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Microclimate of territory of Matera and the heat island effect

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Abstract

This work is focused on micro-climate analysis of the Matera town. We carried out several measurement campaigns of climate parameters in summer and winter season by measuring temperature and relative humidity. These analyses show that, in the historical center, the temperature values are greater than in areas with presence of vegetation.
We analyzed the temperature and relative humidity trend of the last seven years. The average seasonal temperatures rise, due to an increased use of air conditioners, causes the growth of urban temperatures.
The sparse vegetation present in the town center does not allow the dissipation of the latent heat.

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Keywords: global warming; urban heat island; materials; vegetation; microclimate

1. Introduction

Since the industrial revolution until today, the west governments, before, and emerging countries, after, inputted a vast quantity of CO2 in the atmosphere. This caused an increase of the global mean temperature with effect on the ices melting and increase of the level sea. In the period 1990-2005 it was measured an increase of environment global mean temperature of about 0.3 °C. The estimates done by different research institutes predict an increase trend of 1.8–2.0 °C in 2100 year.

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To contrast this phenomenon, the principal countries responsible of the CO2 emission signed the Kyoto protocol and the European Union promoted many laws to contrast the increase of the CO2 concentration in the atmosphere. A cause connected with the climate change is the phenomenon of the heat island in the cities (phenomenon described in the five relation of the IPCC Assessment AR5). Man activities (industrial production, vehicular traffic, thermal plants, etc.) influence the urban micro-climate producing an increase of the temperature and pollution.

Climate change is a threat and, at the same time, a new challenge for the twenty-first century town, projected in a scenario of strong fragility of the environmental system.

Different studies stated that the increase of people and buildings in the town, in restricted area of territory, causes a different characterization of the urban climate from that of the surrounding rural areas (Fig. 1). This phenomenon is due to different weather variables, particularly the range of temperatures. The so-called Urban Heat Island Effect depends on how the town is built, the materials employed, how the streets and buildings are arranged, as well as the level of heat generated by the combustion of hydrocarbon for the transportations and domestic uses. The geometry of streets and buildings, their shape and height (canyon effect) entrap the heat in the façade of the buildings and the streets, before releasing it in the atmosphere (Fig. 2) [1].

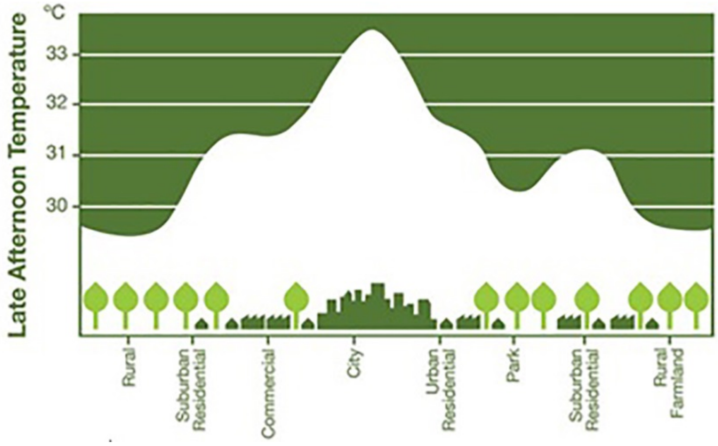

Fig. 1- The profile of the Urban Heat Island.

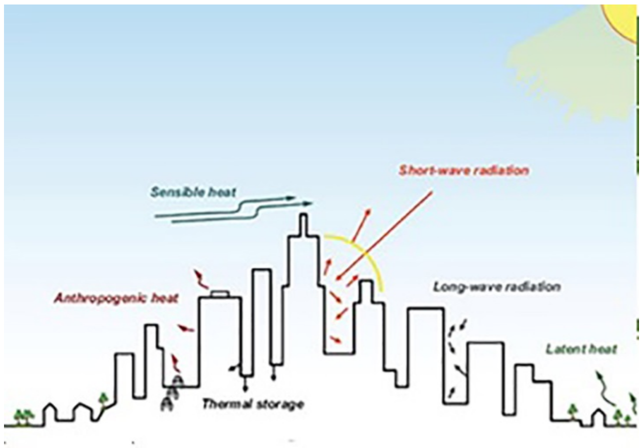

Fig. 2 - Energy exchanges within the town.

The authors in the 2013 year performed the anemological analysis of the Murgia Park of Matera for one year. They verified the principal direction and intensity of wind [2].

If on one hand, cities and their immediate surroundings have greatly contributed to climate change, with their consumption and their greenhouse gas emissions (coming from industrial activities, vehicular traffic, air conditioning systems), on the other hand they are the centers of economic, political and cultural innovation, and play a strategic role in the experimentation of new policies and new urban and territorial planning strategies aimed to reduction of the emissions and integration of actions adapt to specific local contexts.

The increase in industrialization, urbanization and population has increased the number of buildings in the town, concentrating and intensifying the energy consumption and the urban microclimate, eliminating green spaces and replacing them with roads and large waterproof cemented areas and, finally, altering the properties radiative properties of the atmosphere due to high levels of pollution associated with previous activities.

That the town center was warmer than the surrounding countryside is already known since a long time, but in the last 20-30 years the above data have led to greater attention to the urban microclimate changes, transforming what was only a popular wisdom in the best known of the effects of urbanization on local climate: the so-called "urban heat island" (UHI); this term identifies the temperature differences between urban area (warmer) and the surrounding rural areas (cooler) [3].

The analytical evaluation of the microclimate of the urban texture was studied by urban microclimatology [4, 5, 6] and it is a complex issue, since there are almost unlimited combinations of different cli-mate contexts, urban geometries, climate variables and purposes of the projects.

An urban microclimate is the distinctive climate in a small-scale urban area. It is influenced by the material and the configuration of the built environment and it is characterized by a set of atmospheric variables that are substantially different from the conditions prevailing over a larger area.

The heat island effect is directly connected to global warming, so inside the town the main effects of this temperature difference will be connected to an increase of energy consumption and of pollutants and greenhouse gas emissions, a worsening of the life and comfort of the population and a deterioration of air and water quality.

The "urban heat island" effect on temperatures appears especially during the night when green areas get cold rapidly, while the artificial elements remain warm longer (on average is 10-15 °C during daytime hours, while it assumes values of about 5-10 ° C during the night) [7].

The characteristics of the materials used for the casing of the buildings and the road surface play an important role on the intensity of the warming of urban areas.

This work means to investigate the possible presence of the phenomenon in the town of Matera, characterized by significantly smaller dimensions than the large metropolises in the literature examined [8]. In the case in which the UHI effect was present, the goal is to identify the temporal dynamics, to quantify the intensity and indicate some possible mitigation actions.

To achieve these results you must first analyze the environmental data obtained from existing weather stations; the observed time interval is very wide, but the positions of the stations may not be sufficiently representative of the area and the spatial variability of micro-climatic parameters is not examined.

2. Microclimate of Matera town

In Matera, the climate is warm and temperate. The winter months are much rainier than the summer ones. Analyzing climate data provide by ALSIA (Lucana Agency Development and Innovation in Agriculture), the annual average temperature in Matera, considering the time step 2010-2016, is 15.6 °C. In the time step 2010-2016, the average rainfall is 652.3 mm (Fig. 3 and Fig. 4, Table 1).

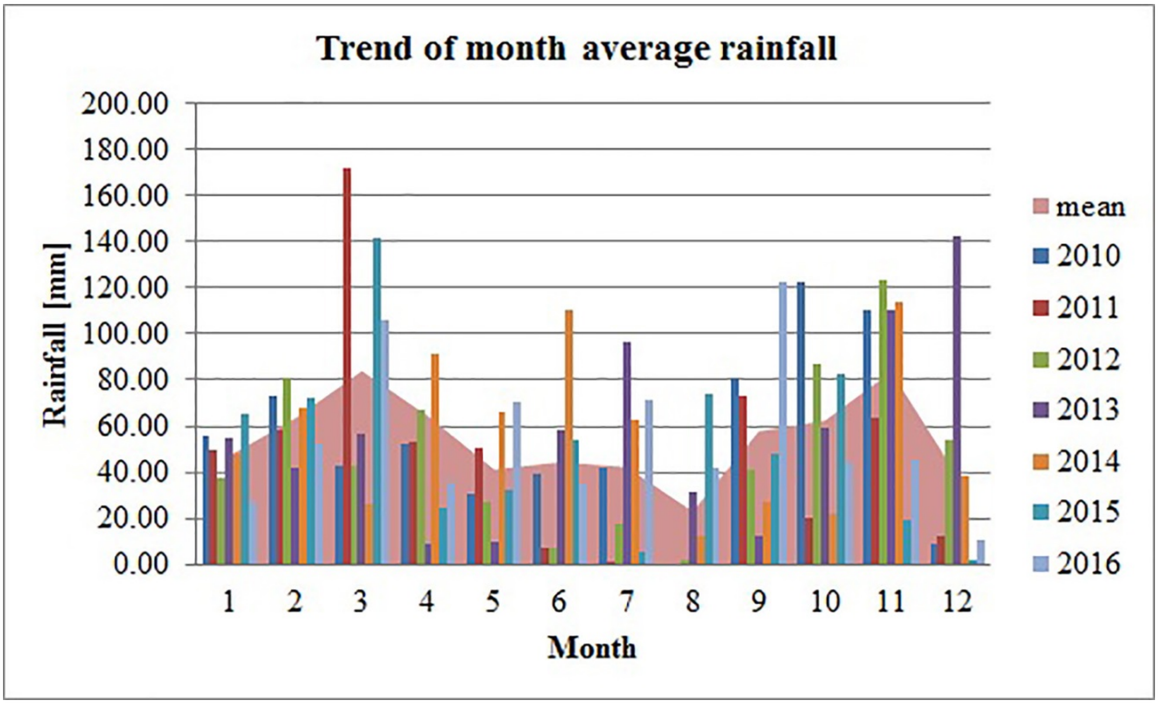

Fig. 3 - *Trend of monthly rainfall for time step 2010-2016.*

The driest month is August 2010 with a value of 0.0 mm of precipitation. Instead the wettest month is March 2011 with a value of 171.8 mm of precipitation.

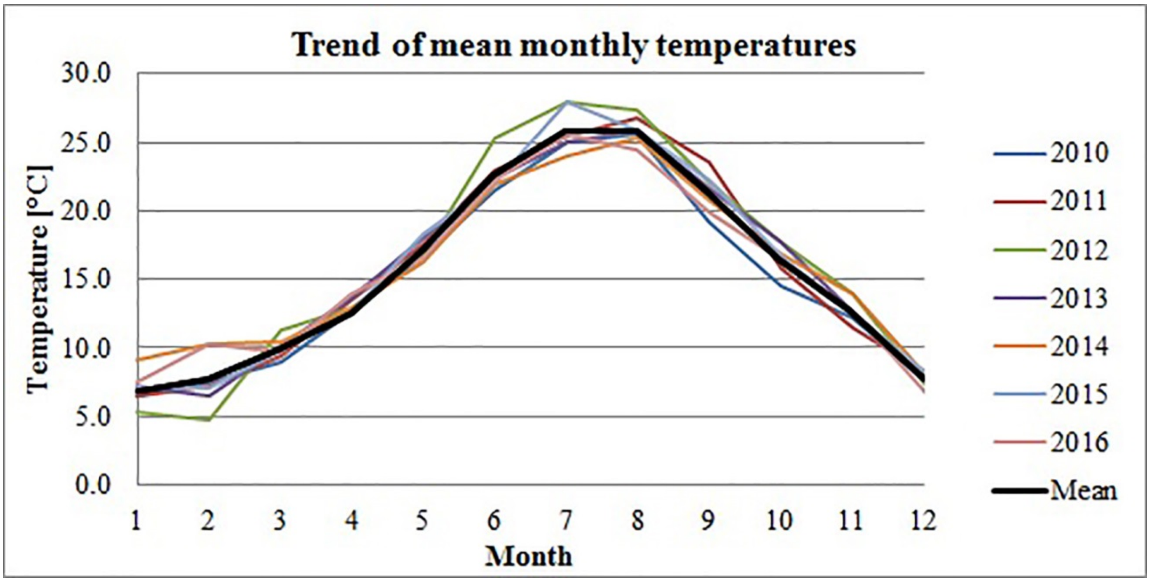

Fig. 4 - *Trend of mean monthly temperature for time step 2010-2016.*

With an average of 28.0 °C, July 2012 and July 2015 are the warmest months. January 2012 is the coldest one, with temperatures averaging 5.0 °C.

Table 1 - Average air temperature and rainfall for time step 2010-2016

Month	Mean Temperature [°C]	Minimum Temperature [°C]	Maximum Temperature max [°C]	Rainfall [mm]
January	7.0	6.4	7.7	47.2
February	7.7	7.0	8.4	63.5
March	10.0	9.3	10.8	84,0
April	12.6	11.8	13.5	64.4
May	17.2	16.2	18.2	41.2
June	22.6	21.6	23.7	44.5
July	25.9	24.8	27.0	42.3
August	25.9	24.9	26.9	23.1
September	21.3	20.5	22.3	57.8
October	16.5	15.8	17.3	62.5
November	12.7	12.1	13.4	83.7
December	7.7	7.0	8.5	38.2
Mean/Total (for rainfall)	15.6	14.8	16.5	652.3

The precipitation varies 60.6 mm between the driest month and the wettest one. Throughout the year, temperatures vary by 18.9 °C. Fig. 5 and Table 2 show the trend of relative humidity for the time step 2010-2016. The relative humidity is between 51.6% and 83.0%.

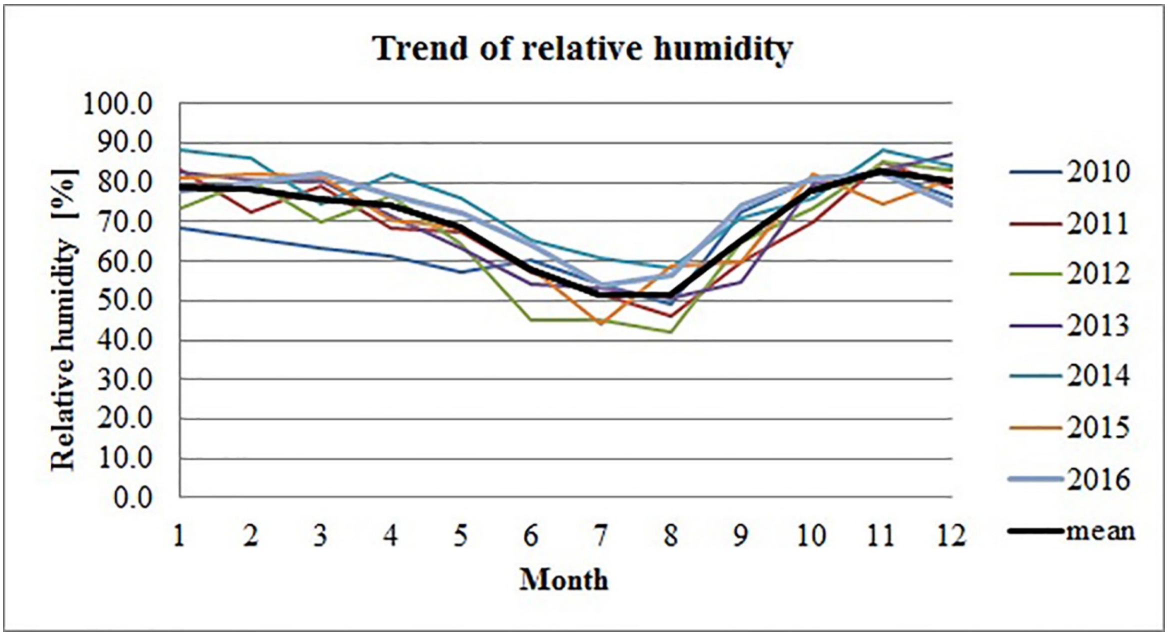

Fig. 5 - Trend of relative humidity for time step 2010-2016

Regarding relative humidity, the wettest month is November with 83.0% of relative humidity, while the driest month is August with 51.6%. Another important parameter is direct irradiation (Table 2 and Fig. 6). The month with the highest irradiation is June with 235.1 W/m^2.

All these factors may contribute to the accumulation of heat in the air and in building structures, to a decrease in the humidity present in the atmosphere and to an increase of the temperature of the individual surfaces.

Table 2 - Average relative humidity and average solar radiation for time step 2010-2016.

Month	Mean Relative Humidity [%]	Minimum Relative Humidity [%]	Maximum Relative Humidity [%]	Solar radiation [W/m^2]
January	78.7	76.2	81.0	80.9
February	78.2	75.6	80.7	103.6
March	75.9	73.0	78.6	137.0
April	73.9	70.9	76.9	183.3
May	68.7	65.4	72.1	225.8
June	57.7	54.6	60.8	235.1
July	51.9	49.1	54.7	231.1
August	51.6	49.0	54.3	212.1
September	65.1	62.2	68.1	163.9
October	77.5	75.0	80.0	121.3
November	83.0	82.8	87.2	86.1
December	80.4	78.0	82.8	80.3

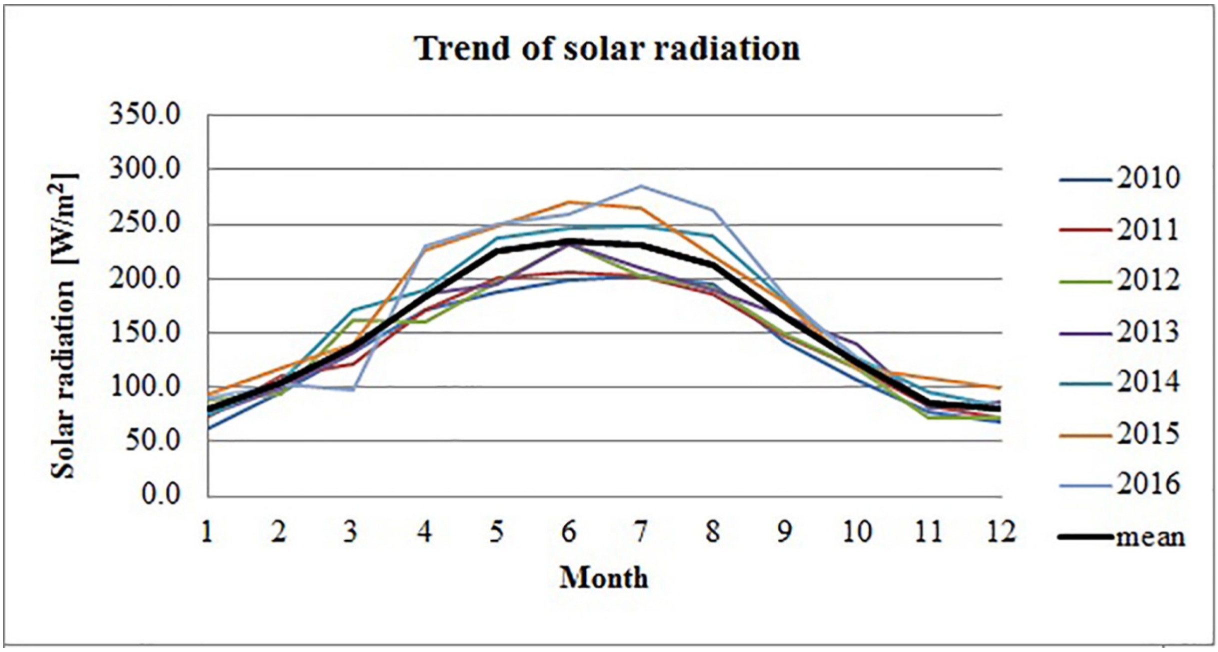

Fig. 6 - Trend of solar radiation for time step 2010-2016.

3. Measures campaign of urban microclimate

The measures campaign was conduct during summer and winter period to relieve the effect of urban heat island that has its negative effect especially in these seasons. In summer season, in fact, because of the high solar irradiation and the little present of vegetation, the temperature of urban areas is major than the temperature records in rural ones. We monitored the temperature and relative humidity of seven point of the town, characterized by different altitude and different typologies of road surface. The surface finishing modifies the proportion of solar energy that is reflected or absorbed by materials. The albedo values depend, in fact, on different characteristics of the material, including the color and the roughness; in general, more the material is light, more the albedo value is high. In Table 3 the points monitored and their characteristics are shown:

Table 3 - Altitude and albedo of measure points

No.	Measure points	Altitude [m]	Road surface	Albedo	
			Urban area		
1	University of Basilicata	441.8	Asphalt surrounded by dense vegetation	0.10	
2	"Tramontano" Castle	414.1	Green grass	0.26	
3	"Vittorio Veneto" Square	386.2	Light stone without vegetation	0.65	
4	Cathedral	394.8	Light stone without vegetation	0.65	
5	"S. Pietro Caveoso" Square	347.1	Light stone without vegetation	0.65	
6	Municipality	407.6	Asphalt without vegetation	0.10	
7	"Fiorentini" Street	353.7	Light stone without vegetation	0.65	
			Rural area		
8	C.da Matinelle ALSIA weather station	247.0	Dry grass	0.20	

The measures are conduct at different time (8:00, 12:00, 16:00 and 20:00 o'clock) for time step 21/06/2016 to 20/07/2016 for summer season and for time step 05/11/2016 to 16/11/2016 for winter season in the seven measures point to have the correlation between temperature and different solar radiation. The value of solar radiation is given by ALSIA. Table 4 shows an example of measures conducted.

Table 4 - Measured temperature and relative humidity.

No.	Measure points	Date	Time	Temperature °C	Relative Humidity %	Solar radiation W/m²
1	University of Basilicata			18.8	73.0	
2	“Tramontano”castle			19.6	70.3	
3	“Vittorio Veneto” square			17.7	78.0	
4	Cathedral	21/06/2016	08:00	18.7	73.7	165.0
5	“S.Pietro Caveoso” square			18.6	75.2	
6	Municipality			18.5	75.0	
7	“Fiorentini” street			18.8	74.0	
1	University of Basilicata			24.7	47.2	
2	“Tramontano”castle			24.5	46.0	
3	“Vittorio Veneto” square			24.5	44.5	
4	Cathedral	21/06/2016	12:00	25.7	42.3	580.0
5	“S.Pietro Caveoso” square			27.0	39.6	
6	Municipality			27.1	39.2	
7	“Fiorentini” street			24.4	45.5	
1	University of Basilicata			28.3	47.1	
2	“Tramontano”castle			28.4	46.0	
3	“Vittorio Veneto” square			28.3	40.8	
4	Cathedral	21/06/2016	16:00	26.6	43.0	406.0
5	“S.Pietro Caveoso” square			27.0	43.0	
6	Municipality			27.2	44.1	
7	“Fiorentini” street			26.2	42.3	
1	University of Basilicata			22.9	55.5	
2	“Tramontano” castle			23.3	54.8	
3	“Vittorio Veneto” square			24.0	52.4	
4	Cathedral	21/06/2016	20:00	22.3	55.4	5.0
5	“S.Pietro Caveoso” square			23.3	54.0	
6	Municipality			23.2	54.1	
7	“Fiorentini” street			22.7	56.0	

For the analysis of urban microclimate we decide to use the average value of day acquisition and two peculiar axis of the Town, Fig. 7.

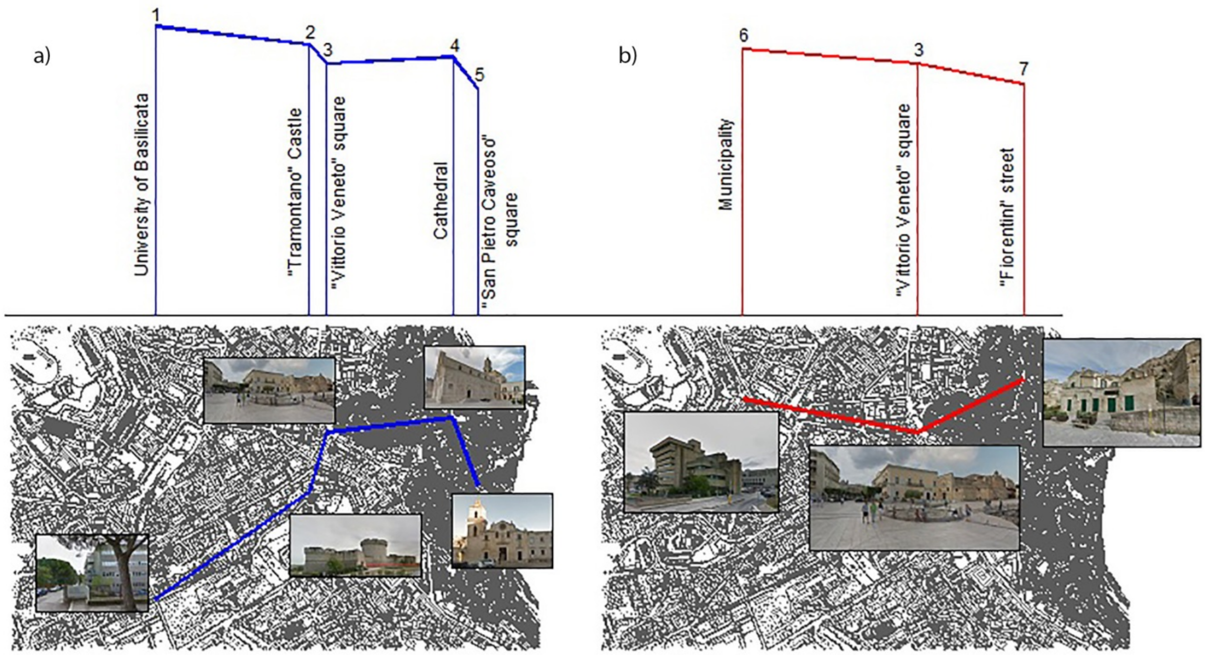

Fig. 7 – (a) Measuring axis 1 and (b) Measuring axis 2.

The maps show the relative positions of the sites where the measures were conducted and a corresponding abstract graphic indication of their altitude.

An analysis of the effect of heat island of Matera necessarily requires the availability of environmental data for the town itself and the surrounding rural locations, used as a reference for the thermal alteration quantification.

The existing station that best meets the specifications shown is the meteorological station in Contrada Matinelle (North Matera), separated from the town center by an air-line distance of about 9.5 kilometers and situated at an altitude of 247 m s.l.m.

It is important to underline that the town is located in the east part of Basilicata with an altitude of 401 m above sea level, on the border with the southwestern part of the province of Bari (the municipalities of Altamura, Gravina in Puglia, Santeramo in Colle), and the extreme part northwestern province of Taranto (with the towns of Ginosa and Laterza). It is located right on the border of the Murge plateau to the east, and Bradanica pit to the west, crossed by the river Bradano.

In Apulia and in Basilicata Regions, part of the territory is characterized by the presence of ravines, namely deep furrows characterized by subvertical and embedded walls in the limestone rocks, carved by streams, currently non-existent, on the Ionian side of the Murge.

The old town center is situated on the western slope of one of these canyons, the so-called "Gravina di Matera", one of the most important and well-known erosion phenomena, and it is divided into two districts, the famous Sassi (Barisano to NO, Caveoso SE), where dwellings are in large part excavated in later levels in the calcareous sandstone.

Fig. 8 - A part of urban area of Matera overlooking the ravine.

In Fig. 9 and Fig. 10, we show the trend of average air temperature for axis 1 and 2 during summer season.

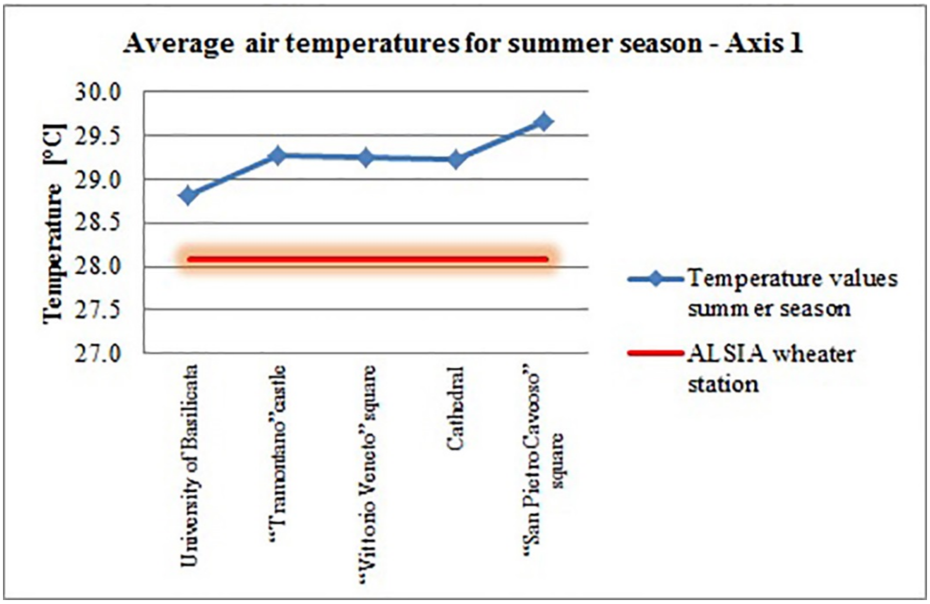

Fig. 9 - Average air temperature for axis 1 in summer season.

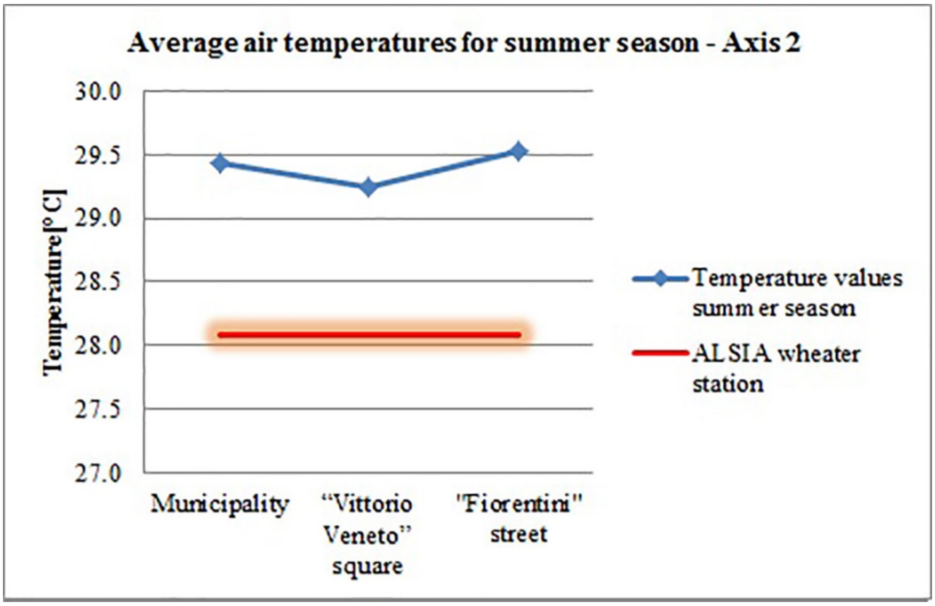

Fig. 10 - Average air temperature for axis 2 in summer season.

For axis 1, it is interesting notes the influence of dense vegetation surrounding the University of Basilicata: this is the reason of the lower air temperatures compared to those measured in "Tramontano" castle which is characterized by a similar altitude. Another consideration concerns the measurement points "Vittorio Veneto" square, the Cathedral and "San Pietro Caveoso" square. In this case, the road surface (light stone) is the same but altitude is different: air temperature decrees with the increase of altitude.

For axis 2, the presence of asphalt without the presence of vegetation in "Municipality" measurement point causes a relevant increase of temperature compared to "Vittorio Veneto" square, even if its altitude is major than the altitude of measure point of "Vittoro Veneto" square. Regarding measurement points "Vittorio Veneto" square and "Fiorentini" street we can state the same conclusion related axis 1: air temperature decreases with altitude increase.

In Fig. 11 and Fig. 12, we showed the trend of average air temperature for axis 1 and 2 during winter season.

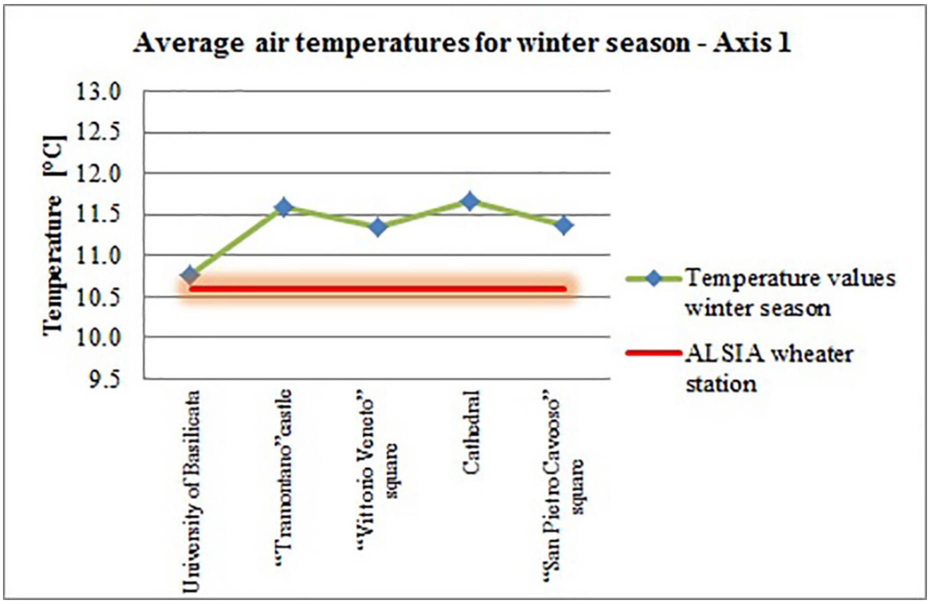

Fig. 11 - Average air temperature for axis 1 in winter season.

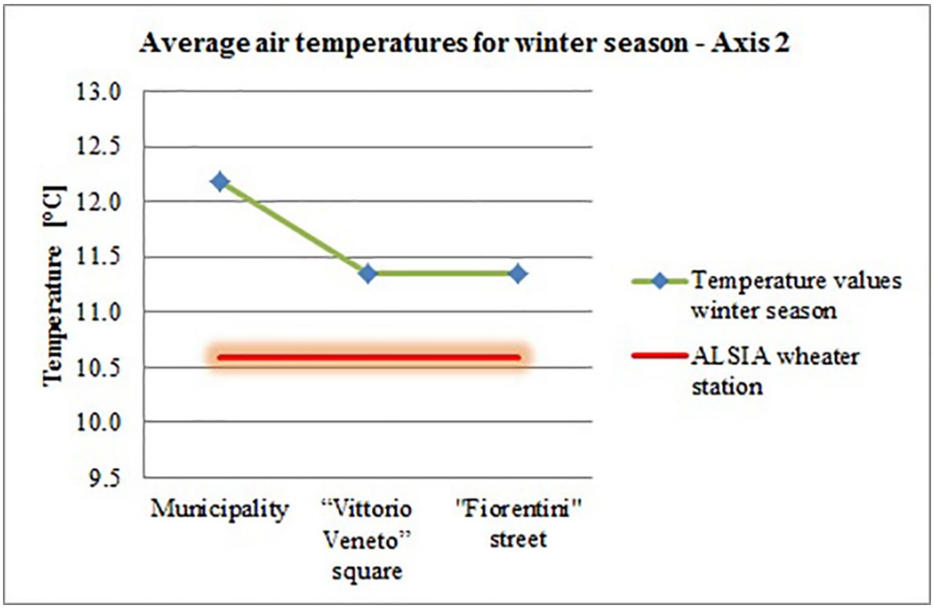

Fig. 12 - Average air temperature for axis 2 in winter season.

In winter season the air temperature trend is quite similar different. For axis 1 the present of vegetation produce a negative effect on temperatures that are minor compared to area characterized by absence of vegetation. The trend of temperature perfectly follows the elevation profile of the Town and of its morphology. In "Vittorio Veneto" and "San Pietro Caveoso" squares characterized by big space, temperatures are lower. In the Cathedral, the measuring point was chosen in an area surrounded by buildings and this helps to have higher temperatures though the elevation is greater than the other points of axis 1 measurements.

For axis 2, the measurement point of Municipality is affected by the presence of buildings and by switching on the heating system of the municipality buildings during the winter season. The absence of heated buildings and a lower population density characterizes the low temperature of "Fiorentini" street.

In both the seasons the comparison between the temperatures of Matera town and Matinelle area show differences in their microclimates. The average annual urban area temperature in summer is greater than about 1.5 °C compared to the nearby rural area, while in winter the difference is about 1.0 °C. Although this average information synthesize surveys of years, seasons, different times of day and despite positive values can be offset by negative ones, it is however possible to state that the heat island of the town of Matera, given that the two stations used can be considered representative of the urban and rural territory, doesn't have an intensity comparable to that of annual metropolis analyzed in the literature that clearly involving greater annual temperature alteration.

The overheating of the air creates a form of discomfort, due both to solar radiation heat both to town activities and is linked, as to the conformation of the urban texture, as to the types of present materials.

In fact, in the center of the town, the large concentration of built areas and road surfaces, coupled with the high thermal conductivity of certain materials, such as reinforced concrete, asphalt, determine an absorption of 10% more solar energy, compared to a corresponding area covered by vegetation.

4. Conclusion

The combined effects of urban heat island (UHI), urban population growth and energy overexploitation compromise the comfort of urban areas. High levels of pollution in the atmosphere along with "cementification" of urban areas, side-effects of human activities, and the excess of asphalted areas (low albedo) in comparison to green areas cause temperature difference between cities and rural areas.

Urban morphology, materials and vegetation play a central role in this context, because they influence building's energy demand and local climate at urban scale.

There are many urban heat island mitigation strategies with a positive impact on both local and global climate, involving various professional fields (such as urban planning, architecture, natural resources management and transportation), that have different benefits.

In contrast to other types of surfaces, green ones return the solar energy according to biochemical and biological cycles: the main effect of the reduction of ground temperature differences is due to the processes of reflection/absorption of solar and thermal radiation that reaches the ground, and to evapotranspiration process that "steals" heat to the environment.

The presence of green areas, besides to promoting cooling in urban environments and seasonal shading of infrastructure, buildings and dark surfaces, also have other complementary benefits in urban areas, like improving air quality through oxygen production, $CO2$ capture, filtration of suspended particulate matter and reducing energy demand for air conditioning; improving water quality through retention of rainwater in the ground and soil erosion control.

Considering the effects of vegetation in mitigating potential temperatures, a difference can be noticed depending on the amount of green areas, vegetation type (green roofs, green areas with trees, shrubs, and grass), atmospheric conditions, locations, building density, and height.

It is necessary to consider that the decrease of temperature, due to the transpiration of plants, is minimized in the presence of individual trees, while definitely becomes sensitive in the case of large green areas, but at the same time an area covered by trees has more influence on the reduction of heat island compared to the same area covered with grass that, however, in turn, is certainly more advantageous with respect to a pavement.

So small green areas placed at the correct distance between them, in order to create an overlap of the effects, may contribute effectively to the reduction of the temperature and to improve the comfort level of the town and its inhabitants.

Future developments of the work will focus in particular on the investigation of the direct and indirect effect (density and height of buildings in a town area influence potential temperature, mean radiant temperature, and Predicted Mean Vote distribution) of different urban textures on buildings energy performance.

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