588: Set up of a monitoring system for a preliminary evaluation of the Urban Heat Island in the town of Palermo

Giorgio Beccali *, Maurizio Cellura *, Simona Culotta [1]*, Valerio Lo Brano *, Antonino Marvuglia *

*Dipartimento di Ricerche Energetiche ed Ambientali, University of Palermo, Italy**

[1]Simona Culotta: simonaculotta@dream.unipa.it

Abstract

Surface energy balance of urban areas depends on the thermal features of building materials, as well as the overall urban layout and various anthropogenic factors. In extended urban areas, all these factors give rise to the phenomenon known as Urban Heat Island (UHI).

From the point of view of urban health, the occurring of UHI drastically changes the fluid dynamic interaction between the air and the city surface, often preventing the dispersion of gaseous pollutants. In the last years in fact, several studies have monitored the increasing trend of breathing diseases and allergies correlated with the presence of UHI.

Nowadays, a rational design of the urban areas within large towns should take into account important factors such as energy requirements, consumption of natural resources, vehicular traffic and air pollution. The study and monitoring of UHI can supply very important data useful to address a correct urban planning policy.

At this aim, the authors have created an automatic monitoring system able to acquire weather data in different points of the urban area of Palermo and compare them to the data recorded in a nearby rural area. This paper describes the system setup and the first analyses accomplished with the recorded data.

Keywords: urban heat island, urban monitoring, weather data, thermal comfort

1. Introduction

The "Urban Heat Island" (UHI), caused by microclimate change brought by manmade alterations of the land surface is the phenomenon in which the urban temperature attains significantly higher values than in the rural areas nearby the town. The intensity of the UHI is measured by the maximum temperature difference between urban and rural area and depends on the size of the city, its population, density of built-up area, urban layout, building materials, industrial development of the city and regional climate [1].

The presence of an UHI causes many negative effects on the urban climatic, thermal and comfort conditions. First of all, the mixing of the air layers above the urban area is limited by the physical features of the territory itself: the presence of high buildings increases the mean surface roughness and this phenomenon definitely influences the formation of spontaneous air motions. The UHI is able to drastically change the air stratification and the energy balance that governs the thermodynamic stability of the air masses above the urban area.

Furthermore, the heat island causes negative effects on air quality, reducing the ability of low layers of the atmosphere to disperse pollutants. This persistent presence of higher temperatures in the cities (especially at night) causes a cyclical air circulation pattern above and around them (thermal inversion), trapping air pollutants within the urban area. As a result, it has been estimated a subsequent accumulation and gradual increase in concentrations of air pollutants [2].

In a hot climate (where the diurnal temperature mean value is large) the high daytime temperature during summer is the main problem rather than the nocturnal heat island (even though the latter may reduce the efficiency of night ventilation of buildings) [3], but the heat waves caused by the presence of the UHI have a significant impact on the energy consumption. Many alarming growths of electric energy demand due to the massive use of HVAC systems have in fact recently occurred during the summer season, causing unforeseen load peaks that brought the national power grid to the point of collapse [4],[5].

Many strategies to mitigate the occurring of UHI effect have been suggested in the literature and can mainly be classified into six categories [2]:

- Modification of urban geometry;
- Use of light coloured surfaces;
- Policies to increase energy efficiency;
- Management of traffic and better transportation system design;
- Use of permeable surface;
- Use of vegetated surface.

Before starting any retrofitting action to improve the local urban micro-climate conditions is very important to perform a detailed climate zoning of the urban area with the support of weather stations strategically distributed in the space.

2. Palermo climate at a glance

The city of Palermo (38°7' N, 13° 22' E) is located in the north-west of the isle of Sicily and faces the Tyrrhenian Sea. The city has an area of 158 km² and its population exceeds 687,000 inhabitants with a density of about 4,350 inhabitants/km².

The traditional shape and architecture of Palermo had a very fast and sharp change between the1960s and 1970s, due to an intense speculative expansion. During that period some neighbouring villages were integrated in the town by an abnormal expansion of modern buildings and many important historical buildings, often characterized by great architectural interest, were destroyed.

The climate in Palermo is typically Mediterranean, with warm dry summers and moderate rainy winters. Spring and autumn seasons are characterized by mild temperatures. Summer is hot and rather windy. Seldom during summer the temperature rises over 42 °C. Normally, in the middle of the winter the temperature can rise above 20 °C. The absolute minimum temperature recorded in the city centre in the last 30 years was -0.5 °C (during the famous snowfall of 8 January 1981) [6]. Deserving of mention the heat wave that invested the city in the 2007 summer when maximum temperature monitored by the Department of Energy and Environmental Researches of the University of Palermo (DREAM) was 43.8 °C and at the same time, the values of humidity were low (7-8%) while the wind speed was much higher than the average (12 m/s). The event was provoked by the famous hot wind called 'Scirocco' (already known as Jugo or Ghibli or Sirocco) originating from the Sahara region.

The winters are cool and rainy with rainfall concentrated between October and March. Generally rains are weak or moderate, rarely violent. The snow is not impossible, although rather rare. It is always weak snow concentrated in a few hours and that completely dissolves almost immediately. Fog is very rare.

3. Description of the Weather Monitoring Network

The weather monitoring network created by DREAM currently consists of five stations located in different parts of the town and a comparison station (indicated by a red marker in right bottom of Fig. 1) in a close scarcely built area. An additional station (indicated by a blue marker in Fig. 1) has been embedded into the DREAM network, but it is operated and owned by a private association called MeteoPalermo (www.meteopalermo.it).

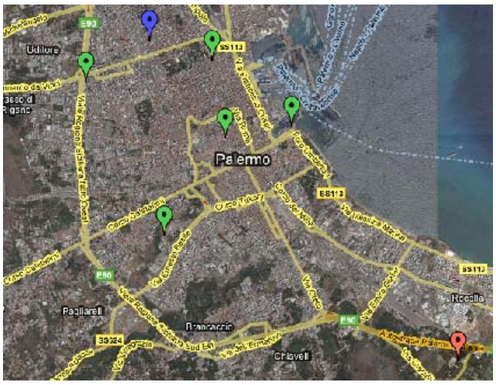

Fig. 1. Positions of the weather stations of the monitoring network

In the following, the weather stations are listed along with their geographical coordinates and their typology:

"Merlino": Longitude: 13° 20' 46.25'' E, Latitude: 38° 06' 14.42'' N. Typology: Urban Station.

"Morgana": Longitude: 13° 21' 20'' E, Latitude: 38° 07' 51.95'' N. Typology: Urban Station.

"Cassandra": Longitude: 13° 22' 15.84'' E, Latitude: 38° 07' 15.88'' N. Typology: Urban Station.

"Amaltea": Longitude: 13° 21' 29.18'' E, Latitude: 38° 07' 09.06'' N. Typology: Urban Station.

"Pizia": Longitude: 13° 19' 49.59'' E, Latitude: 38° 07' 41.64'' N. Typology: Urban Station.

"MeteoPalermo1": Longitude: 13° 20' 35.09'' E, Latitude: 38° 08' 03.90 N. Typology: Urban Station.

"Albunea": Longitude: 13° 24' 11.73'' E, Latitude: 38° 05' 04'' N. Typology: Extra-urban Station.

The weather stations are equipped with:

- Temperature sensor;
- Barometer;
- Hygrometer;
- Anemometer and vane;
- Rain meter;
- Solar radiation sensor;
- UV sensor.

The system is then connected to a data logger. The whole station is powered by an accumulator charged by a photovoltaic solar collector. The data logger is connected to a GSM modem for data transmission to a remote database.

4. Download, Pre-processing, storage and Analysis of Data

The data acquisition system is based on the interaction between the weather station, a data logger and a GSM modem sending data via GPRS at regular time intervals to a Windows PC located at the DREAM building, in which proprietary software is installed.

When the weather station sends the SMS containing the updated data, an ASCII file with the records related to a whole week is created. A Linux server connects to the folder where the text file is generated and copies the file into a local folder. The procedure is automated by a bash script.

```
#!/bin/bash
mount -t smbfs /IPnumber_of_remote_PC/C$
/meteo -o username = user name, password =
password, fmask=0700
echo "copy of data"
rsync -cur /meteo/name_of_the_station/data/
/var/meteo/ name_of_the_station
sleep 5
umount /meteo
echo "sharing on METEO unmounted"
```

This procedure is repeated for each weather station. Once the ASCII file has been acquired by the server, it has to be modified and re-formatted in order to allow the updating of the MySQL server where all data are recorded.
This procedure is realized through a PERL script. In the following a short excerpt of the script used is provided:

```
#modification of the date format
perl -pe 's{(\d\d)/(\d\d)/(\d\d)}{20$3-$2-$1}g'
station1b.txt > station1c.txt
perl -pe 's{(\d\d)/(\d)/(\d\d)}{20$3-0$2-$1}g'
station1c.txt > station1d.txt
perl -pe 's{(\d)/(\d\d)/(\d\d)}{20$3-$2-0$1}g'
station1d.txt > station1e.txt
perl -pe 's{(\d)/(\d)/(\d\d)}{20$3-0$2-0$1}g'
station1e.txt > station1f.txt
#delete blank spaces at the beginning of the
row
perl -pe 's{\s+20(\d\d)-(\d\d)-(\d\d)}{20$1-$2-
$3}g' station1f.txt > station1g.txt
#delete multiple spaces
perl -pe 's{\s+(\S)}{ $1}g' station1g.txt >
station1h.txt
#separate hours and seconds by colon
perl -pe 's{(\d\d\d\d)-(\d\d)-(\d\d)
(\d\d).(\d\d)}{$1-$2-$3 $4:$5}g' station1h.txt >
station1i.txt
perl -pe 's{(\d\d\d\d)-(\d\d)-(\d\d) (\d).(\d\d)}{$1-
$2-$3 0$4:$5}g' station.txt > station1l.txt
#substitute an X to the space between year-
day and hour
perl -pe 's{(\d\d\d\d)-(\d\d)-(\d\d)
(\d\d):(\d\d)}{$1-$2-$3X$4:$5}g' station1l.txt >
station1m.txt
#separate the fields of the txt file by tab
perl -pe 's{\s(\S)}{\t$1}g' station1m.txt >
station1n.txt
#substitute the X with a blank space between
year-day and hour
perl -pe 's{(\d\d\d\d)-(\d\d)-
(\d\d)X(\d\d):(\d\d)}{$1-$2-$3 $4:$5}g'
station1n.txt > station1o.txt
```

The text file thus obtained is ready to be inserted into the database server. The chosen DataBase Management System (DBMS) is MySQL, the most popular among the open source DBMSs. This database server allows an excellent integration among Linux operation system installed in the server, Apache web server used to publish web pages and PHP scripting language used for the creation of dynamic web pages. The complete set of the above mentioned software for management and online publication of large amounts of data is also known as LAMP package (Linux-Apache-MySQL-PHP).
By this way, the Linux system has a MySQL database always updated every thirty minutes containing weather data related to all the stations installed.
The database is updated by using an SQL command like:

```
load data infile 'station1o.txt' ignore into table
station1
```

The database is thus readable and interactively available over TCP/IP network.
LAMP platform allows the design of a series of dynamic html pages to display and analyze data in tabular and graphical form.

Web visitors can have two different representations of the data: a numerical representation with the current values and a graphical representation of historical time series.
Two kinds of queries can be run: temporal queries and spatial queries. The time query allows, once chosen the station or stations of interest, to extract data related to a specific time interval that could even span over the whole period in which the station has been operating. The spatial query allows the investigation about the occurrence of a particular meteorological event in the sites of one or more weather stations.
By exploiting the flexibility of the LAMP platform it was possible to create a set of dynamic html pages, which allow the visualization of the current weather situation and of the statistical analysis accomplished with data, both in graphical and table format. All data are automatically published on the web page http://www.dream.unipa.it/meteo, which displays the location of the weather stations by using Google Maps API.
As an example, Fig. 2 shows the 24-hours diagrams of the air temperature and humidity for one of the weather stations.
The generated graphs are dynamic and are created by the system every time a visitor enters the web page.
Several statistic elaborations are also provided in graphical form.

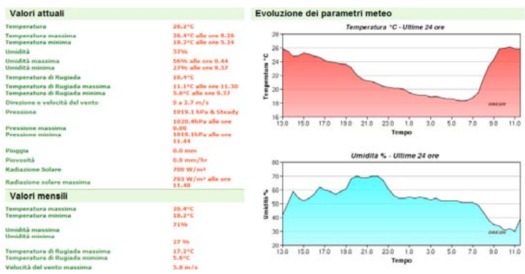

Fig. 2. Example of the information available on the website

In the specific section of the website used for the statistical elaborations (Figure 3 shows that the access to this section is protected by password) these are reported in a graphical form as well. The statistical elaborations concern temperature,

rainfall, solar radiation and wind speed and direction.
In the following, a summary of some pieces of information contained in the statistical section of the weather section of the DREAM website will be provided.

Fig. 3. Access to statistical elaborations

4.1 Temperature Indexes

For temperatures analysis, the authors have built interactive graphics that allow the user to select the desired reference period, to zoom in on a particular area of the chart or change the scale of representation. Figures 4, 5 and 6 show the evolution of the temperature, humidity and bar in the year 2007 as recorded by one of the weather stations.

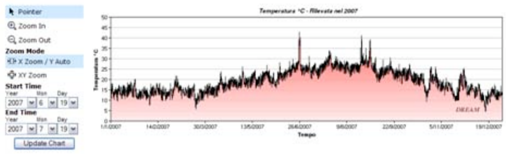

Fig. 4. Historical trend of temperature

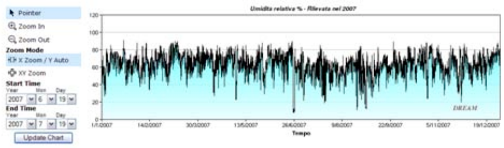

Fig. 5. Historical trend of humidity

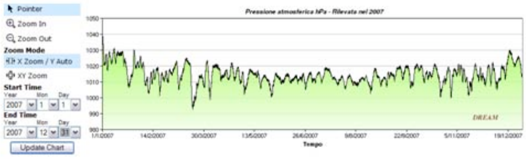

Fig. 6. Historical trend of atmospheric pressure

In Figure 7 visitor can see the daily average temperature versus the normal temperature computed in the period 1961-1990. The normal temperature is a monthly average statistical analysis CLINO (CLImate NOrmals) computed with the data referring to thirty years, as defined by the World Meteorological Organization (WMO) by WMO [7]. The graph available at the DREAM website refers to the Normal temperature computed with the data collected in Palermo by the Astronomic Observatory G.S. Vaiana. This kind of graph allows the immediate detection of days characterized by strong thermal anomalies.
In Figure 8 the daily average temperature is plotted along with the normal temperature obtained by using the maximum and minimum temperature values recorded by the Astronomic Observatory from 1961 to 1990.

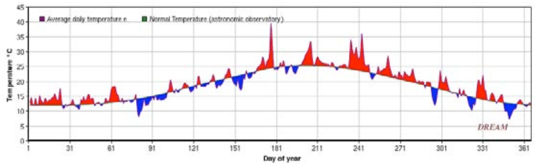

Fig. 8. Evolution of the average daily temperature compared to the normal temperature 1961/1990

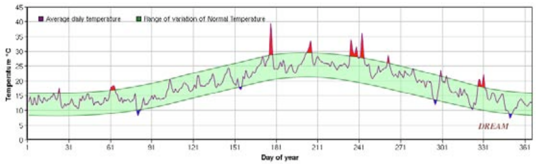

Fig. 9. Daily average temperature versus maximum and minimum normal temperature 1961/1990

4.2 Rainfall Indexes and Evolution of Rainfall

In the section devoted to the rainfall it is possible to display the diagram of the ombrothermic index of Bagnouls and Gaussen [8], which is defined in the way as the dry month, corresponds to the month having the ratio between precipitation and temperature less than two. It is used for identifying drought related phenomena (indicated by positive values of the index) as well as hydrological stress due to excessive amounts of rainfall (i.e., monthly values < -300).
The diagram consider a dry month, when the average value of the rainy total precipitation expressed in mm is lower than twice the average value of temperature expressed in °C.
Figure 10 shows the Bagnouls and Gaussen ombrothermic diagram computed for the year 2007. The red curve shows the evolution of the monthly average temperature, while the green one shows the rainfall depth. It is possible to observe that in 2007 the dry season was between April and August.

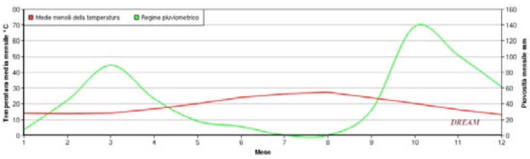

Fig. 10. Bagnouls and Gaussen ombrothermic diagram

Figure 11 shows the bar plot of the monthly total rainfall depth in mm.

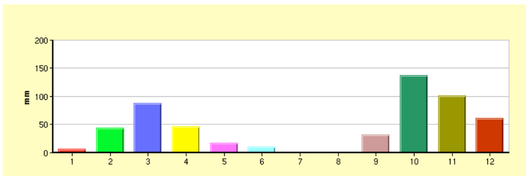

Fig 11. Millimetres of rainfall month by month in 2007

It is also possible to display a bar plot showing, month by month, the number of days in the month with rainfall depth ≥ 1mm (as showed in Figure 12, referring to "Cassandra" weather station) or = 0mm as showed in Figure 13. This information is compared with the monthly average values of rainfall depth computed with the data collected in Palermo by the Astronomic Observatory G.S. Vaiana in the period 1970-1999 [9].

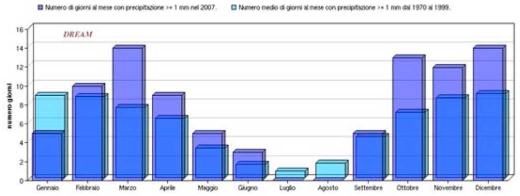

Fig 12. Number of days per month in 2007 with precipitation ≥1mm (light purple bars) vs. monthly average values for Palermo, computed for the period 1970-1999 (light blue bars).

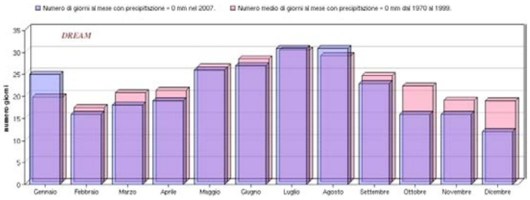

Fig 13. Number of days per month in 2007 with precipitation =0mm (light purple bars) vs. monthly average values for Palermo, computed for the period 1970-1999 (light pink bars).

4.3 Wind Data

In the section devoted to wind data, the visitor has the option to choose the time period (from last 24 hours up to the whole period of operation of the weather station) for which to generate the available graphs.

It is possible to display the wind speed frequency histogram (Figure 14) useful for the anemometric characterization of a site.

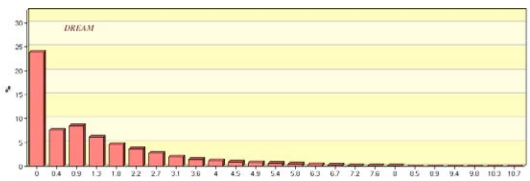

Fig 14. Wind speed frequency histogram

It is also possible to display several polar diagrams coupled with the "wind rose" that shows the prevailing wind direction during the selected period.

The wind rose is a polar diagram obtained by dividing the horizon in 16 sectors (each of 22.5°) that shows the prevailing wind direction during the selected period (expressed in terms of percentage of wind speed observations, out of their total number).

Furthermore, it is possible to split data (and plot the related wind roses) in diurnal and nocturnal ones, with the wind records subdivided into velocity classes (< 1m/s; from 1m/s to 2.5m/s; > 2.5m/s), where data are considered as nocturnal if they refer to hours following the sunset time of the day taken into consideration.

Figure 15 shows the wind speed polar diagrams; Figure 16 shows the nocturnal wind speed polar diagrams subdivided into velocity classes.

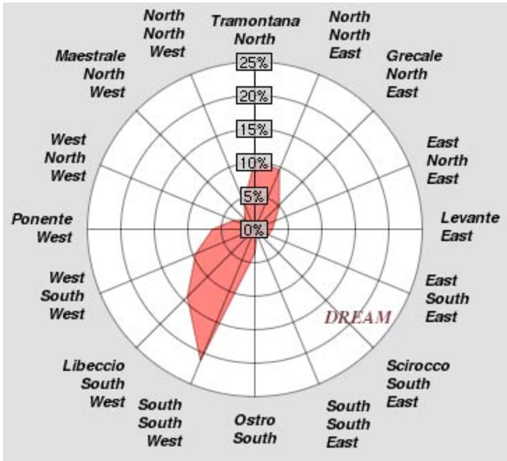

Fig. 15. Wind rose of "Cassandra" station referred to its whole operation period

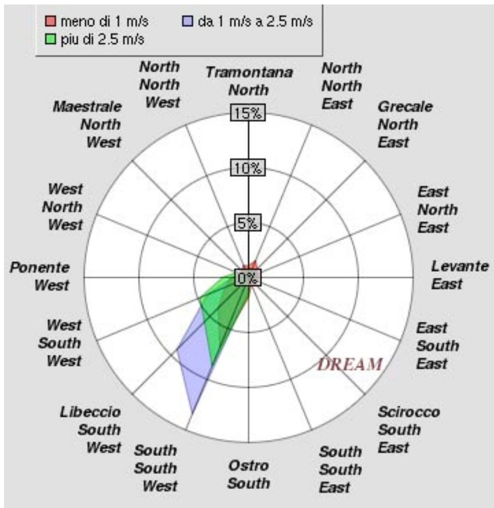

Fig. 16. Nocturnal wind rose of "Cassandra" station referred to its whole operation period

4.4 Download

For authorized users there is the possibility to download the desired data referred to any weather station in a portable document format (pdf) file (shows figure 17). The allowed time intervals for the download are: current week, current month, previous month, current year, and whole operation period of the selected station.

Dati meteo della stazione cassandra

Tempo	Temperatura °C	Umidita %	DewPoint °C	Velocita m/s	Direzione	Pressione hPa	Pioggia mm	Radiazione Wm^2
2007-05-20 00:00:00	17.5	54	8.1	2.2	202.5	1012.6	0	0
2007-05-20 00:30:00	16.7	55	7.6	2.2	202.5	1012.6	0	0
2007-05-20 01:00:00	16.7	54	7.3	2.7	202.5	1012.3	0	0
2007-05-20 01:30:00	16.4	55	7.4	2.7	202.5	1012.2	0	0
2007-05-20 02:00:00	16.4	55	7.3	2.7	202.5	1012.2	0	0
2007-05-20 02:30:00	16.3	55	7.2	2.2	180	1012.1	0	0
2007-05-20 03:00:00	16.2	55	7.2	2.7	202.5	1012	0	0
2007-05-20 03:30:00	16.1	56	7.3	1.3	202.5	1012.1	0	0
2007-05-20 04:00:00	15.8	57	7.3	1.3	202.5	1012.2	0	0
2007-05-20 04:30:00	15.8	54	6.5	2.2	202.5	1012.3	0	0
2007-05-20 05:00:00	15.8	54	6.5	3.1	202.5	1012.4	0	2
2007-05-20 05:30:00	15.8	54	6.5	2.7	180	1012.4	0	30
2007-05-20 06:00:00	16.7	51	6.5	3.1	202.5	1012.4	0	100
2007-05-20 06:30:00	17.6	49	6.8	2.7	202.5	1012.6	0	181
2007-05-20 07:00:00	19.1	58	10.6	0.4	202.5	1012.6	0	270
2007-05-20 07:30:00	18.9	56	9.9	0.9	67.5	1012.7	0	359
2007-05-20 08:00:00	19.7	53	9.8	0	45	1012.9	0	447
2007-05-20 08:30:00	20.2	46	8.2	0.4	45	1012.8	0	533
2007-05-20 09:00:00	20.3	43	7.3	0.4	0	1012.8	0	611
2007-05-20 09:30:00	20.2	52	10	1.8	0	1012.9	0	685
2007-05-20 10:00:00	21.6	51	11	1.3	0	1013.1	0	747
2007-05-20 10:30:00	21.3	52	11.1	2.2	0	1013.2	0	800
2007-05-20 11:00:00	21.6	52	11.3	2.2	22.5	1013.3	0	845

Fig. 17. Example of pdf file for data download

5. Conclusion

One of the most relevant micro-climatic effects of dense urbanization is constituted by the UHI.
Because the UHI has a direct effect on the energy consumed for heating and cooling in buildings there is an urgent need to develop a prediction model to estimate the UHI intensity from weather data.
The use of a single urban climate record to estimate the shape and evolution of a UHI is certainly inadequate, while it is necessary to consider the overall intra-urban distribution of every weather parameter. The values of the monitored parameters should constitute the starting point for the activity of urban planners and designer interested in mitigating the negative effects of UHI and improving the comfort conditions of the town's occupants [10].
However, unless a specific measurement campaign is carried out, it is very difficult to find urban weather data collections publicly available and characterized by a spatial and temporal scale adequate to the investigation of the intrinsic dynamics of weather phenomena.
Starting from the goal of studying the features of the UHI in the city of Palermo, the authors implemented a system for real-time monitoring of several weather parameters in different locations within the town and also in a comparison site slightly outside the urban area. The system is web-based and thus it makes the acquired information available in any remote location using only a web browser.
The described monitoring network is an innovative technological solution, not only because it is the first and only weather monitoring system currently available in the city of Palermo able to allow a comparative study between the urban and extra-urban micro-climatic conditions, but also because of its public availability.

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