urban fabric, consisting of courtyard buildings with varying heights between 2 and 5 floors. Few vegetation is concentrated in the squares and main road of the district. The intended use is purely residential. The neighborhood is approximately 4.2 km from the sea and 13.5 km from airport. The weather station is located on top of a residential building (70m asl). Referring to Oke's Urban Climatic Zone classification [9], the district matches the UCZ 2. Figure 2 shows the average

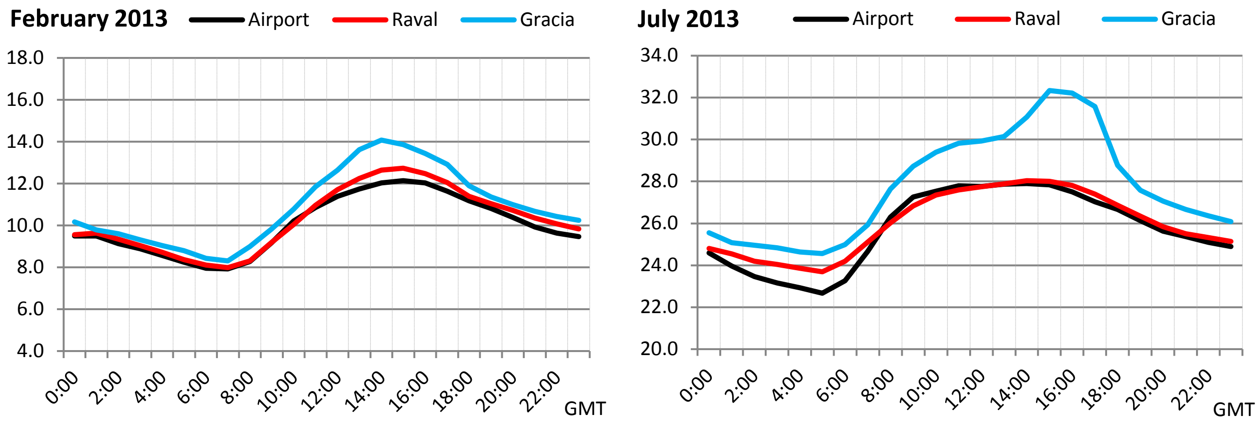


Figure 2 Monthly-average diurnal cycle of urban air temperature (°C)

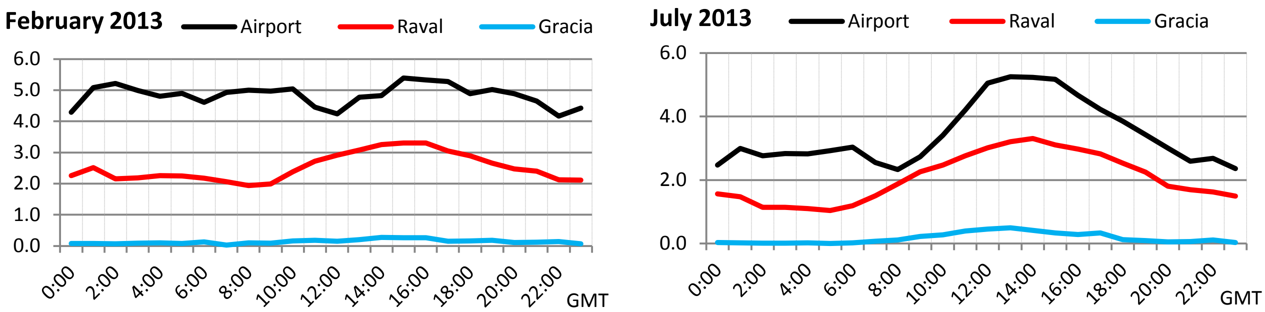


Figure 3 Monthly-average diurnal trend of Wind speed (m/s)

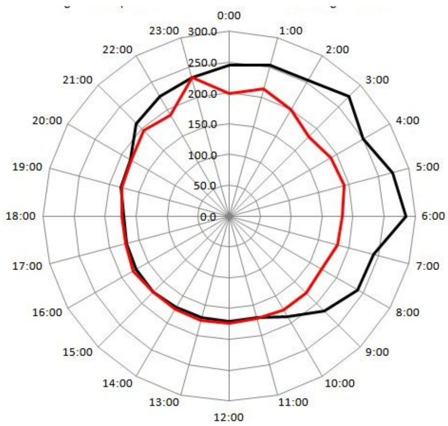


Figure 4 *Monthly-average trend of Wind direction*

Airport Raval

daily temperature in February 2013 and July 2013, respectively the hottest and coldest month of the year. Figure 3 shows the trend of the wind speed at the two sites. In February in Gracia there is a maximum Dt of 2 ° C at 14:00 GMT (15:00 local time). At the same time is recorded the maximum Dt also in the Raval , but only of 0.6 ° C. In July is recorded a peak temperature in Gracia in the early afternoon, with a maximum Dt of 4.7 ° C at 16:00 GMT (18:00 local time). Temperatures in Gracia remain higher than at the airport throughout the day. On the contrary, in the case of Raval, the temperatures are almost identical to those recorded at the airport, with the exception of the very early hours of the morning. This result can be explained at the light of the wind speed trend in the two sites; in Raval, unlike Gracia's station, wind speed is not negligible, especially in the summer. During the diurnal hours of the typical day of July is recorded a progressive increase in the average wind speed, which coincides with the alignment of urban temperatures on the values recorded at the airport. In the same hours the wind direction in the Raval coincides with the direction recorded at the airport, about 180 ° to the north. So we are in a situation of prevailing wind from the South. Taking into account the proximity to the sea and those prevailing wind conditions, can be deduced that the weather station in Raval is less affected by urban surfaces than more northern areas like Gracia. Furthermore the meteorological station is located above the average height of the buildings; this means that recorded temperature and wind speed are not representative of the average condition into the urban canyon.

2.2 Urban Heat Island intensity in Rome:

The two urban stations in Rome are located urban contexts which differ for relative position to the city center, for density of the urban fabric and presence of vegetation. The station Arenula is situated in the city center, in a mixed-use neighborhood, with large presence of offices, retail spaces, accommodation facilities and institutional buildings. The building fabric, intricate and compact, it is made up basically of courtyard buildings that shape urban canyons particularly high and narrow. The district is one of the most compact and densely built area of downtown; it is about 14.5 Km from Ciampino Airport. The ARPA's meteorological station is located at street level. The vegetation is mostly concentrated near the Tiber river, at about 500 m away from the point of measurement. The urban parameters match the UCZ 2. The second station is located

Figure 4: *Left to right: Urban fabric in via Arenula; Urban fabric in Cinecittà District; Urban stations location within the city and respect to the Airport*

in the suburb of the city, in the neighborhood Cinecittà-Tuscolano, at only 6.5 Km from Ciampino Airport. The district is characterized by an inhomogeneous building density. The northern and southern side are primarily large green spaces, with scarce presence of built areas. In the core of the district, along Tuscolana road, the urban fabric is very dense, consisting of tall building blocks, up to 8 or 9 floors, linked by a quite wide road network. Moving away from the Tuscolana road, the buildings become more sparse and the presence of vegetation increases. The building and vegetation in-homogeneity in the area do not allow an univocal classification into the frame defined by Oke.

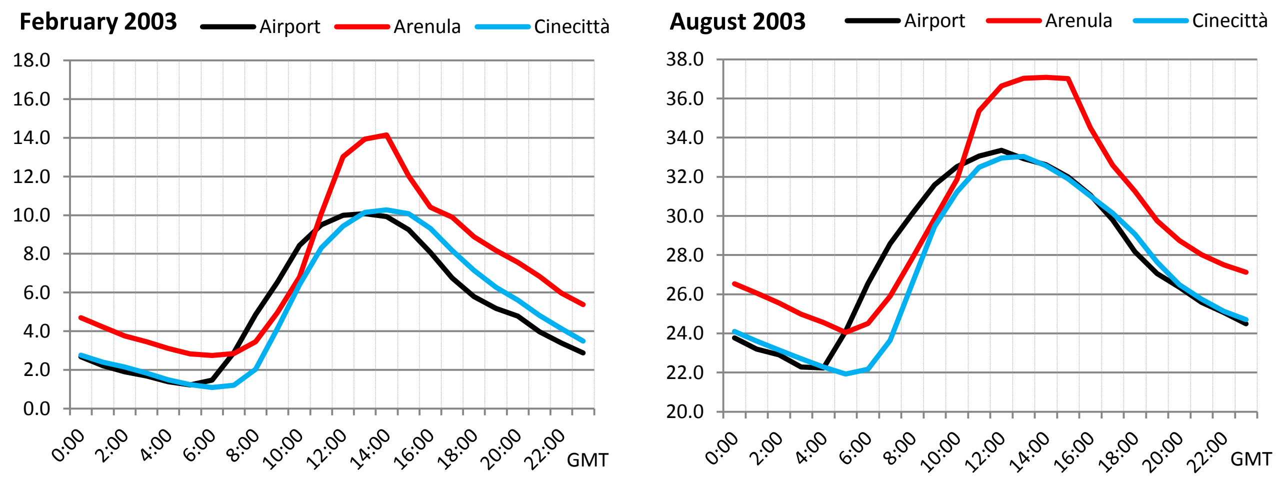


*Figure **5**: Monthly-average diurnal cycle of urban air temperature (°C).*

The graphs show the average daily temperature trend in February 2003 and August 2003 , respectively, the hottest and coldest month of the year. In the early hours of the day, both in winter and in summer, the temperatures recorded in the urban stations are lower than the ones at the airport. This happens because both meteorological stations are affected by the shadows of the surrounding buildings. Both in winter and in summer, temperatures are clearly higher in Via Arenula , with Dt up to 5 ° C in August at 17:00 local hour , and 4.2 ° C at 15:00 local in winter. The temperatures recorded in Cinecittà tend to be rather equal, or lower, than the airport , with the exception of the interval between 14:00 and 22:00 in February, when is recorded a fairly constant Dt of around 1°, with a maximum of 1.4 ° C at 17:00. The different temperature trend in the two urban sites is not surprising; the station Arenula is placed exactly in the center of Rome, in a densely built area, while Cinecittà is situated in the south-east edge of Rome, adjacent to a large urban park which starts in the Roman countryside and extends to the city. Furthermore, when observing the two sites at urban scale, both Ciampino airport and Cinecittà can be classified "sub-urban" areas, due to a similar presence of vegetation and built-up areas. This results in a very similar daily temperatures trend.

2.3 Urban Weather Generator model:

Parameter	Gracia	Arenula
Urban Parameters		
latitude	41.4	41.8
longitude	2.2	12.5
city radius	4500m	6500m
District Parameters		
Average building height	18.7m	18.2m
Horizontal building density	0.61	0.5
Vertical to horizontal urban area ratio	1.53	1.56
Horizontal vegetation density	6%	7%
Latent anthropogenic heat	0	0
Sensible anthropogenic heat	8 W/mq	8 W/mq
Building		
Glazing ratio	0.3	0.3
Internal heat gain	5.8 W/mq night - 2.0 W/mq day	5.8 W/mq night - 31.8 W/mq day
infiltration/ventilation	0.5	0.5
Daytime cooling sistem set poin	**24**	**24**
Nightime cooling system set point	**26**	**26**
Daytime heating system set poin	20	20
Nightime heating system set point	20	20
Heat released to canyon	**1**	**0.5**
Rural site		
Vegetated fraction	0.2	0.85
Construction	asphalt 0.05, stone 0.15, soil 0.2	asphalt 0.05, stone 0.15, soil 0.2
Non-vegetated surface albedo	0.15	0.15

Table 1 : UWG parameters

The Urban Weather Generator (UWG) was developed by Bueno et al. [2] to calculate air temperature trend inside urban canyons from measurements at weather stations located in rural or sub-urban areas. It is based on Masson's scheme for the Town Energy Balance [6], combined with a building energy model derived from EnergyPlus algorithms. The evaluation of the model consist in using the measured data at the rural station as input for the calculation of the UWG, and then compare the calculated temperatures with the recorded urban temperatures. Table 1 shows the most relevant parameters used for the simulation, which refer to geometrical and local features, radiative and thermal properties of existing materials and building model characteristics. The "District" parameters has been calculated over a circular urban area with a radius of 250m around the reference station. The radius was defined in agreement with similar studies [5,8,9], but also in order to get representative parameters of the dominant morphology surrounding the studied area. The parameters related to "Building" have been identified in accordance with the prevailing intended use in the two sites, that is residential in Gracia and offices in Arenula.

Results

In the case of the Raval in Barcelona and Cinecittà in Rome, the UWG model is not able to take into account the proximity to the sea or the condition of sub-urban site, so the calculation is not reliable and it is not reported. In the case of Gracia the temperatures calculated from UWG match the ones actually recorded during the late afternoon and the early hours of the morning. The prediction error increases in the summer simulation, in which the calculation underestimates actual temperatures during most of the day . Furthermore, the simulation does not detect the peak of temperatures between 14 and 18 . Figure 8 compares two different Dt : the one between recorded temperatures in Gracia and recorded temperature at the airport and the Dt between the recorded urban temperatures and the calculated urban temperature. It aims to emphasize the improvements on temperature prediction produced by UWG, considering that the airport weather stations are generally taken as a reference station for an entire city. In the case of Gracia, in both summer and winter and throughout the day, the temperatures calculated by UWG are closer to reality than those recorded at the airport. For the case Arenula in Rome, the UWG calculation approximates quite

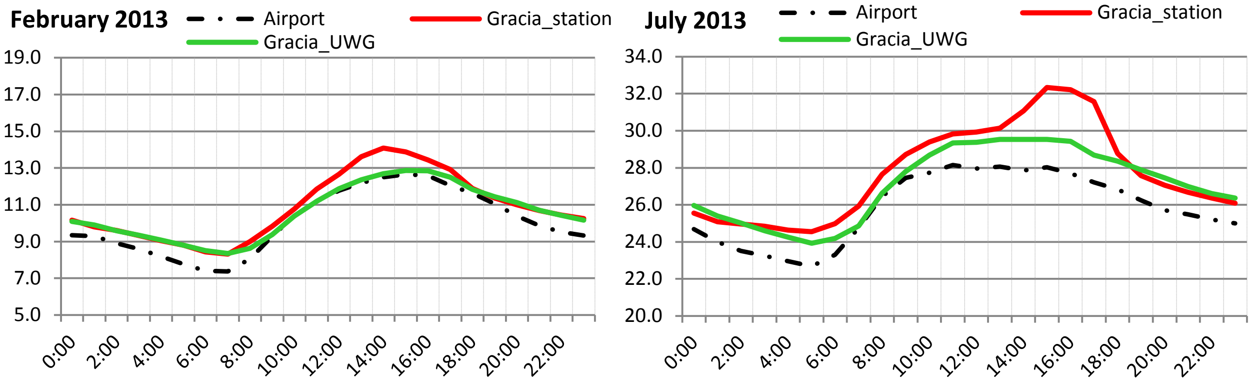


Figure 6 Monthly-average diurnal cycle of urban canyon air temperature calculated by the UWG and observed in Gracia's station

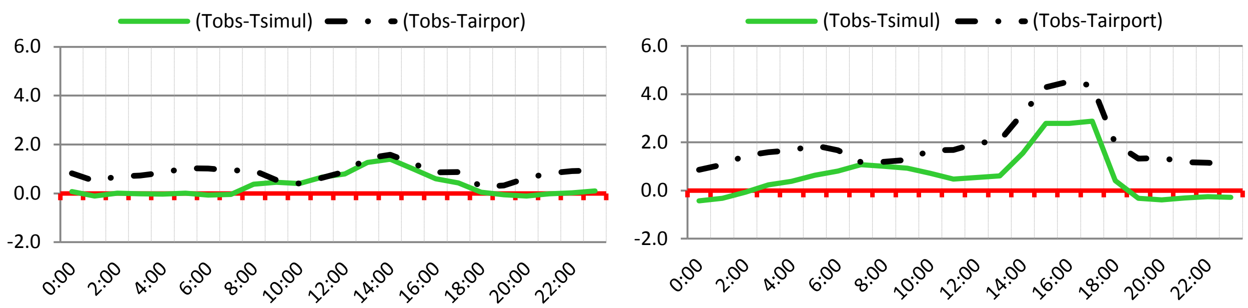


Figure 7 Differenza tra le temperature misurate all'aeroporto o da UWG con le temperature osservate in Gracia

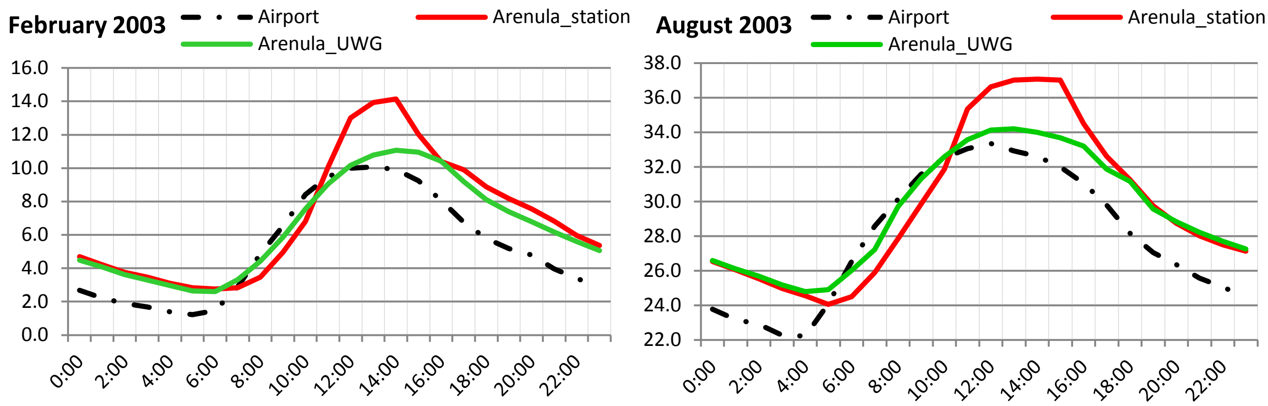
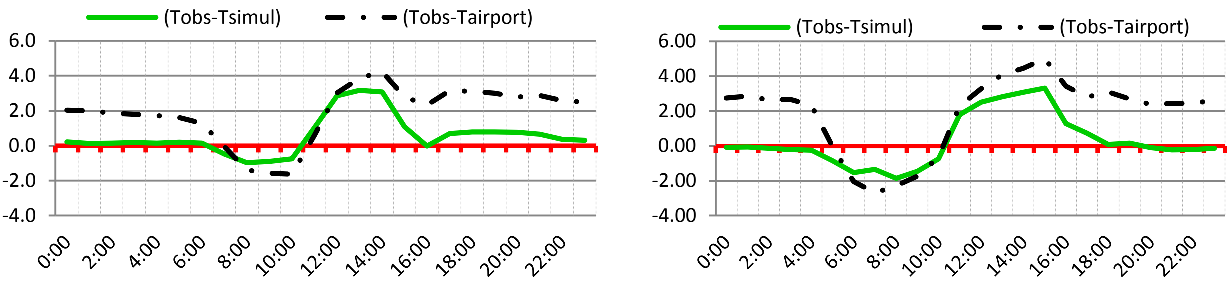


Figure 8 Monthly-average diurnal cycle of urban canyon air temperature calculated by the UWG and observed in Arenula's station



Figurr 9 Differenza tra le temperature misurate all'aeroporto o da UWG con le temperature osservate a via Arenula

closely the urban temperatures, except for the time interval between 12:00 and 16:00, when is recorded a peak temperature at the urban station. Such systematic error for this time period suggests that the model does not adequately consider the contribution of radiation and radiative trapping on the air temperature increase. It should be highlighted that UWG returns an uniform air temperature for the urban canyons, while the measurement station recorded temperature at 2m from the ground. Nevertheless, the calculation generated by the UWG is quite reliable. Figure 10 shows a substantial reduction in the error indeed. Between 00:00 and 6:00 and between 16:00 and 23:00 the difference between calculated and recorded temperature is almost canceled.

Discussion

The heat island phenomenon is present in both cities. In Barcelona is clearly predominant in Gracia district with respect to Raval, especially in the summer months, with a maximum intensity in July of 4.7 ° C at 18:00 local time. In the case of Rome there is a maximum intensity at Via Arenula, with Dt 5 ° C in August at 17:00 local time. Unlike the case of Barcelona, Rome temperatures are significantly higher than the reference rural site even in winter, with a maximum Dt of 4.2 ° C in February at 15:00 local time. The reliability of the UWG calculation strongly depends on the location of the urban site within the city and on its features. The model calculates best when the urban site is located in a fairly central position and in a rather homogeneous urban fabric. In Barcelona it is not possible to get reliable results for Raval, because of its proximity to the sea. For Rome-Cinecittà, similarly, the simulation do not supply realistic temperatures due to the peripheral location of the site and its proximity to large green areas. The simulation that best predicts the urban temperatures is the one for Arenula, in Rome. In this case the UWG calculation significantly reduces the error compared to rural meteorological data. Similarly, for the case of Gracia in Barcelona the simulation produces a considerable reduction of the error. However, in both cases, there is a systematic error during the central hours of the day which suggests an underestimation of the effect of radiation and radiative trapping.

Conclusion

The urban environment highly affects the local microclimate . The lack in urban site-specific weather data remains, nowadays, the great limit for a correct energy demand estimation in urban context. At the same time, do not exist much models of urban energy analysis relevant to the architectural and building engineering field. In no event UWG predicts urban temperatures exactly. However, the degree of improvement made can be significant. A careful analysis of the urban context must be made before applying the model. The more the urban site meets the conditions of symmetry with respect to the city and homogeneity in building density and morphology, the more the calculation will be reliable. With those precautions, the UWG can be a useful tool for modeling urban microclimate and perform more realistic energy analysis.

Acknowledgements

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