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The influence of urban features on air temperature distribution

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Abstract
The knowledge of the influence of urban features on air temperature distribution in a city is very important, especially considering the population increase worldwide and the impact of urban climate on human health. The aim of this study is to investigate the distribution of air temperature in the city of Florence during the summer and to evaluate its relationship with building height, urban density and presence of trees. A significant positive relation between minimum air temperature and mean height of buildings and urban density was found throughout the entire summer period especially during the hottest months (July and August).

Keywords: Urban density, green areas, microclimate, air temperature

Introduction:
In the last few years, and even more for the future, the importance of urban climate and of thermal comfort within the cities is increasingly being recognised (Mills, 2007), as can be observed by the growing number of international conferences and of sessions in conferences on meteorology and climatology concerning urban climate (for example: ECAC – European Conference on Applied Climatology; ICB – International Conference on Biometeorology; ICUC – International Conference on Urban Climate). The increasing interest of urban meteo-climatic conditions is related to the growing importance of the consequences of climate change on human health, and it is also related to the increase of percentage of people that in the future will live in urban areas, as forecasted by the last "State of the World Population" by United Nations Population Fund: "For the first time in history, more than half of human population, 3.3 billion people, will be living in urban areas and by 2030, this is expected to swell to almost 5 billion: in the next few decades we will see an unprecedented scale of urban growth, especially in the developing world" (United Nations Population Fund, 2007). The increasing size of urban areas will have a great influence on urban climate, and it is for this reason that it is very important to study the relationship between urban features and air temperature distribution (Oke, 1988; Ali-Toudert and Mayer, 2006). The use of meteorological stations located in cities and in areas characterized by different level of urbanization in order to study temporal and spatial air temperature distribution is increasingly widespread (Huang et al., 2008; Ren et al., 2008). In fact, air temperature is the most important parameter used in biometeorology, combined with other environmental and subjective parameters, to describe the thermal comfort and the impact of weather condition on human health in urban areas (Nikolopoulou et al., 2001; Johansson and Emmanuel, 2006). Therefore, it is very important to study the air temperature distribution within a city, in order to find a relationship between urban structures and human well-being (Botty'an et al., 2005): in this way, urban

planners could take into account some suggestions for managing the rapid growth of the cities expected by the UNPF forecasts.

Materials and methods

In this study, the relationship between urban features and air temperature distribution in the city of Florence were analysed during the summer of 2007. Florence is a very well-known tourist city, located in the centre of Italy. The city covers an area of approximately 102 km^2 with a population of about 360.000 citizens and it is situated in a plain surrounded by hills along the Arno river (lat: 43°47'N, lon. 11°15'E, elevation: 50m a.s.l.). Rainfall averages about 850 mm per annum and occurs mainly in spring and autumn, while summer is dry and hot. The study area was preliminary divided in 72 areas using a pre-existing partition made by the Statistic Department of the Florence Municipality (SDFM): for each area, data about the mean building height (expressed as number of floor per Km^2) (F) and the urban density (expressed as number of buildings per Km^2) (UD) were taken from the last Italian building census (2001). Moreover, a geo-referenced database of the trees managed by the Environmental Department of Florence Municipality (in public green areas and along the streets) was used to estimate the percentage of green area (number of trees per km^2) (GA) in each sector. A categorization of F into terziles (values 33^{rd}; 34^{th} – 66^{th}; > 66^{th} percentiles) and of UD and GA into quartiles (values 25^{th}; 26^{th} – 50^{th}; 51^{st} – 75^{th}; > 76^{th} percentiles) was performed. According to these categories, 21 types of sectors, from the previous 72 areas, were identified and a network of air temperature sensors (Hobo Pro Series logger) was placed in a representative area of each sector (Figure 1).

(Figure 1)

Hourly air temperature data were collected to calculate daily minimum (Tmin), maximum (Tmax) and average air temperature (Tave) and daily temperature range (dTr); even monthly averages of these variables were calculated.

Temporal distribution of air temperature during the day was analysed in order to compare differences of this variable among the stations. Mean monthly diurnal changes of air temperature (TM) were calculated; (1) the value of the i^{th} hour (TM_i) was calculated as the average of the i^{th} values (T_{ij}) of every day (j) of each month:

(1) $TM_i = \sum_j T_{iJ}/n$; n number of the days of the month

The stations were then grouped according to their position in street (S) and garden (G). To compare differences between the two groups, the series of mean daily changes (TMG) of each group was calculated as the average of the daily series (TM) of each station (2).

(2) $TMG_i = \sum_j TM_{ij}/N$; N number of sensors of the group

Pearson product moment correlation (r) was used to investigate the influence of the sensor's location characteristics (building height, urban density and percentage of green areas) on monthly averages values of air temperature.

Results:

Air temperature variables showed a great variability among the stations during the study period: differences in monthly values among the stations varied from 3°C to up 3.9 °C in Tmin , from 2.9 °C to up 3.5 °C in Tmax, from 2.6°C to up 3.1 °C in Tave and from 3.6°C to up 5.9 °C in dTr (Table 1).

The air temperature distribution analyses (Table 2) showed that F is positively related to almost all the monthly average ($r_{TminJun} = 0.655^{**}$ $p = 0.001$, $r_{TaveJun} = 0.643^{**}$ $p = 0.002$; $r_{TmaxJun} = 0.458^{*}$ $p = 0.037$; $r_{TminJul} = 0.624^{**}$ $p = 0.003$; $r_{TaveJul} = 0.675^{**}$ $p = 0.001$; $r_{TminAug} = 0.699^{**}$ $p < 0.001$, $r_{TaveAug} = 0.697^{**}$ $p < 0.001$), with an higher correlation for Tmin, especially in August.
Furthermore, monthly temperature averages showed also a positive relation with UB, even if less meaningful than F parameter ($r_{TminJun} = 0.531^{*}$ $p = 0.013$, $r_{TaveJun} = 0.573^{**}$ $p = 0.007$; $r_{TmaxJun} = 0.458^{*}$ $p = 0.037$; $r_{TminJul} = 0.579^{**}$ $p = 0.006$; $r_{TaveJul} = 0.609^{**}$ $p = 0.003$; $r_{TminAug} = 0.520^{*}$ $p = 0.016$, $r_{TaveAug} = 0.548^{*}$ $p = 0.01$).
(Table 2)
Conversely no significant relation was found between GA and monthly temperature averages.
Finally air temperature differences between streets and gardens were analysed. Mean hourly values of air temperature collected by sensors located in streets were higher than those collected by sensors in gardens during the whole day and this difference was higher during the night. In June and August, temperature difference was about 1.2 °C in the afternoon and 1.7 °C in the night (data not shown), while in July it ranged from 0.9 °C to 1.9 °C (Figure 2).

(Figure 2)

Discussions and conclusions:
The results of this study show the important relationship between air temperature and mean building height and density, supporting the hypothesis of many authors on the connection between air temperature distribution and the sky view factor (SVF) (Oke, 1981; Unger, 2004; Petralli et al., 2006a). The higher relation was found with the mean building height, especially as regards Tmin and, consequently, Tave. The rise in minimum air temperature according to the height of buildings had a statistical significance in all the months analysed. As regards monthly average of maximum temperature, a significant, although weak, relation was found only in June, both with building height and urban density. These results support the well known theory that UHI effect is stronger during nighttime (Oke, 1981).
The higher values of Tmin in urban environment have some very important consequences on biometeorological studies. Human health, in fact, is strongly linked with minimum air temperature: the daily number of emergency calls, for example, rises with the increase of minimum air temperature (Petralli et al., 2006b) and the same do the number of hospital admissions of tourists (Morabito et al., 2004), with great logistic and pecuniary problems for the Health Care System.
As regards the number of trees, no relation with air temperature parameter was found: this is in contrast with many urban climate studies that underline the importance of trees in the UHI mitigation (Streiling and Matzarakis, 2003), but it can be due to the fact that trees data used in this study were incomplete and limited only to the green areas managed by the Florence Municipality.
In fact many authors underline the benefits of shade trees concerning the reduction of urban air temperature (Thorsson et al., 2004) and the potential energy savings in air conditioning of buildings during summer (Carver et al., 2004; Akbari, 2002).
According to this, our analyses of hourly differences of temperature between sensors located in streets and gardens underlines the importance of the mitigating effect of green areas, especially during the night. For this reason further studies must be done including data concerning both public and private green areas in Florence.
The increase in the number of people who will live in cities and the expected growing of the cities size will strenghten the UHI effect with important consequences on human health. Therefore, it is important

that biometeorologists and urban foresters contribute to improve the knowledge on urban climatology to support urban planners that will play an active role in the UHI mitigation.

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Table 1 – Variation of monthly mean averages of Tmin, Tave, Tmax and dTr among the sensors: Min: minimum value; Mean: mean value; Max: maximum value; DT difference between the maximum and the minimum value.

	Min	Mean	Max	DT
June Tmin	16.0	17.6	19.5	3.5
June Tave	21.0	22.6	24.1	3.1
June Tmax	25.9	27.3	28.8	2.9
June dTr	7.8	9.7	11.4	3.6
July Tmin	16.4	18.3	20.3	3.9
July Tave	24.0	25.4	26.7	2.7
July Tmax	30.7	32.5	34.1	3.5
July dTr	10.4	14.2	16.3	5.9
August Tmin	16.4	18.0	19.4	3.0
August Tave	21.9	23.3	24.5	2.6
August Tmax	26.8	28.4	30.2	3.4
August dTr	7.6	10.4	12.1	4.5

Table 2 - Pearson product moment correlation values (r) among monthly averages of temperature parameter and urban density (UB), building height (F) and trees density (GA)

	UB	F	GA
June Tmin	.531(*)	.655(**)	-.386
June Tave	.573(**)	.643(**)	-.418
June Tmax	.458(*)	.458(*)	-.233
June dTr	-.222	-.368	.250
July Tmin	.579(**)	.624(**)	-.330
July Tave	.609(**)	.675(**)	-.347
July Tmax	.287	.299	.068
July dTr	-.337	-.368	.332
August Tmin	.520(*)	.699(**)	-.355
August Tave	.548(*)	.697(**)	-.356
August Tmax	.232	.377	-.169
August dTr	-.294	-.342	.192

Figure 1 – Map of Florence showing the subdivision in 72 areas and the location of the 21 sensors used in this study

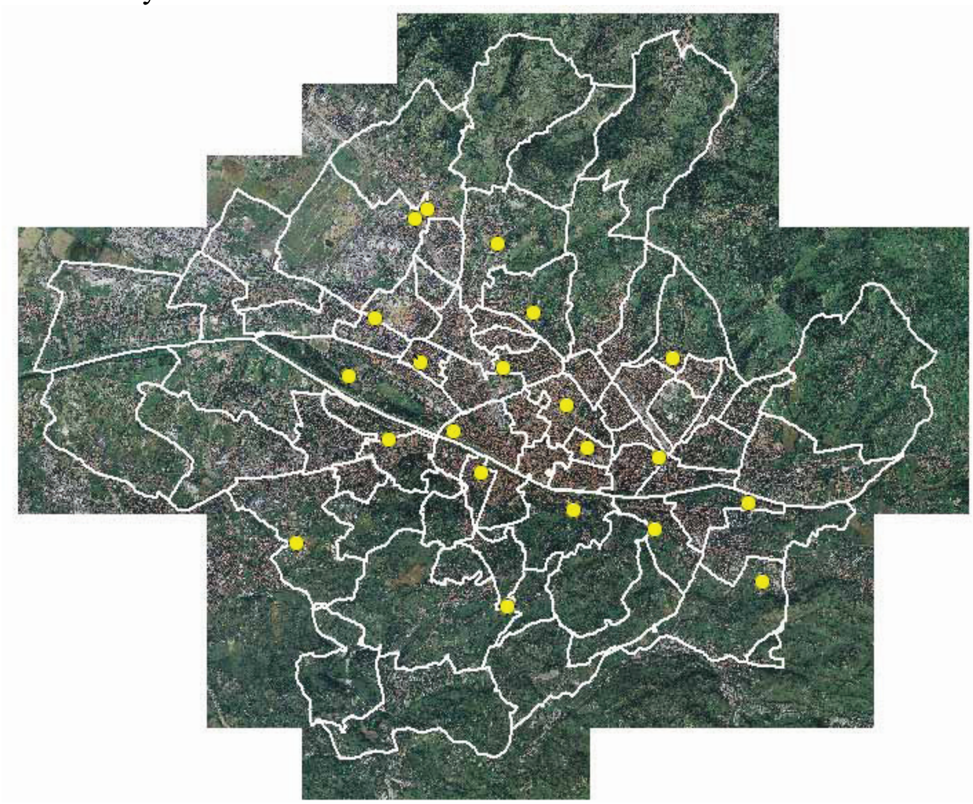

Figure 2 – Mean daily changes of air temperature in streets (unbroken line) and gardens (broken line).