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Evidence of the Urban Heat Island in Rome by Climatological Analyses[1]

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With 4 Figures

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Summary

The analysis of air temperature data covering a period of 12 years in a meteorological station network situated in the low Tiber Valley, shows clearly the effect of the heat urban island due to the city of Rome. This effect occurs with different intensity according to the seasons and to minimum and maximum temperatures.

Zusammenfassung

Nachweis der städtischen Wärmeinsel in Rom durch klimatologische Analysen

Die Analyse von 12jährigen Temperaturbeobachtungen eines meteorologischen Stationsnetzes im unteren Tiber-Tal zeigt deutlich die Auswirkung einer durch die Stadt Rom verursachten Wärmeinsel. Dieser Effekt tritt mit den Jahreszeiten und nach Temperaturminima und Temperaturmaxima unterschiedlicher Intensität auf.

1. Introduction

The study of climatological modifications produced by man has become in the last years ever more important for the prediction of climatological trends on a planetary and on local scale, as well. The present work is an analysis of the air temperature data collected between 1964 and 1975 in a station network installed in the low Tiber valley district. The stations are representative of the urban and extraurban situations and therefore from the analysis of the relative data, useful indications can be desumed on the mean characteristics of Rome heat island. The relative data processing and results are presented. The latter are then discussed and some estimations of the differ-

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ence between urban and rural temperature ΔT_{u-r} are carried out on the basis of relationships found in literature. The values thus obtained seem to be in good agreement with those attained by processing data.

2. Description of the Area and of the Station Network

Fig. 1 shows the map of the area interested together with the station network, used for the present work. The district, even with its particularity, presents some characteristics which make it representative of similar places

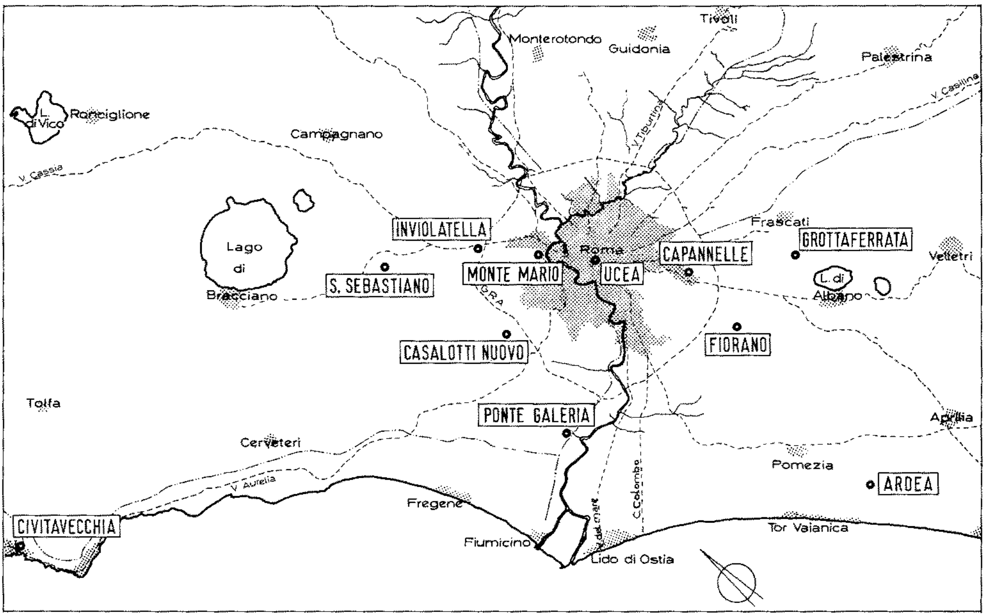

Fig. 1. Map of the area and stations network

along the coastline of the Italian peninsula. In fact, it lies on a large valley, which opens from the Appennines towards the sea surrounded by hills and mountains with Rome in its centre. In more details we have on the North the Tolfa mountains reaching only 600 m, to the East the Sabini mountains reaching over 1000 m, and to the South the Colli Albani with over 800 m, steeping down towards the Pontina plains till reaching the sea.

The climatological stations considered (Table 1) are representative of the different areas present in this district: coastline, rural, suburban and urban. The period examined, from 1964 to 1975 corresponds to the period of maximum development of the city and so it is particularly suitable to check the validity of some relationships between temperature variations and urban development. The measurements are carried out three times a day: 07.00, 14.00 and 19.00 and minimum and maximum temperatures are also recorded.

With these five values the mean diurnal temperature is determined from which the monthly ones were obtained and used in the present work. For each mean value the standard deviation was also calculated in order to verify the data, according to the ordinary criteria of the statistical distributions.

Table 1. *List of the Stations*

No.	Station	Type	Height (m)
1	Collegio Romano	Urban	51
2	Monte Mario	Urban	143
3	Fiorano	Suburban	80
4	Civitavecchia	Coastal	23
5	S. Sebastiano	Rural	130
6	Grottaferrata	Rural on the hills	330
7	Capannelle	Suburban	75
8	Casalotti Nuovi	Rural	80
9	Inviolatella	Suburban	84
10	Ardea	Rural next to the sea	37
11	Ponte Galeria	Rural	15

3. Results

Fig. 2, shows the monthly mean patterns recorded in the different stations for the minimum, mean and maximum temperatures. Above all, the curves of the minimum mean temperatures show that the minimum values occur in January, ranging from 2°C in the Casalotti rural station to 6°C in the coastal station of Civitavecchia. In the city the temperature is about 5°C, whereas in the rural areas is about 2.5°C. For the mean temperature: the lowest values occur also in January ranging from 5.5°C at Fiorano (rural station) to 8.8°C at Civitavecchia. Within the city, the minimum values of mean temperature are about 7°C. The maximum values occur instead during July–August, ranging from 24.3°C at Fiorano to 25°C in Rome and Civitavecchia. Finally, the curve of the mean maximum temperature shows that the highest values occur during the period July to first decade of August, ranging from 28.5°C in Civitavecchia to 32°C at S. Sebastiano. In Rome is recorded a value of about 30°C.

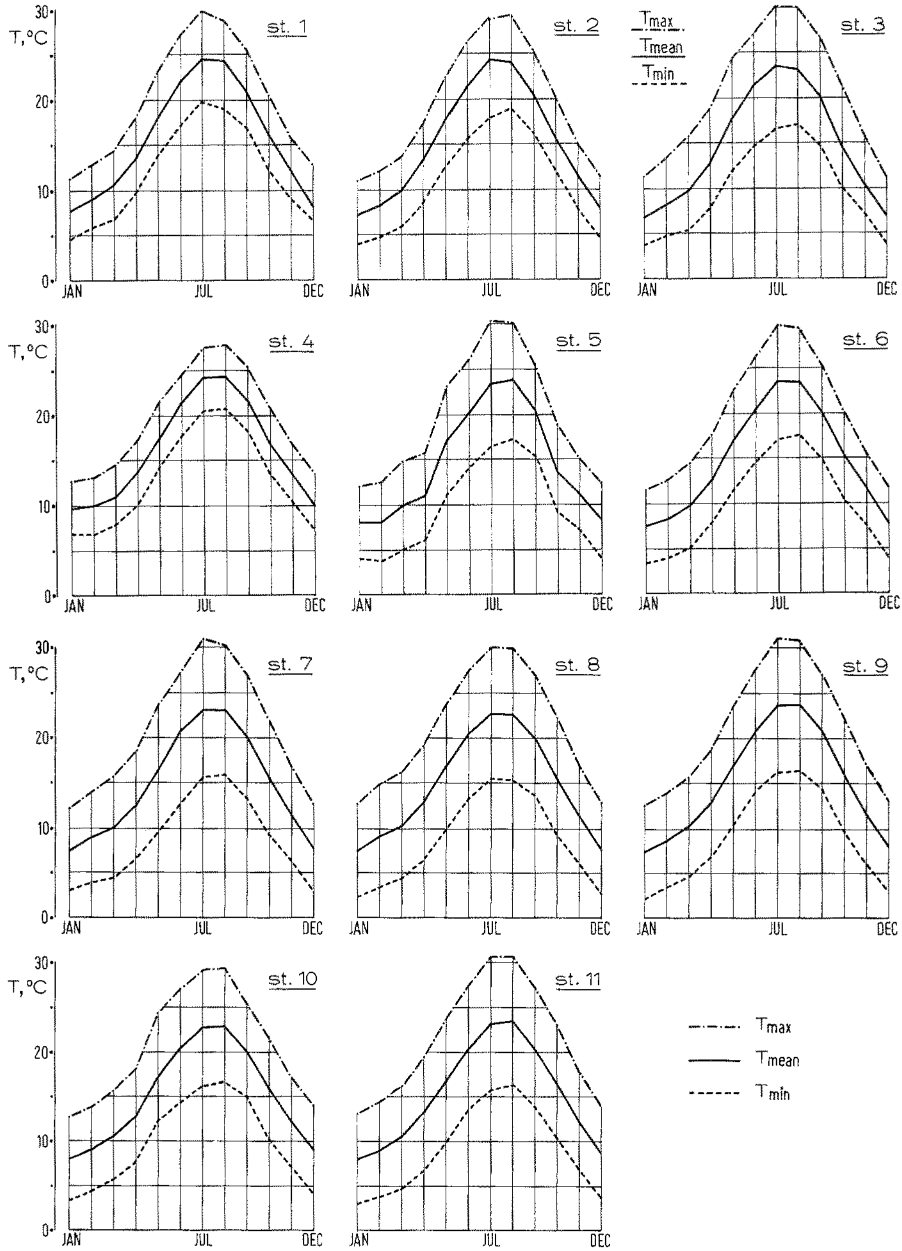

Fig. 2. Mean monthly temperatures (minimum, mean and maximum) for the network stations

Furthermore, the curves show strong temperature variations occurring during the transitional seasons, whereas in winter (December, January, February) and in summer (June, July, August) these variations are reduced. From the data it is possible to deduce that very small variations occurring during December–March, will increase in the following month reaching the maximum in April and May. Then, they will decrease reaching the minimum between July and August and again increase with a maximum between September and October.

Table 2. *Mean Monthly Values of the Diurnal Variations of the Temperature,* $\overline{\Delta T}$ (°C)

Stations	J	F	M	A	M	J	J	A	S	0	N	D	Year
1	6.6	6.9	7.5	8.4	9.6	10.0	10.4	10.0	8.9	8.4	6.9	6.1	8.3
2	7.0	7.3	7.9	8.6	9.8	10.7	11.2	10.6	9.2	8.3	7.2	6.6	8.7
3	7.5	8.8	10.5	11.1	12.4	12.5	13.6	13.0	12.0	11.3	8.5	7.5	10.7
4	5.9	6.4	6.5	7.0	7.1	6.6	7.0	7.1	7.1	7.2	6.2	6.1	6.7
5	7.9	8.7	9.8	9.5	11.9	11.9	13.9	12.9	10.3	9.7	7.8	8.4	10.2
6	8.1	8.6	9.4	9.8	11.0	11.7	12.6	11.7	10.3	9.6	7.9	7.7	9.9
7	9.2	10.4	11.4	11.7	14.1	14.5	15.4	14.4	13.6	12.5	10.3	9.5	12.3
8	10.5	11.3	11.9	12.7	13.9	14.2	14.7	14.8	13.4	13.2	10.8	10.1	12.6
9	10.4	10.4	11.1	12.0	13.3	13.7	14.9	14.5	12.8	12.6	10.8	10.0	12.2
10	9.5	9.5	10.0	10.5	12.2	12.7	13.0	12.6	10.6	11.4	9.9	9.7	11.0
11	10.2	10.6	11.5	12.8	13.9	14.2	15.0	14.4	13.3	12.7	10.9	10.2	12.5

In Table 2, are reported the diurnal variations of the mean temperature. They show clearly that they depend on the coast distance: in Civitavecchia such variation is around 6°C–7°C with a yearly variation of about 1°C. Soon after we have Ardea with an annual variation of 4°C. The inland stations instead, present variations of about 6°C, except for the urban station in which the minimum temperature values, mitigated by the effect of the heat, produced by human activities, cause an annual excursion of 4°C–5°C.

4. Urban Heat Island

To point out the effect of the urban heat island relative to the surrounding areas, were carried out some spatial-temporal sections with the mean values of the minimum, mean and maximum temperatures, collected in stations located at progressively growing distance from the coast. The sections

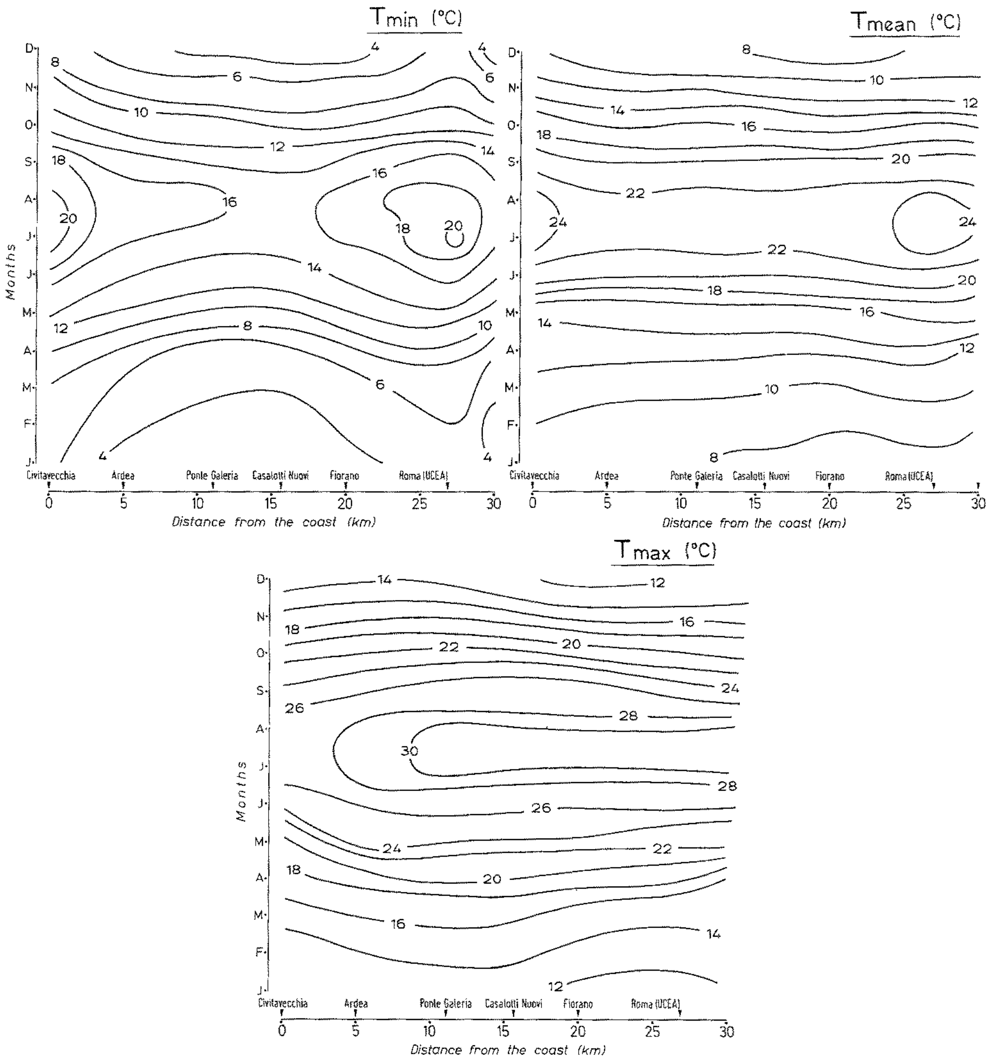

Fig. 3. Time-space section of the mean minimum temperature, the mean temperature and of the mean maximum temperature perpendicular to the coastline

obtained give month by month the trend of the temperature from the coast up to the centre of the city and are reported in Fig. 3.

Taking into account the minimum temperatures the presence of the heat island clearly appears either during the winter months or during the summer months with growing values from the winter toward the summer except for the December month where a second maximum is found.

By comparing the Rome station and the Casalotti Nuovi rural station we obtain for the ΔT_{u-r} difference during the year the trend reported in Table 3.

By considering the mean and maximum temperatures, it may be seen that the effect becomes less evident and tends to disappear. With the mean temperatures it results to be reduced, whereas with the maximum temperatures the effect, which is deduced from the section is essentially associated with the presence of the sea. In fact during the winter months, the temperature along the coastal area is higher and slowly decreases towards the inland.

Table. 3. *Minimum Mean Temperature Difference Between City and Country (Monthly Values, °C)*

	J	F	M	A	M	J	J	A	S	O	N	D	Year
ΔT_{u-r}	2.5	2.5	2.3	3.2	4.1	3.9	4.3	3.6	3.5	3.7	3.0	4.0	3.3

Moreover along the coastal area, the heating associated with the solar radiation is mitigated by the presence of the sea and in summer along the coast the values are lower than those of the inland areas. Therefore a gradient of sign opposite to that recorded in winter and practically the effect of the sea presence is felt up to a distance of ~10 km from the coast.

Beyond this threshold we have a uniform temperature pattern, which tends to increase going towards the inland. The urban heat island effect was also stressed by the section obtained by the data analysis of the stations aligned parallel to the coast. These sections were drawn employing the data relative to 5, 9, 1, 7, 6 stations and the patterns are shown for T_{min}, T_{mean} and T_{max} respectively in Fig. 4. From them it is well evident the presence of the urban heat island in the minimum temperature, while the effect tends to disappear in the mean and maximum temperatures.

The presence of the heat island mostly in the minimum temperatures than in the maximum ones, may be associated with the physical mechanisms which define the effect: i) the heat production for anthropogenic activities and ii) the heat release during the night due to the greater diurnal absorption of solar radiation. The latter depends on the thermal characteristics of the building materials [8].

As far as the first point is concerned an evaluation relative to the winter months and based on the fuel consumption for human activities (heating, road traffic, etc.) indicates a heat production equal to ~ 30 cal cm^{-2} day^{-1}. Data averaged over a 20 years period indicate for the incoming solar radiation in Rome in the winter time a value of ~ 195 cal cm^{-2} day^{-1}, which corresponds to about 165 cal cm^{-2} day^{-1} absorbed by the city.

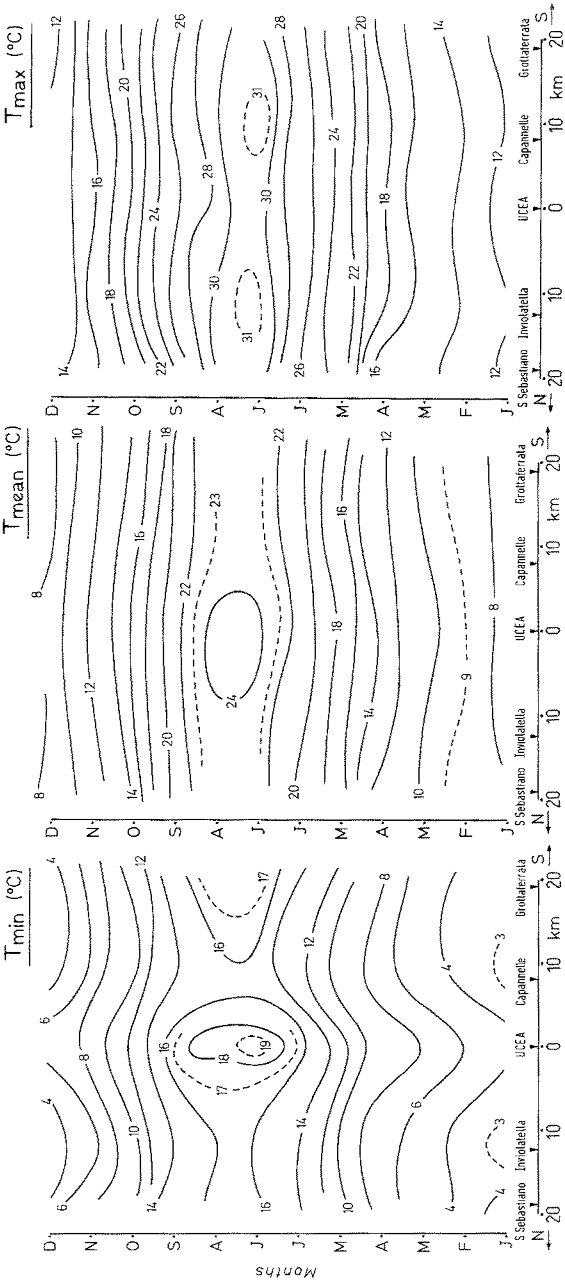

Fig. 4. As Fig. 3 parallel to the coastline for the mean minimum temperature, for the mean temperature and for the mean maximum temperature

It can be seen then even if the anthropogenic heat is only 20% with respect to the solar radiation, it has a remarkable importance in increasing the minimum temperatures during the winter because, being due to the building heating, it is generally produced during the hours following the sunset.
As far as the second aspect is concerned this is particularly important to explain the increase of the summer minimum temperatures.
On this regard from the surveys carried out it results in fact that the maximum of the temperature differences is recorded during the night-time hours and this confirms what was found by means of these climatological analyses.

Table 4. *Comparison Among the Computed and Observed ΔT_{u-r} Values* (ΔT_{u-r} °C)

	Ludwig and Kealhoa [6]	Ludwig [5]	Oke [7, 8]	Observed
Winter	2.0	1.6	–	3.0
Summer	2.3	2.4	–	3.9
Year	2.2	2.0	3.5	3.3

This result is also confirmed by Oke [8] who asserts that the difference maximum ΔT_{u-r} would occur just about 3 or 4 hours after the sunset.
As regards the possibility to express ΔT_{u-r} different relationships were proposed which associate the ΔT_{u-r} values either with meteorological parameters, such as the wind or the temperature gradient, recorded in rural areas, or with parameters which express the size of the city, such as the heat produced by them or more simply the population.
For cities of over 2 000 000 inhabitants Ludwig and Kealhoa [6] suggest

$$\Delta T_{u-r} = 2.6 - 14.8 \left(\frac{\Delta \theta}{\Delta p}\right)_r ,$$

where $\Delta\theta/\Delta p$ is the vertical lapse rate recorded in the rural area.
This relationship was afterwards modified [5] by introducing the population P

$$\Delta T_{u-r} = P^{1/4} \left[0.633 - 0.298 \left(\frac{\Delta \theta}{\Delta p}\right)_r\right] .$$

Finally, Oke [7] proposed in clear sky conditions for the maximum value ΔT_{u-r} the relationship

$$\Delta T_{u-r} = \frac{P^{1/4}}{4\,\bar{u}^{1/2}} ,$$

with $\bar{u}$, mean wind velocity.
By employing the data available for the rural station for the difference ΔT_{u-r} are derived the values reported in Table 4.

As it may be seen from the data, the different relationships proposed agree fairly well with the values ΔT_{u-r} experimentally recorded. A considerable difference instead is found when considering the correlation proposed by Oke [8] on the basis of the data analysis relative to some European cities. In this case in fact we would have $\Delta T_{u-r} \simeq 9°C$ which is well above not only with the values considered, but also with those recorded during the specific measurement surveys in which the maximum value ΔT_{u-r} was 4–6°C [2]. This different behaviour may be perhaps explained by observing

Table 5. *Temperature Data for Rome*

Period	T_m (°C)	T_{mean} (°C)	T_M (°C)
1831–1910	10.7	15.3	20.3
1901–1930	11.2	15.6	20.4
1926–1955	11.6	16.2	20.7
1964–1975	11.7	15.7	20.1

that the Rome area is subject to a rather sharp anemological regime: the mean wind recorded in Rome during the year is about 4–5 m/s with prevailing wind in spring and summer months with respect to the autumn and winter months. In these conditions it can be thought that the wind action, even if not covering the effect of the urban heat island, determines a reduction of ΔT_{u-r} differences with respect to those that could be recorded in the case of wind calm conditions.

We conclude by observing that the presence of the urban heat island effect on the minimum temperatures is confirmed by comparing a previous data series showing very clearly the minimum temperature increase. This increase is particularly significant for the later years in which instead is recorded a temperature decrease in the mean and maximum values. The data through which the comparison is carried out are reported in Table 5 and are deduced by Eredia [3] relative to the period 1831–1910, by Bilancini [1] for the period 1901–1930 and by Gazzolo-Pinna [4] for the period 1926–1955. In the same period the population of the city has increased in a century, from 244 484 (1871) to 2 781 993 (1971) inhabitants.

References

1. Bilancini, R.: Tavole climatologiche di alcune stazioni italiane III: Chieti, Roma, Isernia, Napoli, Portici. Riv. Met. Aer. *XVII*, 34–39 (1957).
2. Colacino, M.: Some Observations of the Urban Heat Island in Rome During the Summer Season. Nuovo Cimento *3C*, 165–179 (1980).

3. Eredia, F.: Il clima di Roma. Tip. Naz. "G. Bertero". Roma 1911.
4. Gazzolo, T., Pinna, M.: La distribuzione delle temperature in Italia nel trentennio 1926–1955. Ser. Idr. Min. LL.PP. Publ. n. 21. Roma 1969.
5. Ludwig, F. L.: Urban Air Temperatures and Their Relation to Extraurban Meteorological Measurements. Am. Soc. Heat. Refrig. Air-Cond. Eng. Publ. n. SF 70-9-40–45, 1970.
6. Ludwig, F. L., Kealhoa, J. H. S.: Urban Climatological Studies. Final Rept.-Contract Cod. DAHC 20-67-C0136. Stanford Res. Inst. California, 1968.
7. Oke, T. R.: Review of Urban Climatology (1968–1973). WMO Tech. Note no. 134, Geneva 1974.
8. Oke, T. R.: 1979: Review of Urban Climatology (1973–1976). WMO Tech. Note no. 169, Geneva 1979.

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