The study of the urban microclimate by means of public transport systems

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Abstract: - The Department of Energetics and Environmental Researches (DREAM) of the University of Palermo has implemented a new technique for the assessment of the urban microclimate using data acquisition equipments installed on vehicles of the urban transport system.
These instruments, equipped with various kinds of sensors, are able to measure the most important weather and climate quantities and the most relevant pollution parameters and to save the position data (latitude, longitude, altitude, speed) by means of a Global Positioning System (GPS). Data can be downloaded from a remote station through the GSM mobile phone network. These equipments, continuously moving across the urban area, could integrate the data from existing fixed stations, and create a virtual network of hundreds of measuring points.
In the field of the pollution control they can contribute to the characterization of causes, the localization of sources and to the application and check of control strategies with a relevant spin-off to traffic planning.
In the paper the first results of the measuring campaigns carried out in the towns of Palermo and Messina and some applications of the acquired data are reported.

Key-Words: Mobile measurements; Environmental Data; Urban microclimate; Heat Island; Bioclimatic Indices.

1 Introduction

An extended and thorough knowledge of the microclimatic and pollution conditions of an urban area is extremely interesting for the purpose of improving studies aimed at characterising the "urban heat island", at determining energy transfers inside urban canyons, at defining comfort indices in an external environment, at identifying diffusion models for pollution deriving from traffic as well as from all other human activities, and also for all the various and complex aspects of the issues linked to energy saving on a micro- and mesoscale [1] [2] [3].

These kinds of studies could be conducted by installing a very large number of measurement stations spread over the whole urban area, but this cannot be proposed for evident reasons of costs linked to the stations themselves and to their management and maintenance.

One possible solution to the problem could be integrating the fixed monitoring network with stations placed on public means of urban and/or extra-urban transport. These buses, continually moving on the main arterial streets, would build a virtual network made up of a very large number of measurement stations.

The installation of sensors aboard mobile vehicles certainly represents a new and original alternative [1]; in the studies conducted in the last years, mobile laboratories have been shown to be useful tools as recently reported in [2] [4] [5] [6] [7] [8].

For some years the Department of Energetics and Environmental Researches (DREAM) of the University of Palermo, to which the authors belong, has been experimenting with a new technique for the assessment of urban microclimate using original data acquisition equipment installed on moving vehicles. A large number of tests was done using measuring equipments built within the DREAM laboratories.

In this work the results of the preliminary tests carried out by the authors beginning in the early

months of 2000, with the aim to demonstrate the feasibility of data collection by means of moving vehicles and to highlight its potential through some examples, have been reported.

2 Preliminary study

During the years 2000 – 2004 the first feasibility studies on environmental monitoring by means of mobile vehicles have been carried out by the authors in the cities of Palermo and Messina [9], [10].

The early campaign was conducted in Palermo with the support of the Municipal Transport Concern of Palermo (AMAT). The equipment used, based on the Dallas DS 1616 integrated data logger, which used its inner sensor for measuring the temperature of ambient air and a Honeywell HIH 3605B sensor for measuring relative humidity, was placed on the roof of the vehicle. The data downloading was carried out by means of a portable personal computer equipped with a serial interface and the specific communication software.

In these early measurement campaigns, georeferenced data have been obtained through the NAVSTAR system equipping the vehicles of the Municipal Transport Concern. Through the matching of time and position data provided by the system and the environmental and time data recorded by the moving equipments it has been possible to associate each reading of thermohygrometric data with the relative position in the urban area.

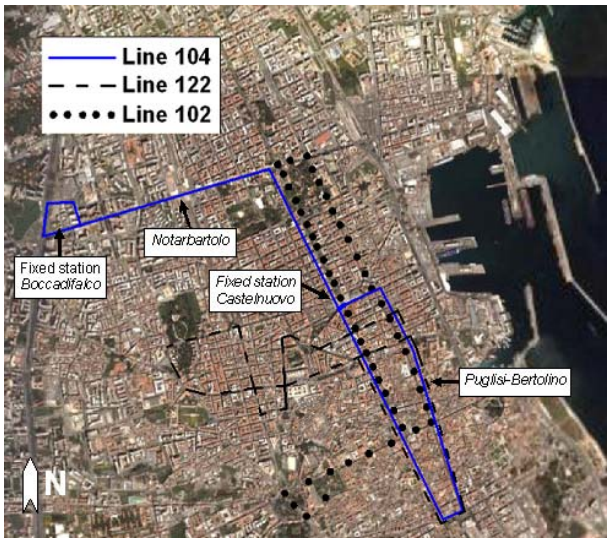

Figure 1: City map of Palermo with the routes of the telecontrolled buses.

Figure 1 shows a map of the city of Palermo where the routes of the telecontrolled buses, on which the moving equipments have been placed, are displayed. The bus lines involve the central zone of the city as well as some peripheral and extra-urban zones.

The main aim of this first measurement campaign has been to assess the feasibility of the project and the reliability of the data obtained with the equipment described above.

In particular, during the first part of the test program, the following items were checked:

- Data Overlapping: control of the data obtained from different instruments in the same time and in the same place.
- Data Integration: data acquired in the same location by diverse equipments at different times can be used to rebuild the time behaviour of the environmental parameters of the location in hand.
- Data reliability: time behaviour of the acquired environmental parameters are compatible with values measured by the nearest meteorological stations.

Figures 2, 3 and 4 show respectively an example of data overlapping, data reliability and data integration.

After the measurement campaign conducted in Palermo, a subsequent measurement campaign has been started in the city of Messina with the support of the Municipal Transport Concern of Messina (ATM), concerning the reliability assessment of an autonomous georeference and data transmission system.

To this end, a piece of equipment called "WCAM" (Weather Climatic Acquisition Mobile), consisting of a micro controller endowed with large memory capacity for data filing, a GPS positioning unit and a GSM transceiver for data transmission, has been designed and manufactured with the aid of the Multicom company from Caltanissetta (Figure 5).

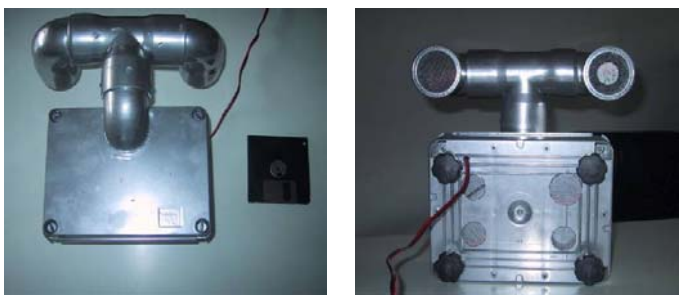

Figure 5: External views of the WCAM equipment

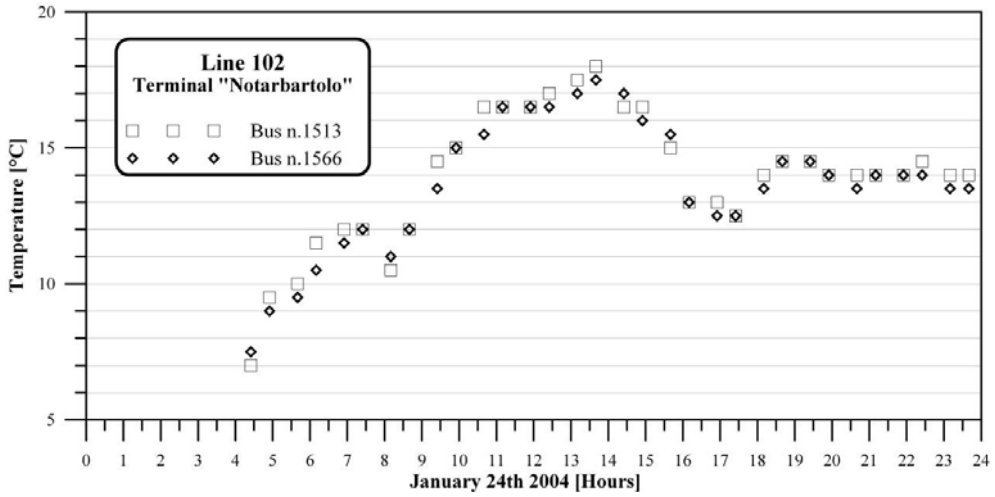

Figure 2: An example showing the data superimposability

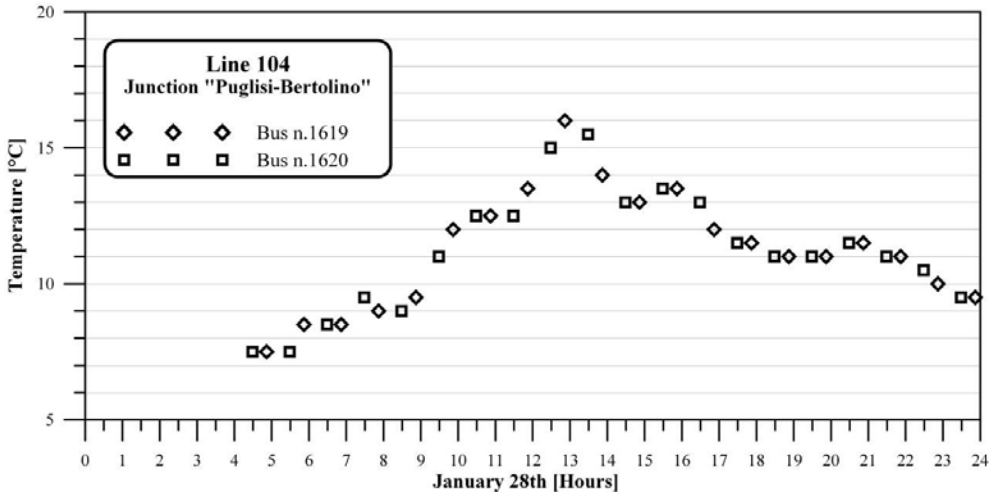

Figure 3: An example showing the data integration

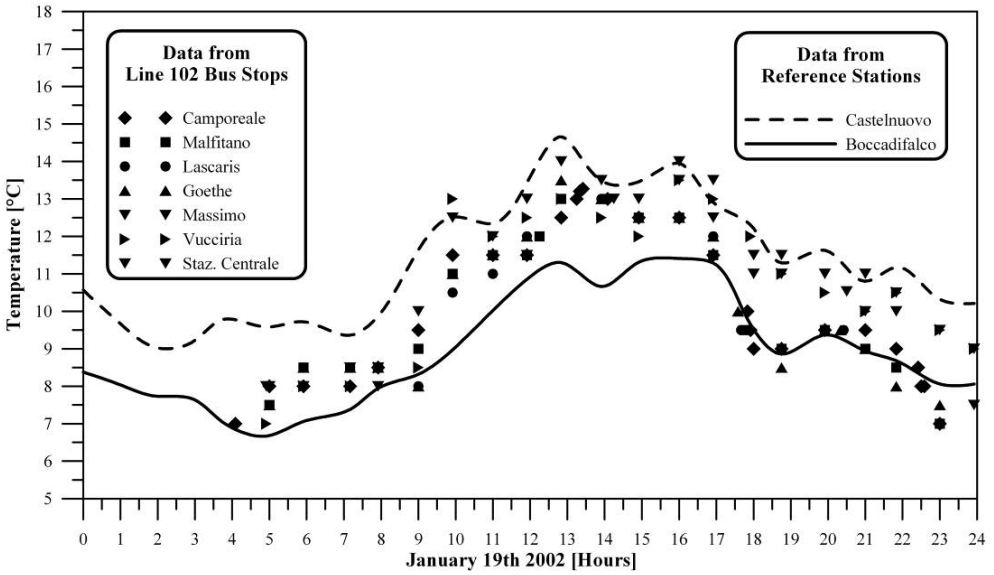

Figure 4: An example showing the data reliability

During design, particular attention has been paid to the versatility of the system; in fact, the micro controller is provided with analogical and digital interfaces, which allow it to interface with almost every type of sensor, making the device capable of acquiring different types of data. In particular, for the thermohygrometric measurements, a Sensirion SH75 (*sensmitter*) integrated sensor has been used.

Later on, specific controlling software called WCAD (Weather Climatic Acquisition Data), capable of downloading data recorded in the memory of the WCAM sensors or monitoring them in real time has been developed.

In order to carry out the control of the georeference capability of the data and to run a test on the precision of the GPS system, it has been chosen to place the acquisition units aboard vehicles bound to follow a fixed predetermined route with a quite strict timetable, i.e. rail vehicles.

The tramway system of the City of Messina has revealed itself to be particularly well suited for our aims. In fact, it runs almost entirely along the coastal line and, in any case, between buildings of little height, which ensures a good cell-phone field for the GSM system and good satellite coverage for the GPS systems placed aboard the mobile vehicles.

The Technical Management Department of the Municipal Transport Concern of Messina (ATM) has assured full and active collaboration, placing two carriages at our disposal, collaborating in placing the sensors, in compliance with the strict security regulations on tramway traffic, and consenting to carry out a series of tests in the tram depot. The two carriages used in the measurement campaign are shown in Figure 6; at the front the WCAM sensors can be seen.

A confirmation of the hypotheses put forward about the suitability of Messina's tramway line for this kind of studies and the proper functioning of the location and data transmission systems is evident from the Figure 7.

In them, each point where the WCAM system effected an acquisition is marked on a plane of geographical coordinates. It is interesting to observe the precision with which the points follow one another on a continuous line, the fact that the points relating to subsequent trips overlap, the lack of points outside the line and the homogeneous distribution of the points on the line (all of which indicates the absence of wrong readings by the GPS system). Figure 8 shows also the measurement points displayed on a topographical map provided with the appropriate cartographical references.

Figure 6: The carriages used in Messina for the measurement campaign

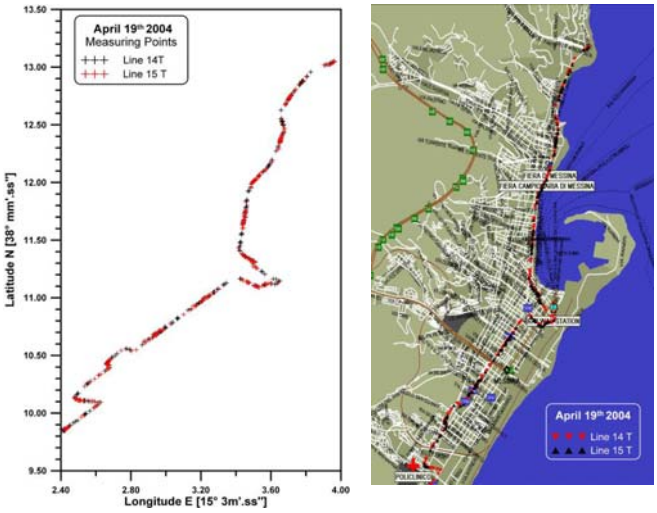

Figure 7: Georeferenced points on the topographical map of Messina

3 Applications of the method

In order to demonstrate the usefulness of the data recorded during the measurement campaigns, some examples of applications are given below: in particular, the possibility is shown to conduct studies on the heat island and on biometeorological indices.

3.1. An example of an application of the method to the city of Palermo : the heat island

Using the temperature data gathered by all the units over a time span of one month the mean value of temperature t_{mj} of the whole urban area covered by the mobile vehicles equipped with the acquisition units has been calculated for three

points in time. In particular, three points have been chosen: late in the morning (j = 10), around the middle of the day (j = 13) and in the evening (j = 21).

Subsequently, following some crossing lines, the differences $\Delta t_{i,j}$ between the temperatures $t_{i,j}$ measured by the mobile vehicles at point i and at time j, and the corresponding mean temperature t_{mj} have been calculated.

Defining

$$\Delta S_{i,j} = \frac{\Delta t_{i,j}}{t_{m,j}} \cdot 100 \qquad (1)$$

the relative percentage difference between Δt_{ij} and t_{mj}, it has been possible to calculate the mean relative percentage difference ΔSm_{ij} for n days for each point of the considered line:

$$\Delta Sm_{i,j} = \frac{1}{n}\sum_{i=1}^{n} \Delta S_{i,j} \qquad (2)$$

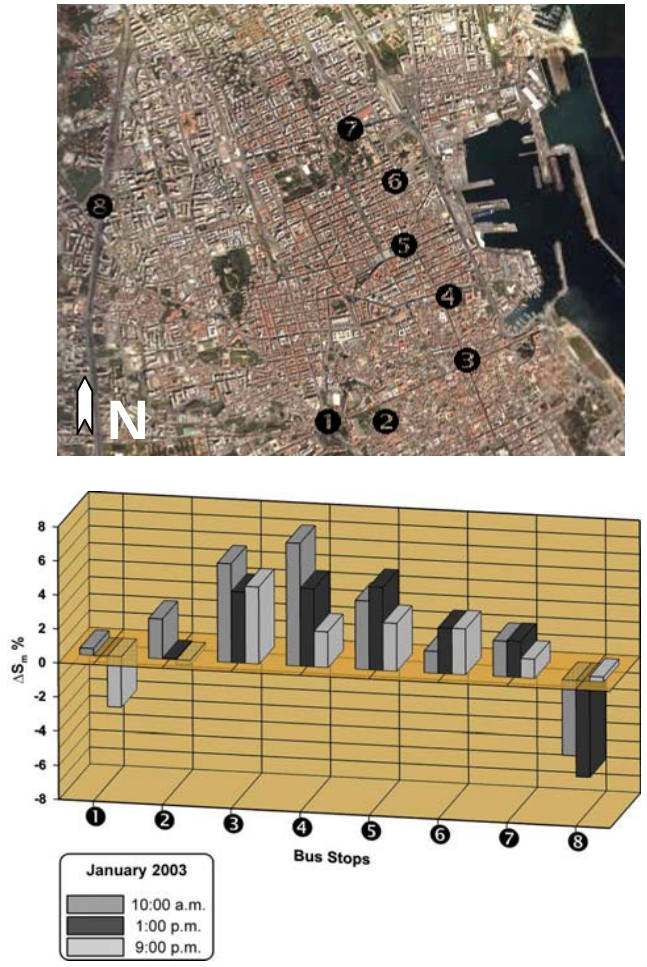

Figure 8: Results of the Heat Island investigation in Palermo

In Figure 9 the mean percentage differences concerning the month of January 2002, recorded at some bus stops, are shown as an example.

As it is possible to see in Figure 9, the measures are referred to bus stops located in the city centre and in two semi-peripheral zones.

From the analysis of the data and from the map, differences in temperature between the city centre and the peripheral zones are evident.

The example highlights how an analysis carried out over a longer period of time and with a larger number of moving stations could lead in a simple and inexpensive way to detailed knowledge of the "heat island" phenomenon for a relatively large city as Palermo, which covers an area of about 158 square kilometres.

3.2. An example of application of the method to the city of Messina: Comfort Indices

Another important result that full capacity territorial coverage with a mobile vehicle surveying system could ensure is knowledge of the distribution of environmental comfort conditions on a probabilistic basis.

This potential is illustrated here by applying a human biometeorological index, widely used in the literature, to the data available for the city of Messina. Taking into account that hourly temperature and relative air humidity data have been acquired, Steadman's THI (Temperature-Humidity Index) [11] [12], an analytic descriptor with two degrees of freedom, was chosen as an example.

It is so defined:

$$THI = t_a - 0{,}55 \cdot \left(1 - 0{,}001 \cdot \varphi\right) \cdot \left(t_a - 14{,}5\right)$$

where t_a is Centigrade temperature and φ relative humidity.

The THI index represents an important opportunity for preventive knowledge, as it supplies an estimate of the feeling caused in the population exposed to the outside thermic and hygrometric environment and permits to analyse the outdoor comfort in a thermophysiologically significant way, according to the evaluation scale shown in Table 1.

The graph in Figure 9, shown as an example, refers to the comfort sensations felt in the vicinity of the ends of line of both tramway lines, one located next to the coast and the other inside the urban area.

THI value (°)	**Classification**
≥ 30.0	EXTREMELY HOT
26.5 ÷ 30.0	VERY HOT
20.0 ÷ 26.5	HOT
15.0 ÷ 20.0	COMFORT
13.0 ÷ 15.0	COLD
-1.8 ÷ 13.0	VERY COLD
-10.0 ÷ -1.8	BITTER COLD
≤ -10.0	EXTREMELY COLD

Table 1: The THI evaluation scale

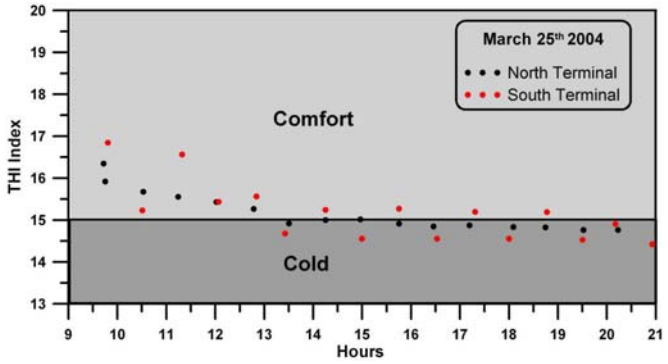

Figure 9: Values of the THI index at both terminals of the tramway line

4 Conclusions

In this work the authors want to prove the feasibility of gathering data of every type by means of mobile vehicles and to highlight its possibilities through some examples.

The moving data acquisition system has proven to be a flexible and useful tool for different types of measurements, and candidates itself as a new method to study spatial and temporal variability of weather, climate, pollution and acoustic parameters in various areas, and urban areas in particular. The system implemented by the Authors allows investigation of location-specific characteristics that cannot be performed with a single or multiple stationary monitoring sites. Repetition of these measurements in different periods as well as on other routes will further increase the reliability of these spatial and temporal studies.

References

[1] Weijers EP, Khlystov AY, Kos GPA, Erisman JW, Variability of particulate matter concentrations along roads and motorways determined by a moving measurement unit, *Atmospheric Environment*, Vol.38, 2004, pp. 2993–3002.

[2] Bitan A, The Jordan Valley Project – A Case Study in Climate and Regional Planning, *Energy and Buildings*, Vol. 4, 1982, pp. 1-9.

[3] Seakins PW, Lansley DL, Hodgson A, Huntley N, Pope F, New Directions: Mobile laboratory reveals new issues in urban air quality, *Atmospheric Environment,* Vol. 36**,** 2002, pp. 1247–1248.

[4] Kittelson D, Johnson J, Watts W, Wei Q, Drayton M, Paulsen D, Bucowiecki N, Diesel aerosol sampling in the atmosphere. SAE Paper No. 2000-01-2212, 2000.

[5] Bukowiecki N, Dommen J, Prevot ASH, Richter R, Weingartmen E, Valtensperger U, A mobile pollutant measurement laboratory-measuring as phase and aerosol ambient concentrations with high spatial and temporal resolution, *Atmospheric Environment*, Vol. 36, 2002, pp. 5569–5579.

[6] Vogt R, Kirchner U, Scheer V, Hinz KP, Trimborn A, Spengler B, Identification of diesel exhaust particles at an Autobahn, urban and rural location using single-particle mass spectrometry, *Journal of Aerosol Science*, Vol. 34, 2003, pp. 319–337.

[7] Pirjola L, Parviainen H, Hussein T, Valli A, Hameri K, Aaalto P, Virtanen A, Keskinen J, Pakkanen TA, Makelä T, Hillamo RE, ‘‘Sniffer’’- a novel tool for chasing vehicles and measuring traffic pollutants, *Atmospheric Environment*, Vol. 38, 2004, pp. 3625–3635.

[8] Ojima T, Changing Tokyo Metropolitan Area and its Heat Island Model, *Energy and Buildings*, Vol. 15/16, 1990, pp. 191-203..

[9] Barbaro S, Giaconia C, Caminiti D, Carollo F, Monitoraggio della qualità ambientale nell’area metropolitana di Palermo. Proceedings of the 57th ATI. National Congress 2002, Pisa, Italia, Vol.I, pp.19-23.

[10] Barbaro S, Giaconia C, Chisesi RM, Caminiti D, Carollo F, Uno studio del comfort termoigrometrico dell’area metropolitana di Palermo. Proceedings of the 58th A.T.I. National Congress 2003, S. Martino di Castrozza, Padova, Italia, pp. 1969-1980.

[11] Steadman RG, The assessment of sultriness: Part I: A temperature-humidity index based on human physiology and clothing science, *Journal of Applied Meteorology*, Vol. 18, 1979, pp. 861-873.

[12] Steadman RG, The assessment of sultriness: Part II: Effect of wind, extra radiation. and barometric pressure on apparent temperature. *Journal of Applied Meteorology*, Vol. 18, 1979, pp. 874-885.