THE INFLUENCE OF SOLAR RADIATION EXPOSURE ON AIR TEMPERATURE DIFFERENCE IN A PARKING LOT: A CASE STUDY IN FLORENCE, ITALY

Luciano Massetti*, Martina Petralli**, Simone Orlandini**

* Institute of Biometeorology, National Research Council, Florence, Italy  ** Interdepartmental Centre of Bioclimatology, University of Florence, Italy

Abstract

The aim of this study is to investigate how different solar radiation exposures might affect air temperature distribution during the day. This study was carried out on a parking lot in a high-density built-up area of Florence (Italy) during Summer 2007 and 2008. Two natural-ventilated air temperature sensors with radiation shields were placed in a sunlit area and in a shaded one. The relationship between the differences in data collected by the two sensors and solar radiation conditions were analyzed. Different hourly temperature values between the two areas during the hottest hours of the day were found both on cloudy and sunny days.

Key words: urban tree, shading, cloud cover

1. INTRODUCTION

There is a growing interest in improving the knowledge of the relationship between urban development and local climatic conditions. In fact, this kind of information can be useful to urban planners and biometeorologists for the mitigation of the Urban Heat Island (UHI) intensity and effects (Beuchley et al., 1972). Air temperature distribution in a city can be strongly affected by several factors depending on city size and urban form (Oke, 1973; Petralli et al., 2008).

In the urban context, green areas might play an important mitigation role of UHI. Vegetated urban parks determine the Parking Cooling Island (PCI) effect which is characterized by air temperature values lower than the surroundings (Hamada and Mikami, 1994; Spronken-Smith and Oke 1999; Potchter et al., 2006). The use of trees in urban area can also be useful from an energetic and environmental point of view for the shading effect on large paved area like parking lot. This cooling effect depends on tree characteristics as dimension, age and canopy and distribution over the area (Gregory McPherson, 2001; Chang et al., 2007). Understanding the influence of urban form on energy balance at city scale (Roberts et al., 2006) and at local scale is a very hard task due to the complexity and variability in size, distribution and thermal properties of the urban environment elements (Asaeda et al., 1996). The aim of the present study is to do a preliminary investigation on the effects of tree shading on air temperature distribution on a parking lot in Florence. Based on measured data recorded by two meteorological sensors placed in a sunlit and a tree shaded area of the parking lot, average hourly differences on air temperature (MHDT) were evaluated and compared in cloudy and sunny days.

2. MATERIALS AND METHODS

Florence, one of the most famous cities of the World, is located in the central part of Italy. It covers an area of approximately 102 km² 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: 50 m a.s.l.). The yearly rainfall averages about 850 mm and occurs mainly in spring and autumn, while summer is dry and hot.

Since 2005, many meteorological stations were set in different part of the city in order to investigate air temperature variability over Florence and build a knowledge useful for the management of urban planning. This particular study was carried out in a parking lot in the suburban area of Florence using two air temperature/relative humidity sensors (HOBO® H8 PRO series Temp/RH Data Logger) with solar radiation shields (RS1-HOBO® PRO accessories). The parking lot (P) is about 1532 m² and it is located in a high density built up area (figure 1a); green areas occupy less than 10% of the total surface of the surroundings and the height of the buildings around the parking lot ranges from 10 m up to 32 m. Two streets run along two opposite sides of the parking lot (S) approximately according to a NW-SE direction and buildings (B) are present along both the two other sides of the square and the streets. On the south corner of the parking lot there is a Pinus pinea L. tree (T) about 12m high and 10m canopy diameter (figure 1b).

The two air temperature sensors (M1, M2) were placed at the standard height of 2m above ground level (Egan and Baldelli, 2008): M1 in a sunlit area of a parking lot and M2 in the tree shaded one.

Air temperature in high resolution mode, with an accuracy less than 0.2 °C over the operational range -30 °C to +50 °C (HOBO® H8 Pro Series User’s Manual), and relative humidity were measured every 15 minutes.
Unfortunately relative humidity data are not available because one of the two relative humidity sensors stopped working after few months.

![Image](image.png)

Figure 1: Orthophotograph of the suburban area (a), study area (b): P parking lot, M1 M2 sensors, T tree, S street, B building

The two sensors were placed in opposite sides of the parking plot, at the same distance from streets and buildings, but the sensor M2 was placed under a tree in order to consider the effect of its shade on air temperature values. Average maximum air temperature values during Summer 2007 are shown in table 1 both for M1 and M2. Shading on both sensors was determined calculating sun’s altitude and azimuth angle for each hour in the site and, afterwards, if the sensors were covered by the shades of the surrounding buildings and the tree (Muhaisen and Gadi, 2005). Data has been collecting by both sensors since may 2007.

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>28.7</td>
<td>31.4</td>
<td>32.5</td>
</tr>
<tr>
<td>M2</td>
<td>28.2</td>
<td>31</td>
<td>31.9</td>
</tr>
</tbody>
</table>

Table 1: Average maximum air temperature values during Summer 2007 for M1 and M2

In this study the difference in hourly temperature values between M1 and M2 (MHDT) was analyzed for data collected during cloudy and sunny days in summer 2007 and 2008. MHDT is defined as $T_{M1} - T_{M2}$, where $T_{M1}$ is temperature at M1 and $T_{M2}$ is temperature at M2.

The daily classification was made using data by the Ibmnet weather station set in the Scientific Research Area of CNR, approximately 4 km far from the parking lot. The weather station is provided with a rain gauge and a CMP6 First Class Pyranometer by Kipp & Zonen® for the measurement of cumulated diffuse and global solar irradiation (Jm⁻²). Precipitation and solar irradiation data were used for the classification of day characteristics and assuming that these conditions can be considered averagely similar at our study area. Rainy days were excluded from the data set and the cloud cover was estimated using the ratio between hourly diffuse cumulated solar radiation and global cumulated solar radiation because diffuse radiation is the amount of radiation scattered by the atmosphere particles and so it is higher during cloudy conditions (Li and Lam, 2001). This ratio ranges from 0 to 1 and can be used as an estimation of cloud cover. The analysis was conducted both on the whole Summer season and on each single month. For each month and for the whole period, a categorization in quartiles was made based on the radiation ratio (C) and days characterized by C values in the 1st quartile were considered sunny while those in the 4th quartile were considered shaded. MHDT for sunny and shaded days was analyzed.

3. RESULTS AND DISCUSSION

Both sensors were shaded by the neighbouring buildings in the first hours after dawn. Until midday M2 is shaded by the tree while M1 is exposed to direct solar radiation. Between 2 p.m. and 3 p.m. both sensors are exposed to solar radiation and afterward buildings shade reaches previously M2 (3 p.m.) and then M1 (4 p.m.) till sunset. Figure 2 shows shading hourly variations at M1 (a) and M2 (b) of DOY (day of the year) 194, situation representative of the shading conditions of the study area during the whole Summer.

![Image](image.png)

Figure 2: Shading hourly variations at M1 (a) and M2 (b) of DOY (day of the year) 194.
In the whole Summer period, MHDT is positive during daytime and in sunny days is always higher than in cloudy ones. MHDT increases always in the first part of the morning and then decreases to 0 just before sunset (figure 3a). Analyzing the hourly trend of each month, the range of the positive values stretched from 11 hours (6 a.m.-5 p.m.) in June (figure 3b) to 13 hours (6 a.m.-7 p.m.) in July (figure 3c) and August (figure 3d) and the maximum values is shifted from 10 a.m. in June to 11 a.m. in July and August.

Maximum values of MHDT in sunny days were about 1.2 °C for the whole Summer, 1 °C in June, 1.2 °C in July and 1.4 °C in August, while for shaded days it was about 0.6 °C in Summer, 0.5 °C in June, 0.7 °C in July and 0.8 °C in August. In cloudy days direct solar radiation is lower and the impact on M1 screen is reduced. In this case MHDT is likely due to the shading effect and particularly to the presence of the tree. MHDT is positive since 7 a.m. to 4 p.m., but the shading effect of tree lasts till 1 p.m. while between 2 and 3 p.m both stations are exposed to the sun. Therefore the persistence of the difference might be ascribed to the presence of the tree that can alter local microclimate.

Even if MHDT is small, the cooling effect produced by the tree can be considered quite interesting because it is the result of only 5% shading of the total paved area. In sunny days MHDT is averagely greater than in cloudy days of about 0.8 °C: this difference might be caused by the combination of several factors such as tree shading, screen performance and heat absorption and release by paved surface and buildings. For this reason it is important to do some more accurate investigations to try to understand the individual contribute of those factors on this difference.
4. CONCLUSION

The average hourly air temperature difference (MHDT) between a sensor placed in a sunlit area and another placed in a shaded one of a parking lot during Summer was always positive and particularly strong during the morning when it reaches its maximum values at 11 a.m. In sunny days MHDT is higher than in cloudy days and this might be due to tree shading on the sensor M2. The presence of a cooling effect also in cloudy days when side effects of solar radiation on the screen are strongly reduced supports this hypothesis. A cooling effect is also present when both sensors are unshaded between 2 and 3 p.m. suggesting that the presence of the tree can affect local air temperature values. The cooling effect is slight but it is important because it is produced by a single tree in a large parking lot. The stronger air temperature difference during sunny days than cloudy ones is probably due to the action of several factors and should be further investigated carrying out studies on the benefits of tree shading on urban environment in order to outline guidelines for building more liveable cities.

Acknowledgements

This study was supported by Tuscany Region “Servizio Sanitario Regionale” grant: MeteoSalute Project.

References


