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MEASUREMENTS OF VERTICAL GRADIENT OF AIRBORNE ULTRAFINE PARTICLES INSIDE AND OUTSIDE AN URBAN CANYON

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Abstract: Ultra fine particles (UFPs) have well known effects on the human health. In urban areas, infiltration of polluted air of UFPs emitted by local sources can contribute to human risk of exposure in indoor environment, where people spend a large part of their time. In the framework of the "Integrated Evaluation of Indoor Particulate Exposure" (VIEPI) project, UFPs outdoor distribution and meteorological conditions have been investigated in a typical urban canyon (height H) located in the city centre of Rome. Both of them play a major role in outdoor-indoor infiltration phenomena. Particle number concentration (PNC) of UFPs and turbulent kinetic energy (TKE), the latter a proxy of the wind characteristic, were measured outside (Z/H=1.1) and inside (Z/H=0.4 and 0.8) the canyon by means of Mini Diffusion Size Classifiers (DM) and sonic anemometers (SA). Outside the canyon, the DM response was also compared with that of a Fast Mobility Particle Sizer Spectrometer (FMPS), while meteorological data were derived from Ciampino Airport. Three sampling days have been selected as representative of a much longer spring sampling period and all data are here presented as daily averaging over these days, on a basis of 30min average values for all variables investigated. Particle number concentrations measured by FMPS and DM at Z/H=1.1 have been compared by applying a linear regression model during selected periods covering the daily time. The results show that the presence of the urban canyon leads TKE increasing with the height, either the night or the day, and that the vertical gradient for UFPs at night inside and outside the canyon was always positive.

Key words: ultra fine particles, TKE, urban canyon, indoor air quality

INTRODUCTION

In urban areas, and especially in proximity of high traffic roads, outdoor ultra-fine fraction of particulate (UFP), up to 100 nm in aerodynamic diameter, can enter the indoor environments contributing to its overall contamination (Zhu, 2005). This phenomenon could increase the human risk of exposure, due to the property of UFPs to have health effects, so indicating the need to study the influence of infiltration on the exposure in indoor locations, such as homes and workplaces, in which people spend most of their time (Wichmann and Peters, 2000, Brouwer, 2010). In presence of an urban canyon, characterised by a street that separates dense blocks, the wind, with behaviour similar to that of a natural canyon, can increase air pollution generated by traffic from street level**.** Moreover, the turbulent kinetic energy, as a proxy of wind speed variance, can influence the local dispersion of UFPs inside the canyon, with potential consequences on its infiltration into buildings indoor at different heights.

In the framework of the project "Integrated Evaluation of Indoor Particulate Exposure" (VIEPI) of the Italian National Institute for Insurance Against Accidents at Work (INAIL), a part of the work has consisted in studying UFPs infiltration in selected research workplaces, by means of high frequency measurements. In this context, some experiments were specifically addressed at investigating the distribution of outdoor UFPs along a canyon, near a high traffic road and the targeted indoor environments. Some preliminary results of this study are here briefly described. (Farrel et al, 2015).

MATERIALS AND METHODS

The canyon is located in the city centre of Rome, near the Physic Department of University Sapienza, where part of the VIEPI project has been carried out. The Department is a five-floor structure, surrounded by similar buildings, close to a high traffic road that runs along the university campus. Three different levels of the building were considered in terms of particle number concentration (PNC) of UFPs and turbulent kinetic energy (TKE): the terrace, i.e. over the canyon, the fourth and second floor, inside the canyon. PNC of UFP vertical gradient has been described by adopting dimensionless unit Z/H, based on the ratio between the height of the specific measurement level (Z in m) and the building height (H = 20 m): Z/H=1.1 refers to measurements over the terrace, Z/H=0.8 and Z/H=0.4 to measurements at fourth and second floor, respectively. TKE was measured inside the canyon, at the fourth and second floor, by means of sonic anemometers (Gill WindMaster, UK). Wind measurements collected at Ciampino airport (LIRA) were used as meteorological conditions representative for the outside of the canyon.

UFPs PNC were simultaneously measured by one Fast Mobility Particle Sizer Spectrometer (FMPS) (FMPS mod. 3091, TSI Inc. Shoreview, MN, USA) coupled with a Mini Diffusion Size Classifier (DM) (DISCMini Testo, Titisee-Neustadt, Germany), noted as DM-UF5, over the terrace and by a DM-UF4, at second floor, inside the canyon. FMPS measures particle size distribution and total PNC in the size range 5.6–560 nm, while DM measures PNC and mean particle diameter in the size range 10-700 nm or 10-300nm (Fierz et al., 2011). The time resolution was 1Hz for each UFPs'instrument: all data have been averaged to 30 min. The investigation was carried out in the spring of 2018 June 19^{th}, 20^{th} and 21^{st}, as representative days of a much longer sampling period. All the variables utilized in this study were averaged over the three-day measurements and calculated as daily trend.

In order to better describe the results associated to stationary and nonstationary conditions, in terms of both micro-meteorological variables and source contributions, we chose considering daily trend as divided into four periods (Table 1).

Table 1. Time periods representing different stationary and nonstationary conditions .

Time period	Notation
00:00 - 09:00	Night-time
09:00 - 11:00	Transition n-d
11:00 - 18:00	Day-time
18:00 - 24:00	Transition d-n

RESULTS AND DISCUSSION

As meteorological conditions over the canyon, we used data collected the 19^{th}, 20^{th} and 21^{st} June 2018 by Ciampino airport. The mean temperature, referred to the time period in table 1, was about 22°C in the night and 29°C in the day. The mean wind speed was 3.23 m/s during the Day-time and about 2.25 m/s in the remaining periods. The mean wind direction presented a prevalence of about 225° (South West) at day instead of the dominant direction of about 77 (Nord East direction) at night, up to the night-day transition, in according with the breeze regime (Leuzzi and Monti, 1997, Pelliccioni et al., 2015).
TKE daily trends measured at the two heights within the canyon are shown in Fig. 1.

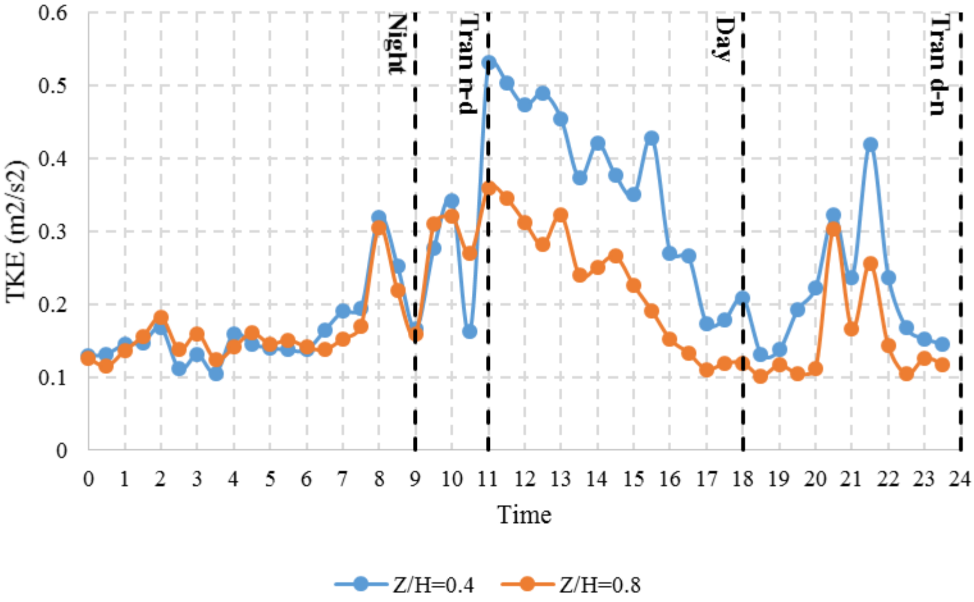

Figure 1. Daily TKE (m^2/s^2) inside the canyon at Z/H=0.4 and Z/H=0.8, where Z is the high of measurement level, in m, and H is the building height (20 m).

The TKE, wind direction and wind speed are reported in Table 2. The ratio between TKEs at Z/H=0.4 and at 0.8 ($R=TKE_{0.4}/TKE_{0.8}$) during the Night-time period resulted 1.01, indicating a nearly constant TKEs vertical profile within the canyon, whilst the ratios became 0.86 and 1.40 during the night-day transition and day-night transition periods, respectively. During Day-time period, R=1.58 corresponds to a decreasing TKE with the height.

Table 2. TKE inside the canyon and meteorological variables derived from Ciampino Airport for the four daily time periods

Notation	TKE (m^2/s^2)		Wind dir (°)	T (°C)	Wind speed (m/s)
	Z/H=0.4	Z/H=0.8	Ciampino Airport		
Night-time	0,16	0,16	82,04	22,12	2,09
Transition n-d	0,26	0,30	73,33	28,11	2,46
Day-time	0,38	0,24	225,48	28,62	3,23
Transition d-n	0,21	0,15	119,03	23,26	2,22

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The daily trends of UFPs PNC simultaneously measured by DM-UF5 and FMPS over the canyon, at Z/H= 1.1, are shown in Fig.2.
The comparison between FMPS and DM-UF5 has been carried out by applying a linear regression model for the periods listed in Table 1, viz.:

$$PNC_{DM-UF5} = \alpha \cdot FMPS + \gamma_0 \qquad (1)$$

By using equation (1) the coefficients of determination (R^2), slopes (α) and intercepts (γ_0) have been therefore derived. Table 3 summarizes the results of the regression model as well the main meteorological variables and UFPs main concentrations for the periods listed in Table 1, furtherly subdivided into smaller time intervals within the diurnal and the transition periods to fit better data from FMPS and DM. In general, all periods can be classified according to TKE, Wind speed and UFPs concentration by FMPS and DMs.

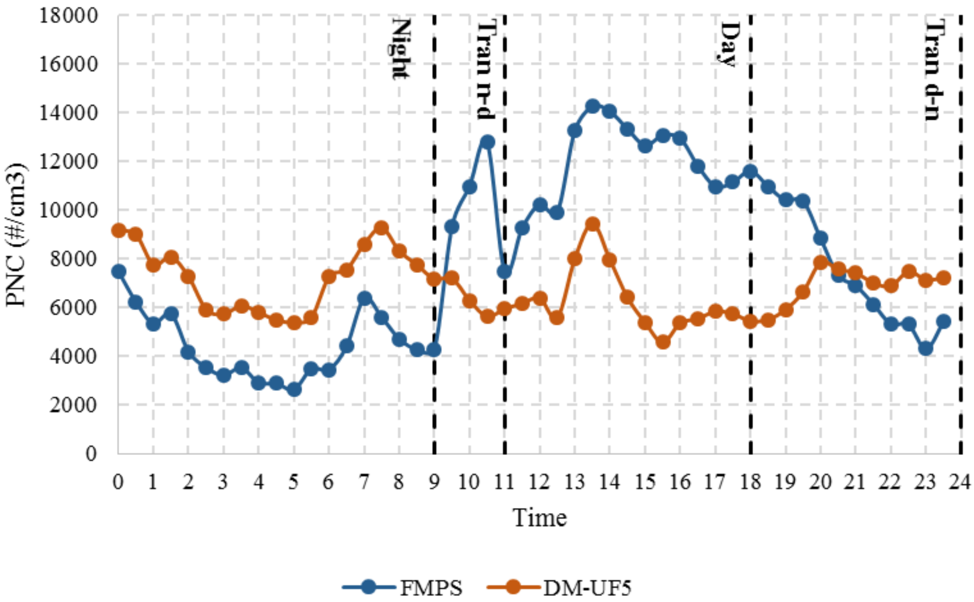

Figure 2. Daily trend of UFPs PNC as measured at level Z/H=1.1 by FMPS and DM-UF5.

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Table 3. Mean values of TKE, WS, PNCs of UFP by FMPS and DMs UF-4 and UF-5 during the considered time periods, and the corresponding results for coefficients by equation (1).

Period	Time	$TKE_{Z/H=0.8}$	WS	FMPS	DM-UF5	DM-UF4	R^2	α	Υ_0
Night-time	00:00-09:00	0.16	2.09	4435	7223	4848	0.83	0.89	3274
Transition n-d	09:30-10:30	0.30	2.46	11026	6376	3202	0.92	-0.4	7153
Day-time	11:00-13:00	0.24	3.67	13476	6755	4111	0.71	0.38	2622
	13:30-15:30	0.32	3.36	10033	6416	3606	0.85	2.72	-29889
Transition d-n	16:00-17:30	0.13	2.53	11723	5619	4053	0.95	-0.2	8358
	18:00-21:00	0.15	2.52	9488	6621	4644	0.76	-0.5	11180
	21:30-23:30	0.15	1.80	5294	7149	4636	0.03	-0.1	7450

Nightime, all variables linked to both meteorological conditions and local sources can be considered almost unperturbed. In contrast, daytime meteorological conditions and local sources become variable. Excepted for the last time interval 21:30 - 23:30, R^2 is always close to unit, indicating that FMPS and DM-UF5 are well correlated. It has also been stressed that relationships between FMPS and DM are strictly connected with the periods, as showed by looking at the different slopes obtained for the considered periods. These differences regarded both the module and sign of α.

The slope was calculated closed to the unit only during the Night-time period. This result supports the choice of using DMs in measuring the difference in PNCs at the two ratios Z/H within the canyon, only considering the Night-time period, in which FMPS and DM-UF5 are high correlated. In fact, we suppose that slopes resulting quite different from unit (in both sign and module) address to a different characteristic of sources in terms of particle size.

During the selected Night-time period, daily PNC measured outside the canyon (DM-UF5) at Z/H=1.1 was 7223 #/cm^3, while that measured inside the canyon (DM-UF4) at Z/H=0.4 was 4848 #/cm^3. The relative daily vertical gradient was positive and resulting about 170 (#/cm^3)/m.

CONCLUSION

Our experiments were addressed at evaluating UFPs distribution within an urban canyon, also accounting for micro-meteorological conditions. For this purpose, we firstly analysed meteorological condition based on the four time periods, covering the daily cycle accounting for Day-time, Night-time, Night-day transition and Day-night transition. During the Night-time period, the TKEs resulted well homogeneous and similar along the canyon whilst they decreased with height during the Day-time.
We than evaluated the effectiveness of using two DMs in measuring PNCs at two different building heights, by simultaneously measuring particles at the highest height by using a FMPS. The comparison between FMPS and DM-UF5 at Z/H=1.1 confirmed that the two instruments are linearly correlated, but it also indicated that they are sensitive in monitoring different particle-size distributions. The best correlation between the two instruments was achieved during the Night-time period, when stationary conditions can be assumed for meteorological condition and sources contributions, which are suitable to be measured properly either by FMPS or DM. During this period, the daily PNC vertical gradient resulted positive and of about 170 (#/cm^3)/m.

The measurements suggested that the presence of an urban canyon could produce an increase of UFPs with height greater than the rate of their reduction with distance from main sources. The positive value of the calculated UFP gradient, between the dimensionless height Z/H=1.1 and Z/H=0.4, can be explained by considering the influence of TKE and wind speed on the dispersion of UFPs inside the canyon. Further studies are needed to better understand the results that could address interesting features in assessing infiltration of UFPs inside the building at different heights.

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