# *MEASUREMENTS OF DYNAMIC AND THERMAL FIELD IN A STREET CANYON. URBCAP NANTES'99*

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**ABSTRACT**
Nantes'99 is a first stage of the european project URBCAP . This project aims to validate the requested models to predict local air quality, and the time and space distributions of harmful pollutants within the different quarters of a city. These models are necessary to assess the urban pollution impact on citizen's health. The experiment Nantes'99 took place in a street canyon of the city center of Nantes. Nantes'99 lasted all the month of June 1999 and the beginning of July 1999. The technical part of this experiment is successful and, as it has just ended, the analysis of the results is not yet completed. Nevertheless, the first observations of the background wind and temperature and the traffic flow are presented here, as well as measurements of time residence of balloons tracers in the street.

**KEYWORDS**
Street canyon, full-scale experiment, pollutant dispersion.

**INTRODUCTION :**
The assessment of urban pollution impact on human health requires, among others factors, to know the spatial distribution of harmful pollutants over the different quarters of a city. Due to the strong heterogeneity of the cities and to the complex chemical transformation in action, the emission inventories, even when being detailed with a fine space and time resolution, are not sufficient. Also, pollutant distribution significantly evolves in time, for exemple the solar radiation which drives the thermal motions and triggers the photochemistry has an impact in this evolution. The extension of the number of air quality network measuring stations is limited for reasons of cost and practicality. Therefore numerical models are needed to analyse the measurements and the meteorological parameters, taking into account the physical and chemical dispersion-transformation processes, in order to produce the requested spatial and temporal distributions.

The pollutant residence time within an atmospheric layer is a major factor allowing to identify the relative importance of the chemical reactions that take place in the urban area. In a single street the residence time of the air mass can be as short as a few seconds in windy conditions ; then only very fast chemical reactions have time to take place, and the mechanisms may be simplified considerably and still describe well the governing processes. On the other hand, during pollution episodes in anticyclonic weather with very low winds, the pollutant residence time within the canopy is at least of the order of several minutes to hours (Mestayer & Sini, 1998). Pollutants can even stagnate in the lowest layers of the urban atmosphere during many hours in the same area : some photochemical peak pollution episodes have been identified to last over several days, with mass convection extending over a few kilometres only (Jaecker-Voirol et al., 1996). This is also the case in some valley systems where air masses are convected back and forth several times over the same area (Guilbaud et al, 1997). In these cases, a larger number of chemical reactions play a significant role, but the chemistry is different from the rural and marine atmosphere due to the presence of high pollution levels in the city and its close surroundings. For exemple, in episodes lasting several days, simulating the nocturnal chemistry can be of importance to determine the content of the background urban air. Moreover, a large number of species is chemically reactive in the lower atmosphere and can form secondary substances, especially during day-time.

Nantes'99 constitutes a preliminary phase of the European project URBCAP. The first aim of URBCAP is to assess the importance of urban canopy processes for understanding the distribution of air pollutants in the urban areas, by combining full-scale experiment and nested numerical simulations. The second aim is to assess the ability of canopy accounting models to determine air quality in the different quarters of an urban area and the source-receptor relationships within this area. The third aim is to validate those models and sub-models that have been developed for predicting local air quality in cities. The project is based on the synergy between local street-scale experiments, a large co-operative experiment at street and city-scale, inserted within the ESCOMPTE regional-scale experimental campaign (in 2001), and demonstrative numerical simulation exercises with a hierarchy of models over nested domains.

## NANTES'99 EXPERIMENT

### Aims of Nantes'99

Nantes'99 has four main objectives :

1. To determine the production of turbulent kinetic energy due to vehicles motion.
2. To measure the influence of temperature distribution of the wall surface on the flow structure in the street and on the pollutant dispersion.
3. To study wind fields in the street.
4. To validate models developed by Ecole Centrale de Nantes, ECN (CHENSI), Centre Scientifique et Technique du Bâtiment, CSTB (PHOENICS), and Centre de Recherche de Méthodologie d'Architecture, CERMA (SOLENE).

CHENSI simulates the air flows generated by the different wind conditions and radiative heating of the surfaces of the street, calculates the production of the turbulent kinetic energy, k, due to vehicles as well as its dissipation rate, $\varepsilon$, and simulates concentration fields of CO in the street. PHOENICS models the convective turbulence (turbulent kinetic energy due to vehicles) and the thermo-radiative turbulence and simulates the concentration fields in the street. SOLENE calculates the thermo-radiative balances of the facets of the street and models the conductive, radiative and convective flows.

The Nantes'99 experiment took place in the street 'Rue de Strasbourg' of Nantes (France) during June 1999 and the beginning of July 1999. This street can be considered as a street canyon. It is straight and about 800 meters long with a great homogeneity in building shapes on both sides. It has a high traffic rate, vehicles moving with a normal urban speed in a single direction of three lanes. Several teams took part in this experiment : ECN (Equipe Dynamique de l'Atmopshere Habitée, Laboratoire de Mécanique des Fluides), CSTB (Service Aérodynamique et Environnement Climatique), CERMA (Ecole d'Architecture de Nantes), Air Pays de la Loire (Ex. Loirestu'Air), the monitoring network of Air Quality in the region of Pays de la Loire, and the Urban Section of the Nantes Council.

### Experimental strategy

The gas chosen to be representative of the pollutant emissions in the street is the carbon monoxide, CO. This gas is a great indicator of pollutant dispersion and dilution in the street since its chemical time reaction is rather long (several weeks) compared to others chemical substances. In order to evaluate the emission of CO, we need to count the vehicles and their speed in the street 'Rue de Strasbourg' and in the streets in the vicinity of the 'Rue de Strasbourg'. To evaluate the residence time of CO in the street a time correlation method is used. This method compares the time variation of the emission rate and the time variation of the flux at the canopy-atmosphere interface, during the whole diurnal cycle (Mestayer & Sini, 1998).

We aim to qualify the validity of the models in relation to the values of turbulent kinetic energy, k and its dissipation rate, $\varepsilon$ (CHENSI) and the three quantities $\overline{uv}, \overline{vw}, \overline{uw}$ (PHOENICS). Therefore, we used fast acquisition sensors in the low level of the street. Sonic anemometers were used to measure turbulent kinetic energy and hot wire anemometers to evaluate the dissipation rate.

With regard to the documentation of the thermal field in the street, several thermocouples had to be placed at different levels within the street, i.e. close to the walls, on the walls and in the middle of the

street, to measure the surface and the air temperature. The temperature data will be used as data input for the two models SOLENE and CHENSI.
To study wind fields and ventilation regimes, 3D propeller anemometers were installed at the high level of the street and completed the system of the sonic anemometers and the hot wire anemometers located at the low level.
To validate models, and in particular SOLENE, data input concerning the radiation are required. Three radiometers were placed on a roof, close to the street, and they measure global, Infra-Red and diffuse radiation. In addition on this roof, a reference mast was erected and equipped with a 3D propeller anemometer, thermocouples and a CO intake in order to get the wind and temperature references.

## Experimental equipment

(Cf. **Fig1**. Sketch of the experimental site).

Two 4 m high masts were fixed on the ground on both sidewalks of the street. Their position was such that the sensors were very close to the traffic. Another mast was situated on a roof, close to the street.
Six CO intakes were connected to the sampling device located upstream the analysis system. Eight CO intakes were installed in the street : 1,50 m and 4 m high on both masts at 15 m on the west side and at 12 m on the east side, two CO intakes in the middle of the street at 12 m high. Depending on the wind direction, six of these sensors were chosen. When the wind was in the axis of the street (which is oriented North-South), the CO intakes were located at 1.50 m on each mast, at 15 m on the west side, at 12 m on the east one and two CO intakes in the middle of the street at 12 m high. When the wind was perpendicular to the street and came from the East, we chose CO intakes at 1.50 m on each side, 4 m and 15 m on the west side and both intakes in the middle of the street. When the wind was perpendicular to the street and came from the West, CO intakes were located at 1.50 m on each side, 4 m and 12 m on the East side and both inyakes in the middle. Also, one CO intake was installed on the roof, near the reference mast. A laboratory-van, which allows to obtain CO, $NO_x$, $O_3$, $SO_2$, $PM_{10}$, humidity, temperature and wind was installed on different locations. It was first located downstream the study section. In this way, we could obtain the pollution close to the main point of the measurements. Then, it was located on the town-hall garden, north of the study section and measured the local background pollution.
Fo the turbulence measurements three sonic anemometers were used and installed on masts in the street : at 1,50 m on each mast and one at 4 m on the east side mast. Three hot wires were also installed at these levels to complete the sonic anemometer measurements. The sonic anemometers have a sampling rate of 4 Hz and hot wires of 1000 Hz. Three other hot wires were fit near the 3D propellers anemometers ans set at 4 m high on the west side mast, 12 m on the east side and 15 m on the west side. The sampling rate of the 3D propeller anemometers was 4 Hz. To measure surface temperature, four thermocouples (T type, Copper-Constantan) were spread along the wall of the west side building and four others on the wall of the east side building at 1,50 m, 6m, 10m and 14 m high. We could measure temperature horizontal profiles in the layer adjacent to the wall with thermocouples situated at 12 m and 4 m on each side of the street. Thermocouples were placed at 2 cm, 5 cm, 10 cm, 20 cm, 40 cm, 80 cm, 150 cm from the wall. Another temperature horizontal profile was measured in the middle of the street at 12 m high from one side to the other side of the street.
A Gill anemometer bivane was fixed on a car, at 2,50 m above the car roof. This anemometer obtained the three wind speed components and their variances. This car was placed within the streets close to the 'Rue de Strasbourg' and documents the cross flow near the study section.
During two days a Sodar was installed 250 m far from the study section. It measured the three wind speed components in the low atmospheric boundary layer from an altitude of 40 m to 500m.
Some balloons were used to visualise the flow in the street. These balloons with a diameter of appoximatively 15 cm were inflated with Helium and their weight was adjusted so that they were in equilibrium in a quiescent atmosphere and they were released in the street. Observers followed their trajectory in order to make its statistical analysis. These were passive tracers with trajectories that represented potential ways of a mass of air coming from the emission source. Propylene was also used as a tracer gas. Injecting this gas in the low level if the street, in a continuous way or by puff release, and detecting it in the high level of the street, we could determine the pollutant time transfer between the two levels. Experiments with tracer gas were performed during six days in three different configurations documenting vertical transfers in the layers adjacent to the building wall.

**Required conditions**

In order to obtain important thermal effects, the required atmospheric conditions were :

- $V < 3\ m.s^{-1}$, V is the reference speed measured on the roof, at an altitude of 30 m
- Sunny weather and great solar radiation
- High traffic.

Nevertheless, it is worth documenting some strong wind, weak solar radiation and low traffic conditions. All wind directions had to be accounted.

*Main Intense Observation Periods (IOP)*
The wind speed had to be less than 3 m.s$^{-1}$ and the weather sunny. A day of measurement began at 8h a.m. and finished at 8h p.m.. During these periods all the sensors were kept operational.

*Secondary Intense Observation Periods* (at least, one day during the month of measurement)

- Measurements said to be 'low traffic reference', on Sunday (the 13$^{th}$ of June) with operating conditions of a main IOP
- Strong wind, with or without sunshine
- Nocturnal measurements (until 9h30 p.m., when the traffic becomes lower)
- Low wind without sunshine.

*Routine measurements*
The rest of the time, 24h/24, the whole device remained operational except the sensors located at 1,50 m, the measurements of the bivane anemometer, tracers (balloons and propylene), the Sodar.

**Assessment of the experiment Nantes'99**

The technical part of Nantes'99 experiment was successful. Required operating conditions for this experiment have been present ; ten days of main IOP was hoped, 12 were obtained. On the whole, the sensors worked satisfactorily, except the hot wire anemometers and the Sodar. Concerning the hot wire anemometers, the value of the ratio *signal/noise* remainsed low for high frequencies that had been required, as a result of the low mean speeds wind, thus, of low turbulence levels. Moreover, hot wires are sensors very sensitive (wires of tungsten, 5µm of diameter), particularly to the dust, which is very frequent in a street of a city-centre with a high traffic rate. Some hot wires had to be replaced several times, in particular those which were at the low level of the street, closest to the vehicles. Data derived from hot wire anemometers will probably remain additional information, the main measurements at the low level of the street are given by sonic anemometers. The sodar has worked only two days because of the high noise pollution that it generates in the city ; moreover, it is itself sensitive to the background noise pollution.

**RESULTS**

The experiment Nantes'99 has just ended, so the analysis of the results is not complete. Here, we present the data measured on the reference mast, on the roof, for the eleven days of IOP (**Fig 2**. Data of reference wind during IOP days). For all the days, the mean wind speed is less than 1.5 m.s$^{-1}$, the minimum value of this speed 0.2 m.s$^{-1}$ and the maximum one is 2.4 m.s$^{-1}$, which corresponds to the wind speed conditions required. The direction varies from north, north-east, east and for one IOP, the direction is west.
Figure 3 presents the number of vehicles in the study-section during eleven days of IOP, from 8h a.m. to 8h p.m.. The total traffic varies from 12922 to 16512 vehicles between 8h a.m. and 8h p.m. On Sunday, the number of vehicles is approximately half the number of vehicles on Wednesday the 23$^{rd}$ of June. The curve presents the number of vehicles during the rush hour of each day, measured during a quarter of an hour. It varies from 235 to 349 vehicles during the week and 185 on Sunday.
We can observe the evolution of wind and temperature reference and traffic data during one of the IOP days, the 1$^{st}$ of July 1999 (Cf. **Fig 4-5-6**). First, the wind speed varies from 0.4 to 1.6 m.s$^{-1}$, thus the wind speed is low. At the beginning of the day, the wind direction is Southeast and turns towards Northeast at the end of the day. The reference temperature is measured on the roof mast, close to the wind measurements. The difference of temperature in the day can reach 13°C between the minimum temperature (in the morning) and the maximum (in the end of the afternoon).
Figure 6 presents the evolution of the traffic during the day of the 1$^{st}$ of July 1999. We can see that the rush periods occur between 8h15 and 8h45 a.m., 11h45 and 12h45 p.m., 1h30 and 2h00 p.m. and, in the evening, it begins at 16h00 and the traffic is less dense from 7h15 p.m.. We remark that this street is frequented by 5.18% of heavyweights only, in the daytime. The curve represents the mean speed of the vehicles per hour. Their speed varies from 30 to 40 km.h$^{-1}$ in the street, during this day.

In order to visualise the flow in the street, balloons were released in the street. The analysis of these releases has not been completed, but the time residence of these balloons in the street can be measured. Residence time of the balloons and mass of air behaviour are likened. The residence times of the balloons were measured. A few balloons went out of the street from the side streets (15%) and the others went out from the roofs (85%). Table 1 summarises the times residence of the balloons and the corresponding percentage of balloons having this residence time and figure 7 presents the cumulated curve of these residence time.

| Time residence of the balloons, t | Percentage of balloons |
|---|---|
| t≤30’’ | 15% |
| 30’’<t≤1’ | 42.5% |
| 1’<t≤1’30’’ | 17.5% |
| 1’30’’<t≤2’ | 10% |
| 2’<t≤2’30’’ | 2.5% |
| 2’30’’<t≤3’ | 7.5% |

**Table 1**. Residence time of the balloons in the street.

**CONCLUSION**

Here, we presented the preliminary observations of the experiment Nantes’99. The values of the parameters (wind speed and wind direction, traffic, temperature) are not the same for each day of IOP, which will have some consequences for the pollutants behaviour. A data base will be built grouping together wind, temperature and CO measurements and the count of the number and speed of vehicles. Some correlation will be established between the various parameters in order to reach the objectives of Nantes’99 : the determination of the kinetic energy production due to the vehicles, the influence of temperature distribution at the wall surface on the flow structure in the street and on the pollutant dispersion, the study of wind field in the street and its influence on the pollutant behaviour, the validation of the models CHENSI, SOLENE and PHOENICS. The first stage consists of validation / invalidation of the obtained measurements, assembling all the measurements and selecting the most interesting IOP periods. A second stage will consist of developing a data input set for models and data sets of validation, in co-operation with numerical simulation teams.

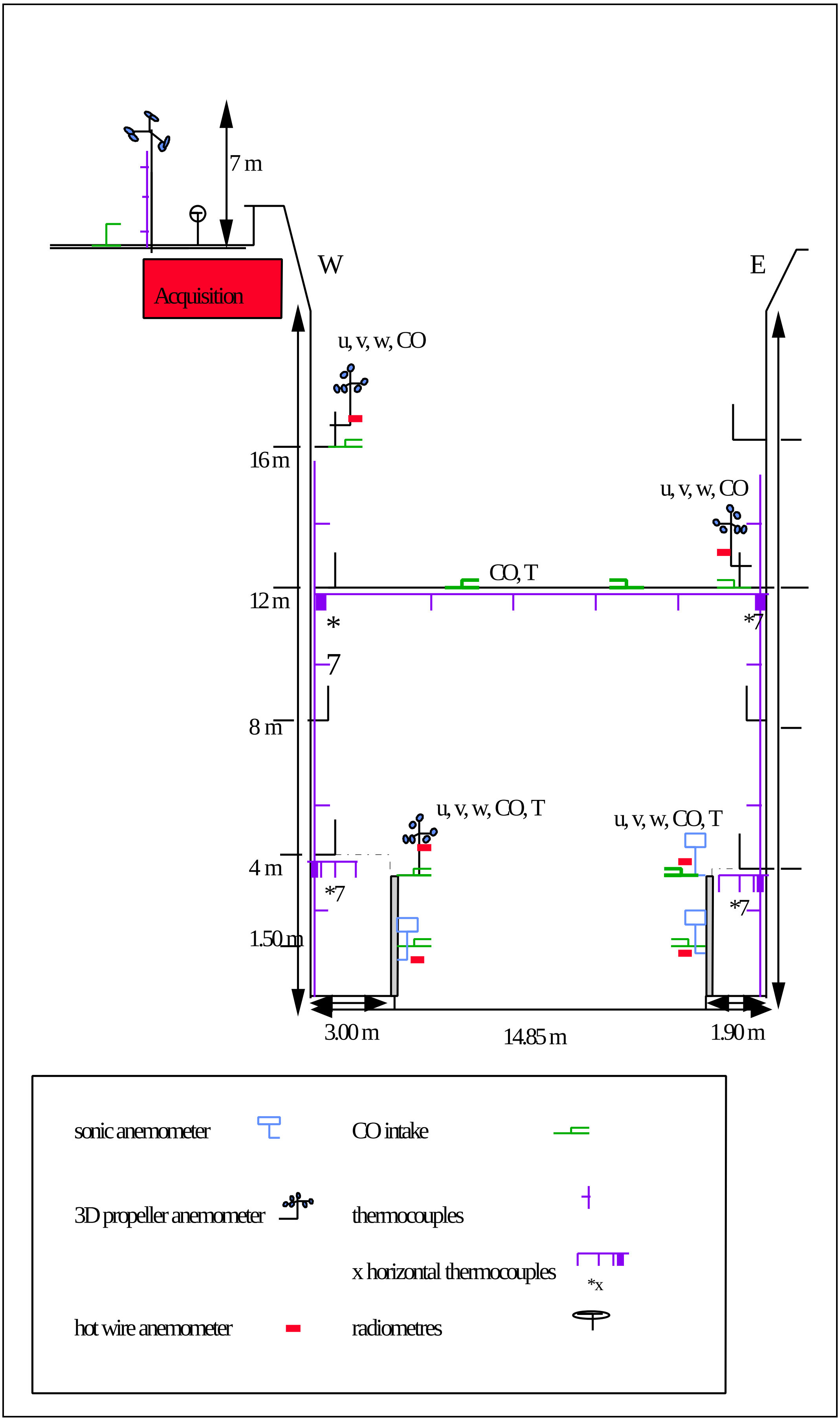


**Fig 1**. Sketch of the experimental site.

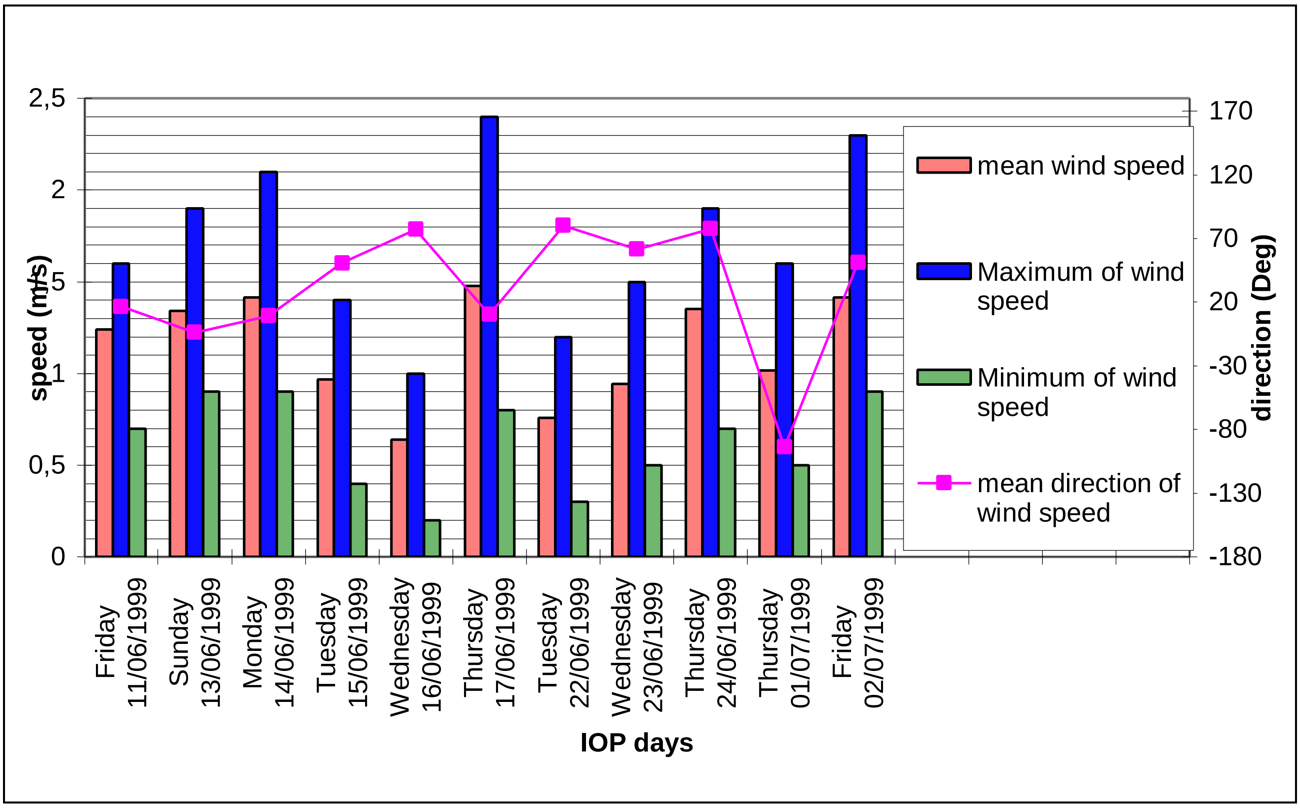


**Fig 2**. Data of reference wind during IOP days

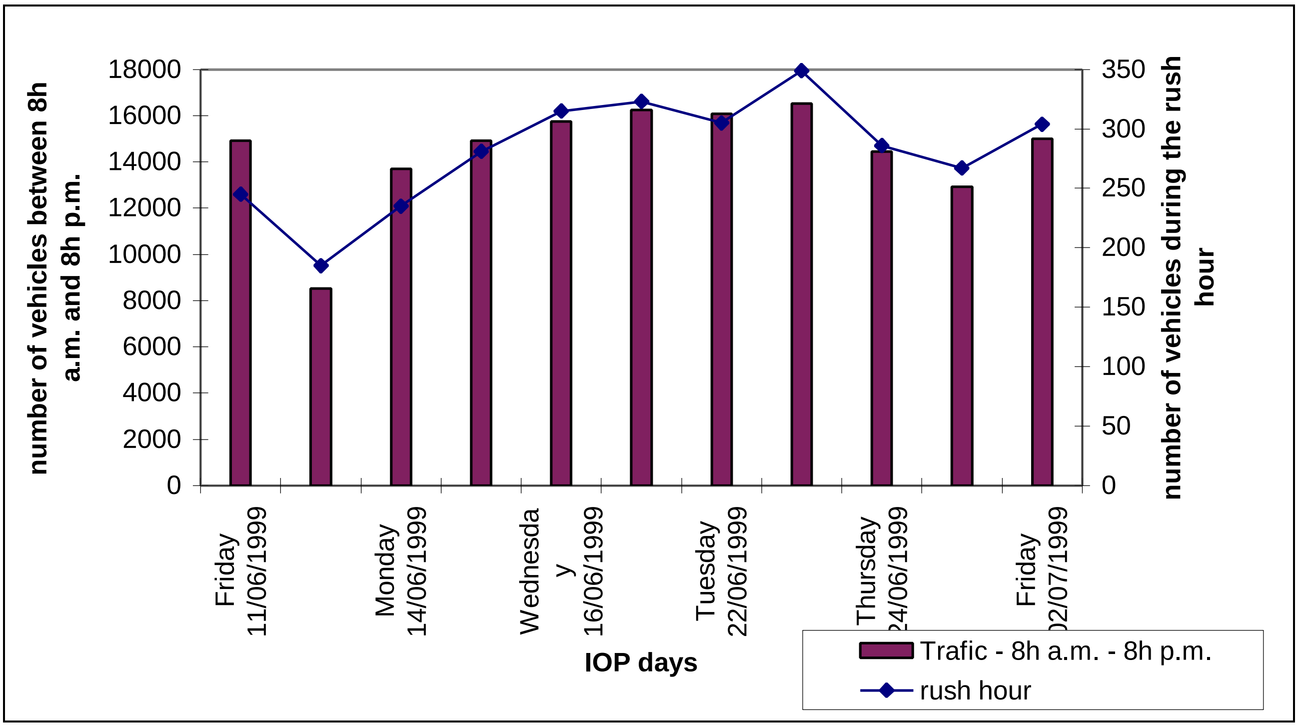


**Fig 3**. Number of vehicles between 8h a.m. and 8h p.m. during IOP days and the rush hour (measured during a quarter of hour) for each day.

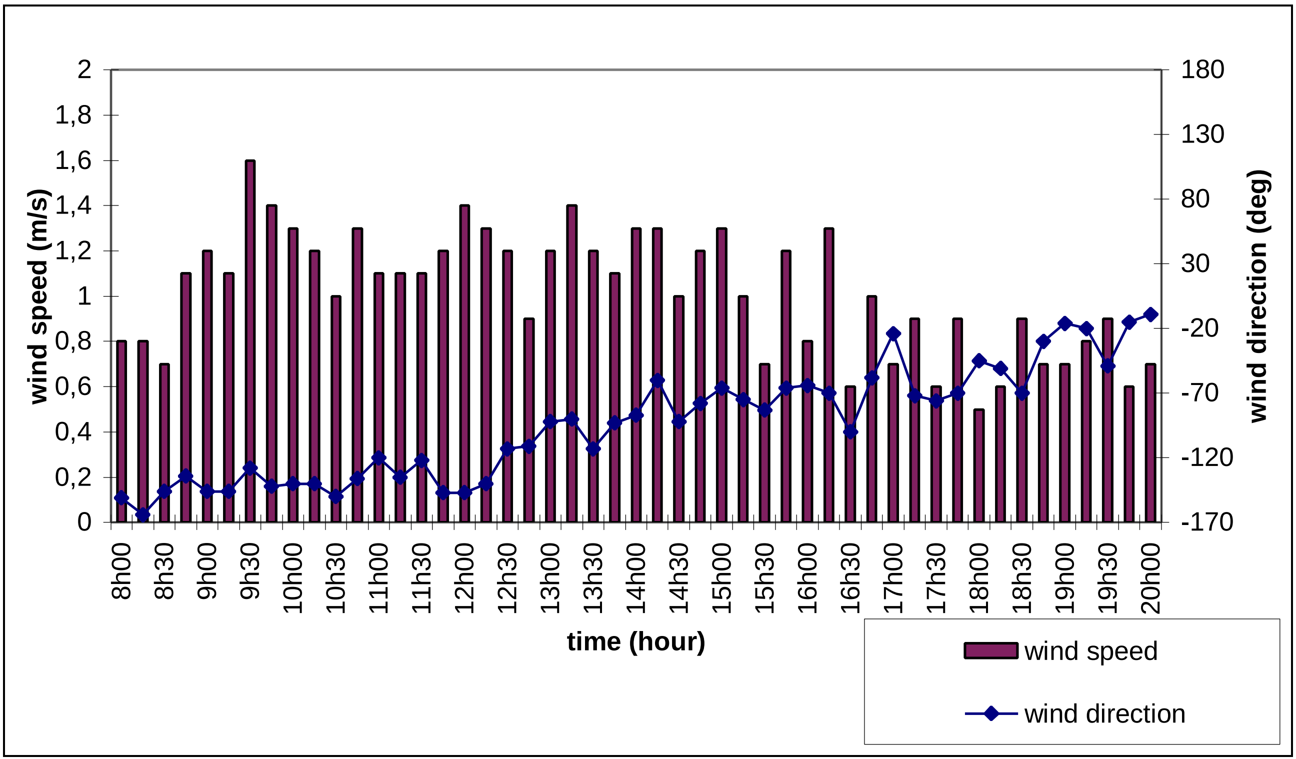


**Fig 4**. Evolution of the data of reference wind measured on the roof.

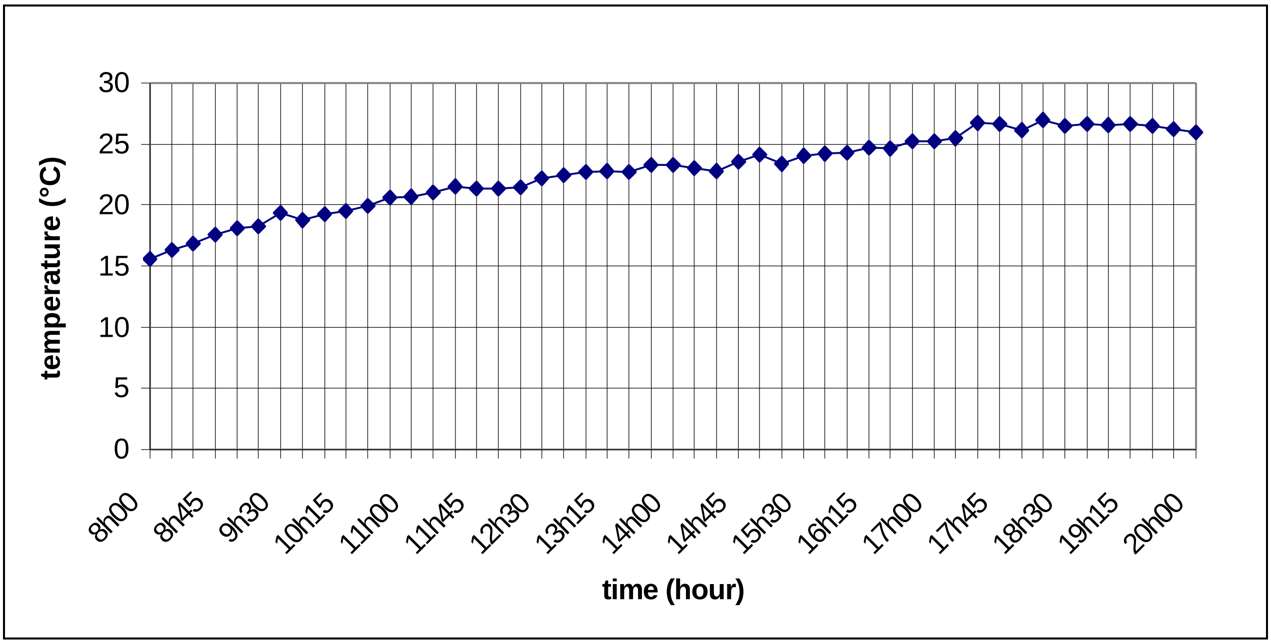


**Fig 5**. Evolution of the reference temperature measured on the roof during a IOP day, the 1st of July 1999.

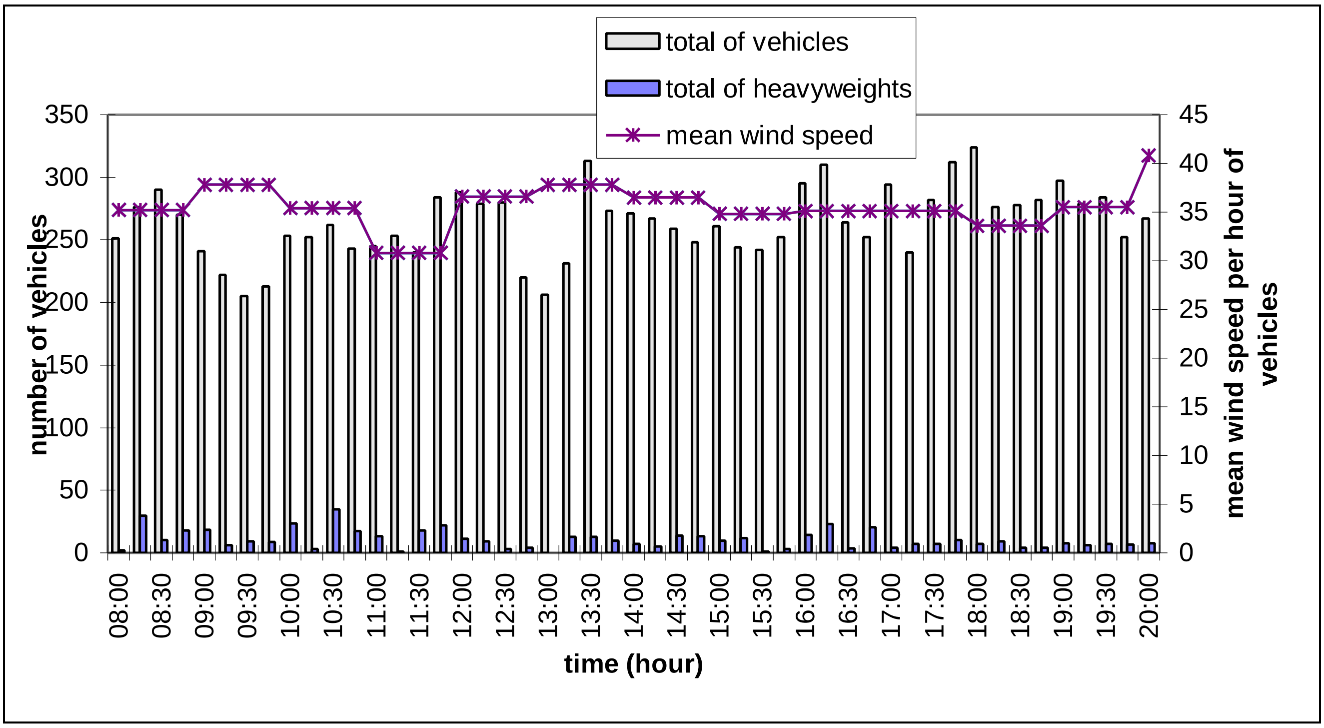


**Fig 6**. Evolution of traffic during a IOP day, the 1st of July 1999

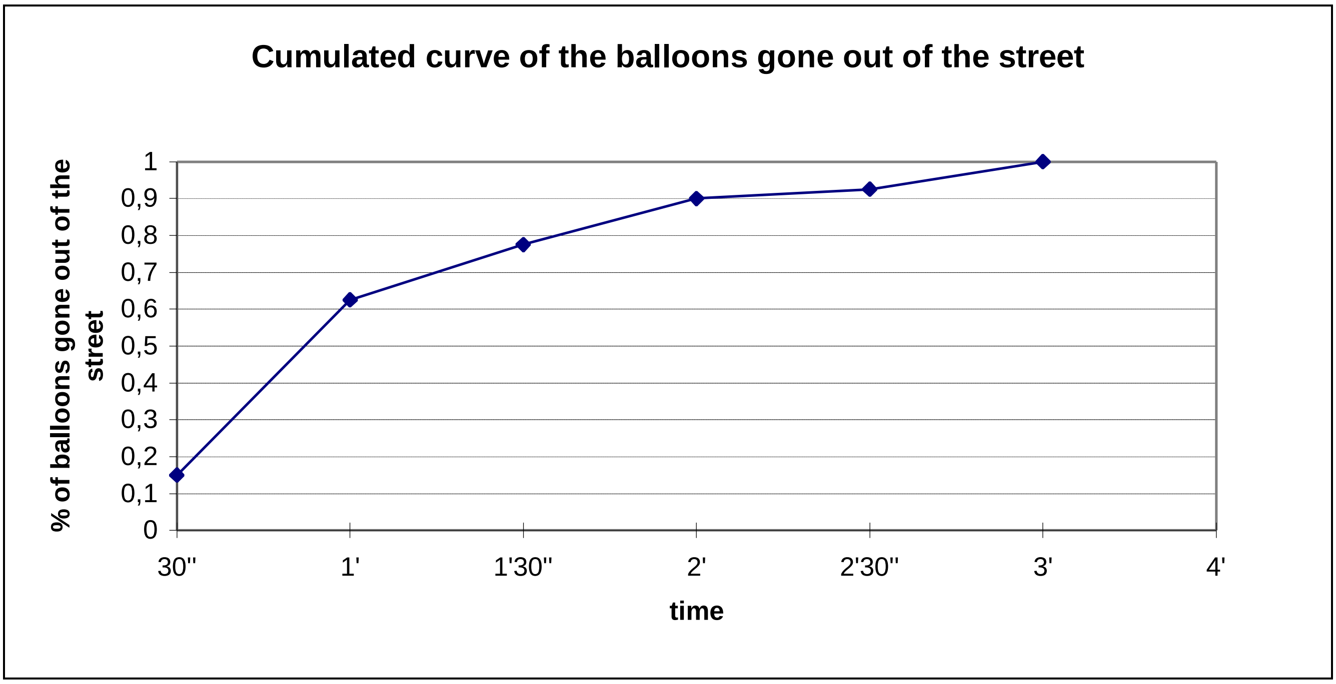


**Fig 7.** Cumulated curve of the residence time of the balloons

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