19th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

THE INTEGRATED EVALUATION OF INDOOR PARTICULATE EXPOSURE (VIEPI) PROJECT: MAIN GOALS AND CAMPAIGN DESCRIPTION

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Abstract: Preliminary results concerning the VIEPI (Integrated Evaluation of Indoor Particulate Exposure) project are described. VIEPI project aimed at evaluating indoor air quality and exposure to particulate matter (PM) of humans within workplaces. Infiltration factors of PM in indoor environments of different sizes with different air ventilation regimes as well as their dependence on outdoor and indoor micrometeorology characteristics are some of the goals of the project. For these purposes, several indoor environments located on different sites of the Rome area were considered for the analysis. To evaluate the influence of the micrometeorological parameters on PM concentrations, four seasonal field campaigns were carried out simultaneously indoor and outdoor during short- and long-term study periods.

Key words: *Aerobiological particles; PM; Ultrafine Particles; Infiltration, Exfiltration, Indoor air quality*

INTRODUCTION

Health of workers is one of the tasks of the Italian Workers' Compensation Authority (INAIL), sponsor of the project VIEPI (Integrated Evaluation of Indoor Particulate Exposure) aimed at evaluating indoor air quality and exposure of workers to particulate matter (PM). Indoor air quality depends on indoor pollutant sources, outdoor characteristics (meteorological conditions and pollutant concentrations (Pelliccioni, 2015), indoor airflow and indoor-outdoor air exchange rate. Infiltration factors of PM in rooms of different sizes and ventilation regimes and their dependence on outdoor and indoor characteristics (mean velocity, turbulent kinetic energy and thermal stability conditions) are some of the goals of the project. For these purposes, three rooms in the INAIL Research Centre at Monte Porzio Catone (hereinafter MPC), a small town located on a hill 20 km from Rome, and seven indoor environments in the Physics Department of the

University of Rome “La Sapienza”, a site located in the centre of Rome (hereinafter PDUR), were investigated. The influence of the micrometeorological parameters on PM concentrations has been evaluated by means of four seasonal field campaigns.

PRELIMINARY RESULTS

Aerobiological particles

Aerobiological particles (diameters 10-100 µm) were collected in accordance with the UNI 11108/2004 and following UNI CEN/TS 16868:2015, using four 7-day volumetric sampler (Lanzoni VPPS 2000 - Hirst type) located on the indoor and outdoor environments of MPC and on the roof of PDUR. Measurements of air temperature, relative humidity, wind speed, radiant temperature and globe-thermometer temperature have been carried out in one room inside the MPC and in one room at the 5th floor of PDUR using a Delta Ohm model 32.1 data logger. Preliminary campaigns have been carried out in MPC: aerobiological indoor monitoring from 13/06/16 to 11/08/17, aerobiological indoor and outdoor monitoring from 29/11/16 to 21/07/17 and microclimatic indoor monitoring from 27/06/16 to 11/08/17. Annual campaigns in PDUR have also been carried out (outdoor aerobiological monitoring from 07/11/17 to 07/11/18 and microclimatic indoor monitoring from 03/11/17 to 07/11/18). Conventional methodologies of aerobiological monitoring were applied to evaluate indoor and outdoor pollen concentrations and to detect effects on occupational health in relation to micrometeorological parameters and workers’ number and presence. The aim was also to establish the relationship between pollens and other physical and chemical pollutants. The results of preliminary campaigns seem to indicate an increase of aerobiological particles concentrations during working hours in relation to workera’ presence and behaviour (Fig.1). Workers interact continuously with indoor environment to realize their thermal and physiological comfort (opening window and door or turning off ventilation). Further purposes will be infiltration factor evaluation between indoor and outdoor environments and aerobiological data comparison in different monitoring stations in Rome.

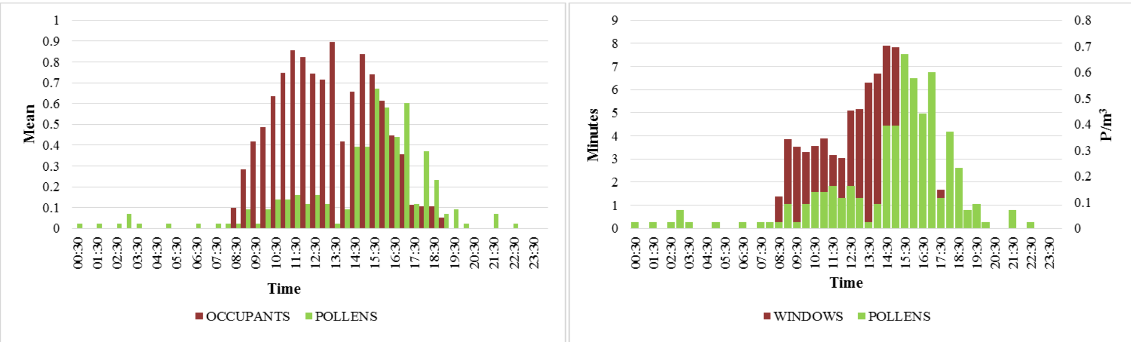

Figure 1. Trend of pollen concentrations in relation to occupant’s presence (left) and to opening windows (right)

PM_{10} measurements

The mass concentration and chemical composition of PM_{10} samples collected indoor and outdoor at PDUR during short- and long-term study periods were evaluated. The short-term (intensive) campaigns were performed in winter 2017 and summer 2018. PM sampling was carried out simultaneously at an outdoor reference site and at five indoor locations, including the Lecture Hall, two classrooms, a computer room and a research laboratory. All the indoor sites overlook the courtyard at the east side of the building where the outdoor sampling was carried out. The Lecture Hall was located at the ground floor, one classroom and the computer room at the 2nd floor, the second classroom and the laboratory at the 4th floor. The intensive campaigns (six weeks in winter and three weeks in summer) were scheduled in order to separately collect daytime, nighttime and weekend PM_{10} samples. The long-term campaign was performed over an entire year (November 2017 - December 2018), at the same sites of the short-term campaign; another classroom at the 2nd floor (exposed to the west-side of the building) and a roof site at the 6th floor were also added. Each sampling had a duration of one month and was performed by using very-low-volume samplers operating at 0.5 L/min. The intensive field campaigns were mainly designed to evaluate the mass concentration and chemical composition of indoor PM and to investigate the role of the presence of students, volume of the classroom, height from the ground and distance from outdoor sources. The monthly samplings were devoted to evaluate the infiltrations dynamics of suspended particles over a long period and their distribution along the horizontal and vertical scale. In both cases, the determination of the macro- and micro-components (elements, ions and organic content) led us to determine the indoor to outdoor concentration ratio (I/O) for each species and to evaluate the impact of the main macro-sources of PM_{10} (soil, sea, organics, secondary inorganics, traffic) on both indoor and outdoor air quality. As an example, Table 1 lists the mass concentration of PM_{10} (determined by gravimetry) compared with the contribution of the five macro-sources during the winter period.

Table 1. PM_{10} and macro-sources concentrations measured during winter intensive field campaign

Winter	μg/m³	PM_{10}	Soil	Sea	Sec. Inorg.	Organics	Traffic
OUT	**Day**	34	9,5	4,1	3,9	17	3,2
	Night	35	6,2	2,3	4,5	16	5,6
	Weekend	23	3,7	2,9	3,2	10	2,6
HALL	**Day**	46	19	1,8	2,4	19	2,6
	Night	25	5,7	1,1	2,1	11	3,9
	Weekend	13	3,0	1,1	1,6	7,0	2,1
A4	**Day**	68	33	2,1	3,9	22	2,6
	Night	37	15	1,3	2,1	13	4,3
	Weekend	19	7,0	1,2	1,6	8,2	2,2
A7	**Day**	80	21	2,3	2,7	29	2,8
	Night	71	7,4	1,3	2,1	26	4,1
	Weekend	61	4,3	1,4	1,6	23	2,0
PC	**Day**	39	16	1,6	2,8	16	2,8
	Night	20	3,7	0,87	1,9	10	4,0
	Weekend	12	1,6	0,71	1,5	7,5	2,3
LAB	**Day**	43	20	1,5	3,1	17	2,7
	Night	19	3,6	0,86	1,7	10	4,5
	Weekend	11	1,8	0,81	1,3	7,0	2,2

During the winter, soil and organic components were the main responsible for the strong increase of PM_{10} observed at all indoor sites during daytime with respect to nighttime and weekends periods. These two contributions were mainly due to the presence of students and are related to mechanical abrasion/re-suspension of soil-related particles and to the primary emission of biogenic particles (human skin debris) and natural fibers, respectively. Both contributions were influenced by the occupancy rate and by the duration of the lessons. Indoor to outdoor concentration ratios (I/O) for secondary inorganic species (in the fine mode of PM) were quite similar in all sites. In the case of ammonium nitrate, I/O was very low because of the higher indoor temperature that lead to the shift in the equilibrium of NH_4NO_3 formation reaction (central heating was switched on during the sampling period) (Lunden et al., 2003). In the case of traffic-related species, almost totally in the fine size range of PM, I/O values close to unity were recorded; it is worthy to note that the highest concentrations were measured during nighttime periods, which included the typical peak traffic time in the urban area. Soil and organics were the most important sources of PM_{10} also during the summer intensive campaign. Even though the lessons were in progress only during the first sampling week, the high ventilation rate (door and windows openings) and the aridity of soil resulted in a high soil contribution from infiltration processes. Conversely, the lower occupancy rate of the classrooms can explain the lower I/O for organics in comparison with the winter period. Infiltration from outdoor governed the behaviour of the other sources, which showed I/O very close to unity with the exception of the computer room and the laboratory, air-conditioned during day hours, which showed lower values.

Ultrafine particles measurements

Another project's task was to understand the contribution of ultrafine particles (UFPs) from outdoor sources to concentrations observed indoor. The UFPs spatial and temporal patterns in the study domain (1 km x 1 km centred on the PDUR), are estimated using a small scale Land-use Regression (LUR) modelling approach at high spatial resolution on the basis of Particle Number Concentration (PNC, as a proxy of the UFPs) monitored data. PNC measurements were made for 7 consecutive days at 21 sites in November 2017 and June 2018. The 21 points of the study domain were chosen to obtain measurements representative of the maximum spatial gradient of detectable concentrations in the area, assuming the road traffic to be the main UFPs source in the urban context. The PNC measurements were made using portable condensation particle counters (3007 TSI) for one week (10 minutes for each site, three times a day) following paths characterizing the area of study: route A (blue) university campus; route B (red) external perimeter of the university campus; route C (green): San Lorenzo district (Fig. 2). Horizontal gradient were calculated for evaluating the observable differences between classrooms located on the same floor but with different orientation of the windows (i.e. S vs N); vertical gradient, for evaluating observable differences between classrooms located at different heights. Three classrooms were selected: a classroom located on the 4th floor, a computer room on the 2nd floor and the Lecture Hall, located on the ground floor. Outdoor measurements were taken simultaneously outdoor at N and S sides of the building and at two different height (10m – 25m) from the ground. Descriptive statistics calculated from the whole set of indoor/outdoor total PNC are listed in Table 2.

Figure 2. Study area and sampling points; routes followed during itinerant measures

Table 2. Mean (standard dev) total particle number concentration (#/cm³) and indoor – outdoor ratios (I/O) for the "horizontal gradient" and "vertical gradient" experiment

Horizontal gradient (2nd floor; North and South side)			
Site	Mean (sd) particles/cm³		
	Overall	*Summer*	*Winter*
A3 in North	12022 (5723)	13308 (6666)	10781 (4283)
Out North	13877 (6882)	12418 (6363)	15328 (7070)
A4 in South	13174 (5478)	13916 (6419)	12472 (4292)
Out South	14505 (7074)	12802 (6192)	16296 (7492)
A3 I/O ratio	0.97 (0.42)	1.18 (0.42)	0.77 (0.31)
A4 I/O ratio	0.97 (0.35)	1.11 (0.29)	0.84 (0.36)

Vertical gradient (ground, 2nd and 4th floor)			
Site	Mean (sd) particles/cm³		
	Overall	*Summer*	*Winter*
HALL in ground	10302 (3059)	9714 (2903)	10882 (3099)
PC in 2th floor	9725 (3725)	7402 (1780)	12049 (3712)
A7 in 4th floor	15848 (6306)	17601 (5365)	14109 (6680)
Out ground	16262 (8954)	10747 (4542)	21833 (8864)
Out 4th floor	13444 (6313)	9907 (4433)	16641 (6049)
HALL I/O ratio	0.77 (0.35)	0.99 (0.34)	0.55 (0.19)
PC I/O ratio	0.67 (0.21)	0.76 (0.23)	0.59 (0.16)
A7 I/O ratio	1.45 (0.78)	2.00 (0.71)	0.90 (0.36)

Outdoor levels temporal patterns were similar in the different measurement sites. Mean indoor levels range between 10781 part/cm³ and 14109 part/cm³ in winter, while in summer they range between 9704 part/cm³ and 1760 part/cm³. Indoor levels were generally less than outdoor during the cold season, while in the warm period they were often comparable or even larger to those found outdoors. The indoor and outdoor UFP time-series were positively skewed, with some very high occurrences. First of all, they reflect the relevant seasonal differences: during the warm period (June) the occupation of the classrooms was rather intermittent, with alternating periods of zero or very limited occupation and periods of greater overcrowding. The prevailing ventilation conditions were those typical of the warm period (natural ventilation with open doors and windows, air conditioners turned on in the Lecture Hall and calculation room). On the contrary, during the cold period, we found that the classrooms were systematically totally occupied, with a series of didactic activities without interruption from 08:00 to 18:00 on most days. However, since there were no particularly rigid temperatures, it was often verified that the upper doors directly open to the outside were open. The average value of the total concentration in number of particles (TPNC, 0.01-10 μm) is largely dominated by particles with an aerodynamic diameter less than 0.3 μm, both indoors and outdoors. Average I/O ratios were always higher during the day than at night for the fractions 0.3-10 μm, and larger than 1 for particles in 5.0–8.0 μm range. A ultrafine I/O ratio larger than 1 was found during several days likely due to cigarette smoke infiltration from the court outside classrooms 3 and 4.

Meteorological measurements

High-resolution measurements, conducted simultaneously indoor and outdoor, are fundamental to improve the knowledge on how these environments interact, in terms of both pollutant load and fluid dynamics. I/O differential pressure measurements can be used to evaluate the role played by outdoor fluid dynamics in infiltration phenomena. Indoor velocity field measurements are also useful to evaluate the complex turbulent flows that characterizes such environments and are hence fundamental for the determination of indoor pollutant concentration and for numerical dispersion models validation as well.

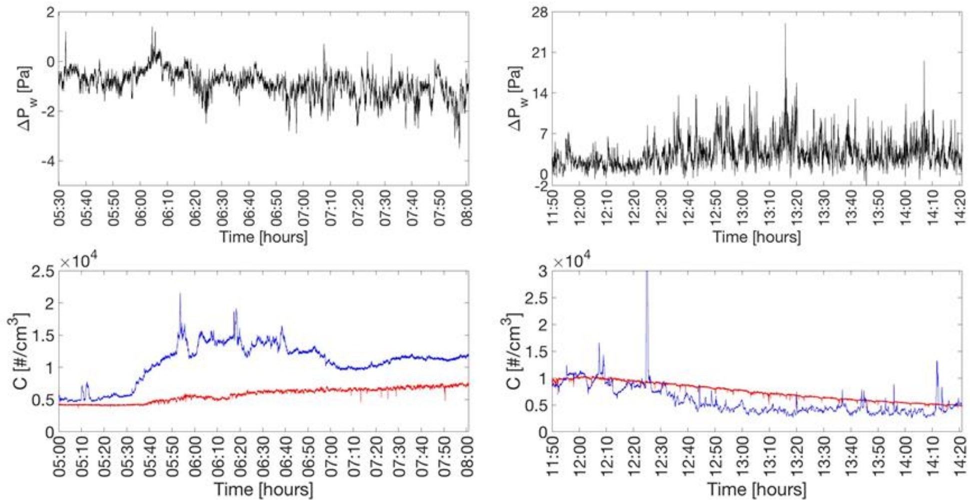

Figure 3. Differential pressure (left-top panel) and concentrations of particle number (left-bottom panel) measured the 21st July 2018 in correspondence of the window. Outdoor concentration is shown in blue, indoor concentration in red. The indoor environment has a pressure lower than the outdoor. The two panels on the right refer to the case in which the indoor pressure is greater than the external one.

In all the campaigns, the measured quantities were: (i) indoor-outdoor differential pressure in correspondence of a window; (ii) differential pressure between the investigated room and the hallway; (iii) wind velocity, barometric pressure, temperature and relative humidity in an indoor environment. In what follows, the temporal trends of indoor-outdoor differential pressure and concentrations in number of indoor, C_{ind}, and outdoor particles, C_{out}, sampled by CPCs are given in Fig. 3. The case of room with both windows and doors closed was first considered. The pressure indoor is lower than outdoor and, consequently, the indoor concentration tends slowly to grow. It can be supposed that this behaviour is related to the infiltration phenomenon, producing an inlet through leakages of polluted air from outdoor.

CONCLUSIONS

The preliminary analysis regarding pollutant concentration and meteorological conditions shows th existence of a relationship between PM infiltration factors, meteorological conditions and particle sizes exists; (ii) Significant increase in indoor PM concentration due to the presence of the students and (iii) Room location (floor and orientation with respect to the wind direction) plays a role in PM infiltration.

REFERENCES

Lunden, M.M., Revzan, K.L., Fischer, M.L., Thatcher, T.L., Littlejohn, D., Hering, S.V., Brown, N.J., 2003: The transformation of outdoor ammonium nitrate aerosols in the indoor environment. Atmos. Environ., **37**, 5633–5644.

Pelliccioni, A., P. Monti and G. Leuzzi, 2015: An alternative wind profile formulation for urban areas in neutral conditions. Environ Fluid Mech., **15**, 135-146.

Perrino, C., Tofful, L., Canepari S., 2015: Chemical characterization of indoor and outdoor fine particulate matter in an occupied apartment in Rome, Italy. Indoor Air, **26,** 558-570.