Assessment of Indoor Mass and Numerical Concentrations of airborne particulate matter in a University Fluid Dynamics Laboratory

Assessment of indoor mass and numerical concentrations of airborne particulate matter in a university fluid dynamics laboratory

Matteo Bo*
Federica Pognant*
Marina Clerico*

* Politecnico di Torino – Dipartimento DIATI, Torino, Italy

Indoor Air Quality (IAQ) is a related to human health and well-being since people spend most of their working and free time in interior spaces. As stated by the World Health Organization (WHO), once complying with normative Occupational Safety and Health (OS&H) limits, more elevated standards of air quality both in productive and non-industrial workplaces should be guaranteed. In this case study – framed in a wider research by the authors – the main results of the assessment of airborne particulate matter (PM10, PM4, PM2.5, PM1) in an indoor university working environment are presented. The activities have been developed in a fluid-dynamics laboratory with a wind tunnel and its premises by means of both traditional samplers and real-time optical technologies. The results confirm the accordance with OS&H requirements. Daily trends and peaks related to laboratory activities and cleaning emissions have been assessed. This outcome highlights once again the strength of integrated approaches between multi-parameter analysers and reference samplers to assess short-time patterns in pollutants concentrations and normative mean conditions.

Keywords: *air quality, air pollution, IAQ, indoor-outdoor, OS&H, particulate matter, workplace.*

Titolo italiano. *La qualità dell'aria negli ambienti indoor è un requisito fondamentale del benessere e della salute umana poiché le persone trascorrono gran parte del loro tempo libero e lavorativo in spazi interni. Come ribadito recentemente dall'Organizzazione mondiale della sanità (OMS), al rispetto dei limiti normativi in materia di salute e sicurezza dei lavoratori (OS&H) dovrebbero essere garantiti standard di qualità dell'aria più elevati in ambienti industriali e non (scuole, uffici, servizi). In questo caso studio – inquadrato in un'attività di ricerca più estesa da parte degli autori – si presentano i principali risultati della valutazione del particolato aerodisperso (PM10, PM4, PM2.5, PM1) in un ambiente di lavoro universitario. Le attività presso una galleria del vento e le sue attrezzature di servizio all'interno di un laboratorio di fluidodinamica sono state analizzate mediante campionatori tradizionali e analizzatori ottici real-time. I risultati confermano la conformità con i requisiti normativi in materia occupazionale. Sono stati inoltre osservati gli andamenti giornalieri in relazione alle attività di laboratorio e i picchi di concentrazione associati alle operazioni di pulizia dei locali. Questo risultato conferma la necessità di un approccio integrato tra campionatori e analizzatori multi-parametrici per la valutazione delle evoluzioni a breve termine nelle concentrazioni di inquinanti piuttosto che uno studio limitato solo alle loro condizioni medie.*

Parole chiave: *IAQ, indoor-outdoor, inquinamento, OS&H, particolato atmosferico, qualità dell'aria, salute e sicurezza sui luoghi di lavoro.*

1. Introduction

Air quality is a basic requisite of human health and well-being. Since people spend almost 90% of their time in indoor spaces (home, office, private and public premises) the need to improve and manage Indoor Air Quality (IAQ) is stated by many international bodies(IARC, 2016; WHO, 2014, 2010). In order to estimate citizens and workers' exposures to air pollutants, detailed studies should be developed considering the time they spend at different locations during their working time and for leisure activities (Colbeck *et al*., 2010; Ott and Siegmann, 2006; Ye *et al*., 2017). Moreover, productive – which are frequently subjected to high concentrations of particles and gaseous contaminants – and non-industrial workplaces (offices, universities) should be both considered for IAQ characterizations (Kellnerová *et al*., 2018; Priyamvada *et al*., 2018; Saraga *et al*., 2011).

The present study concerns the study of airborne particulate concentrations in an indoor university working environment (a fluid-dynamics laboratory). The goal is to evaluate concentrations patterns in relation with specific sources variable over time using real-time particulate matter analysers supporting traditional sampling technologies. Besides, this last – placed at fixed and moving locations – are used to evaluate the respect of Occupational Safety and Health (OS&H) normative limits.

The paper is part of the research activity carried out in recent years by the authors on the assessment of physical and chemical hazard factors in indoor and outdoor work and life environments (Bo *et al*., 2016a, 2016b; Pognant *et al*., 2018). The evaluation complying with the current legislation on safety in the workplace, is based on the good practices for measuring indoor pollutants described in literature (Bo *et al*., 2017).

2. Normative framework

The Italian reference standard for the assessment of physical and chemical risk factors at the workplace is the Consolidated Law on Occupational Health and Safety (*Decreto Legislativo 81/2008 e s.m.i.: Testo unico sulla Salute e Sicurezza sul lavoro*, 2008). Technical standard (UNI, 1994) defines the size fractions of airborne particulate in workplace atmospheres in: total airborne particles (all particles surrounded by air in a given volume of air), inhalable fraction (mass fraction of the total airborne particles that is inhaled through the nose and mouth), respirable fraction (mass fraction of the total airborne particles penetrating the ciliated respiratory tract).

Following existing literature and OS&H best practices, the results of the measurements developed in the study are compared according to the Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (A.C.G.I.H., 1988). It should be noted, in particular, that the Time Weighted Average (TLV-TWA) is referred to a conventional 8-hour workday and a weekly work period of 40 hours, which workers can be exposed, day after day, for their whole working life. The respect of TLV-TWA should guarantee any adverse effects on the health of exposed workers. The TLV-TWA is set to 10 mg/m^3 and 3 mg/m^3 for inhalable and respirable fractions respectively.

The Italian legislative reference for the assessment and management of ambient air quality (outdoor) is based on the EU Directive 2008/50/EC (*Decreto Legislativo 155/2010: Attuazione della direttiva 2008/50/CE relativa alla qualita' dell'aria ambiente e per un'aria piu' pulita in Europa*, 2010). The decree classifies the following particle sizing: PM10 (particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM10, EN 12341: 2014, with a 50 % efficiency cut-off at 10 μm aerodynamic diameter), PM2.5 ([...] at 2.5 μm aerodynamic diameter). The Community limit values, based on long term averages for PM10 consist in 40 μg/m^3 annual mean (25 μg/m^3 for PM2.5) and 50 μg/m^3 daily mean not to be exceeded more than 35 times a calendar year (n.a. for PM2.5).

Due to the lack of a specific regulatory framework for IAQ in life environments, the World Health Organization (WHO) proposed the following guidance values based on ambient air legislation (Settimo and D'Alessandro, 2014): 50 μg/m^3 for PM10 daily mean; 20 μg/m^3 for PM10 annual mean; 25 μg/m^3 for PM2.5 daily mean; 10 μg/m^3 for PM2.5 annual mean. Such values, reprised by some national bodies, represent WHO target to reach environmental quality and should not be intended as threshold normative exposure limits.

3. Materials and Methods

The case study had been developed in December 2018 at a fluid-dynamics research laboratory. The laboratory is targeted to experimental activities using the four existing wind tunnels. During the assessment interval only one wind tunnel was active and operational. In addition to the wind tunnel, the following devices and facilities were functioning along the measurement interval: air compressor (discontinuously active for a duration of few minutes with a frequency of 4-5 times a day since related to the use of the tunnel); lab ventilation system (continuously active in order to heat the wide room); wind tunnel's workstation (PC and desk); displacement gate (communicating with the university yard for occasional loading-unloading operations; during the assessment interval remains closed except for a short opening period of around 10 minutes in the afternoon of 18th December).

The environmental measurement chains were arranged and fed into an area of the laboratory that did not interfere with the escape routes and emergency exits. The instruments, properly synchronized, consist in (Fig. 1):

– a real-time optical particle analyser TUF certificated for

Fig. 1. Measurement chains. On the background the wind tunnel.
dida italiano

the estimation of mass concentration of airborne particulate (PM10, PM2.5), mod. APM2 (Comde-Derenda);
– a research real-time optical particle analyser logging mass concentration of airborne particulate (PM10, PM4, PM2.5, PM1) and particle counting (PN), mod. Frog (Palas);
– a reference dust sampler with PM10 size-selective inlet;
– a reference dust sampler with PM2.5 size-selective inlet.

In parallel with fixed location measurements, a personal sampling was carried out in December 19th on a lab technician during his working hours. The measurement was done by means of a personal portable pump with a respirable selective inlet. Furthermore, continuously monitoring for the qualification of temperature, humidity and atmospheric pressure was done.

All data resulting from the measurement campaign were analysed for research purposes on IAQ in compliance with the regulations. The choice to estimate the concentrations in mass by PM10 and PM2.5 is congruous with the existing studies and literature on the subject. The results are compared with A.C.G.I.H. limits for respirable and inhalable dusts: in particular, for precautionary purposes, PM10 (which includes the respirable fraction) was compared with the TLV-TWA for the respirable fraction equal to 3 mg/m^3. Moreover, in congruity with the existing literature, the results were compared with the WHO quality benchmark values.

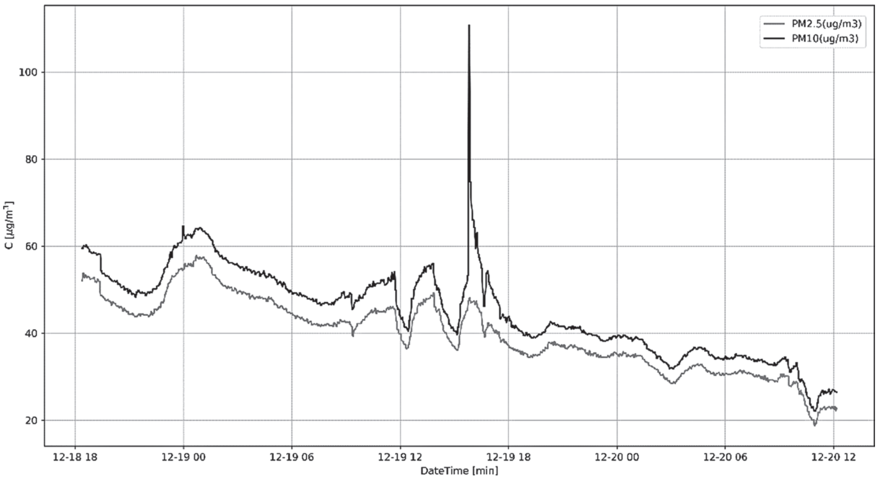

Fig. 2. PM10 and PM2.5 APM2 time series.
dida italiano

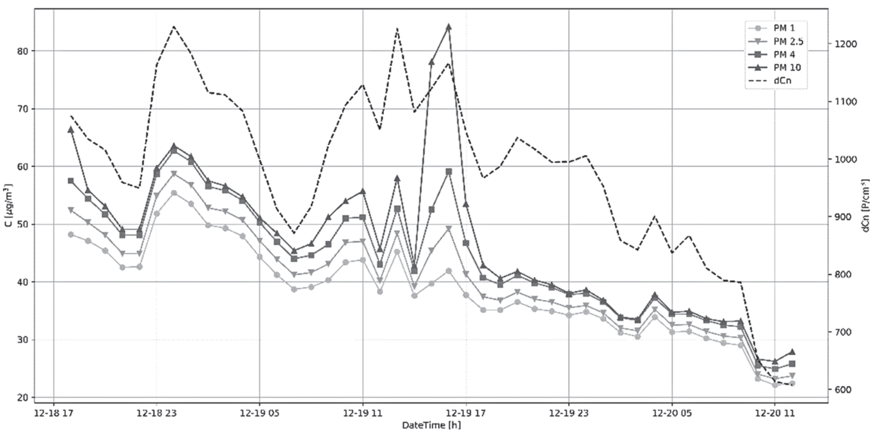

Fig. 3. Particle mass and particle counts hourly mean by Frog dataset.
dida italiano

4. Results and Discussion

According to the documental analysis and the indications supplied by the workers, the activities carried out accords with the intended use of the premises and with what defined as a "typical day" during the preliminary meeting; indeed, no maintenance activity was developed to any of the wind tunnels during the assessment period.

The results are reported as follow. In Fig. 2 the dataset provided by the certified analyser for the PM10 and PM2.5 indicators is displayed. To support such data, the hourly concentration returned by the non-certified analyser are presented (Fig. 3). This last concerned the trend of PM1, PM2.5, PM4 and PM10 and PN for the observation interval. The summary of the results of the fixed samplings is synthetised in Tab. 1. Regarding personal sampling, the measurement developed December 19th over 480 minutes returned a concentration of 0.086 mg/m^3.

From the collected samplings and the recorded concentrations, it is possible to deduce a series of considerations about the trend of particulate concentrations. As expected, generally the highest values are found in the central hours of the day, in correspon-

Tab. 1. Results of fixed samplings.
dida italiano

	[-]	PM10	PM2.5
Sampling time	[min]	1440.7	1440.3
Flux	[l/min]	38.11	38.29
Concentration	[µg/m^3]	40.1	34.5

dence with the major laboratory working activities. However, considering the time scale of the phenomenon, no significant increase of concentrations at the activation of the wind tunnel is found. The increase to some extent of PM10 during working hours is due to the resuspension of coarse particles by the presence of workers in the lab. This is even more evident comparing the 19th (with two workers moving frequently close to the wind tunnel for its set-up) and the 20th (with only one worker staying most of time at the desk) of December. Considering the 20th, which presents minor contribution by human resuspension, despite the activation of the tunnel in two intervals (between 9.06 and 9.33 and between 9.57 and 11.00 as he indicated) there is no significant increase in dustiness compared to the previous night-time.

As already notice during the manned measurements, the peak observed the 19th of December around 4 pm is related to the cleaning activities that took place in the laboratory: although the cleaning of surfaces (floors, shelves,...) was promptly banned in a range of 15-20 m from the samplers, the sudden increase in concentrations occurred in conjunction with brushing and washing the floors in other areas of the laboratory (operation regularly carried out once a week at the premises). This result match with other studies found in the literature (Romagnoli *et al.*, 2016; Wangchuk *et al.*, 2015) and with another research carried out at a printer room of the same university.

Considering the overall trend provided by the analysers, a progressive decrease in the concentrations between the beginning and the end of the measurement campaign is also observed. This decrease is driven by the finer fractions of particulate matter. The contribution of outdoor particulate produced by domestic heating in the district and the traffic of the nearby urban artery of Corso Einaudi (combustion sources) can be traced back to infiltration phenomena. The influencing trend of outdoor pollution founds confirmation in changing of meteorological conditions from the afternoon of December 19th which favoured the dispersion of outdoor pollutants (i.e. precipitations in form of snowfall). The data collected by an urban outdoor public air pollution monitoring station confirm the decrease of outdoor concentrations of particulate matter (PM10 and PM2.5). As reported, personal sampling returned values significantly lower than the TLV-TWA threshold for respirable dusts.

5. Conclusion

The study confirmed the strength of coupling real-time analysers with traditional reference samplers in order to assess short-time trends of pollutants in indoor environments. At the end of the analysis the compliance with occupational requirements at the fluid-dynamic laboratory is verified. However, it should be noted that the long-term averaged values suggested by the WHO for indoor life environments constitute a quality objective to be pursued also at workplaces, in particular non-industrial ones such as a university laboratory. This purpose must be pursued considering the existing background pollution conditions represented by the widespread outdoor urban air quality in which the university is located.

References

A.C.G.I.H., 1988. *TLV – Chemical Substances Introduction* [WWW Document]. URL https://www.acgih. org/tlv-bei-guidelines/tlv-chemical-substances-introduction (accessed 3.12.19).

Bo, M., Clerico, M., Pognant, F., 2016a. *Annoyance and disturbance hazard factors related to work and life environments: a review*. GEAM Geoing. Ambient. E Mineraria 27-34.

Bo, M., Clerico, M., Pognant, F., 2016b. *Parametric Method for the Noise Risk Assessment of Professional Orchestral Musicians*. Noise Health 18, 319-328. https://doi. org/10.4103/1463-1741.195797

Bo, M., Salizzoni, P., Clerico, M., Buccolieri, R., 2017. *Assessment of Indoor-Outdoor Particulate Matter Air Pollution: A Review*. Atmosphere 8, 136. https://doi.org/10.3390/atmos8080136

Colbeck, I., Nasir, Z.A., Ali, Z., 2010. *Characteristics of indoor/outdoor particulate pollution in urban and rural residential environment of Pakistan*. Indoor Air 20, 40-51. https://doi. org/10.1111/j.1600-0668.2009.00624.x

Decreto Legislativo 81/2008 e s.m.i.: Testo unico sulla Salute e Sicurezza sul lavoro, 2008.

Decreto Legislativo 155/2010: Attuazione della direttiva 2008/50/CE relativa alla qualita' dell'aria ambiente e per un'aria piu' pulita in Europa, 2010., 155.

IARC, 2016. *International Agency for Research on Cancer (IARC) monographs on the evaluation of carcinogenic risks to humans*. volume 109. Outdoor air pollution. Lyon, France [WWW Document]. URL http://monographs.iarc.fr/ENG/Monographs/vol109/index.php (accessed 7.12.16).

Kellnerová, E., Kellner, J., Navrátil, J., Paulus, F., 2018. *Monitoring of indoor ultrafine particulate matter at the fire rescue brigade workplaces*. Energy Procedia, 5th International Conference on Energy and Environment Research, ICEER 2018, 23-27 July 2018, Prague, Czech Republic 153, 315-319. https://doi. org/10.1016/j. egypro. 2018.10.071.

Ott, W.R., Siegmann, H.C., 2006. *Using multiple continuous fine particle monitors to characterize tobacco, incense, candle, cooking, wood burning, and vehicular sources in indoor, outdoor, and in-transit settings*. Atmos. Environ. 40, 821-843. https://doi.org/10.1016/j.atmosenv.2005.08.020.

Pognant, F., Bo, M., Nguyen, C.V., Salizzoni, P., Clerico, M., 2018. *Design, Modelling and Assessment of Emission Scenarios Resulting from a Network of Wood Biomass Boilers*. Environ. Model. Assess. 23, 157-164. https://doi. org/10.1007/s10666-017-9563-5.

Priyamvada, H., Priyanka, C., Singh, R.K., Akila, M., Ravikrishna, R., Gunthe, S.S., 2018. *Assessment of PM and bioaerosols at diverse indoor environments in a southern tropical Indian region*. Build. Environ. 137, 215-225. https://doi. org/10.1016/j. buildenv. 2018.04.016.

Romagnoli, P., Balducci, C., Perilli, M., Vichi, F., Imperiali, A., Cecinato, A., 2016. *Indoor air quality at life and work environments in Rome, Italy*. Environ. Sci. Pollut. Res. 23, 3503-3516. https://doi. org/10.1007/s11356-015-5558-4.

Saraga, D., Pateraki, S., Papadopoulos, A., Vasilakos, Ch., Maggos, Th., 2011. *Studying the indoor air quality in three non-residential environments of different use: A museum, a printery industry and an office*. Build. Environ. 46, 2333-2341. https://doi.org/10.1016/j.buildenv.2011.05.013.

Settimo, G., D'Alessandro, D., 2014. *European community guidelines and standards in indoor air quality: what proposals for Italy*. Epidemiol. Prev. 38, 36-41.

UNI, 1994. UNI EN 481: 1994 Workplace Atmospheres – Size Fraction Definitions for Measurement of Airborne Particles.

Wangchuk, T., He, C., Dudzinska, M.R., Morawska, L., 2015. *Seasonal variations of outdoor air pollution and factors driving them in the school environment in rural Bhutan*. Atmos. Environ. 113, 151-158.

WHO, 2014. *WHO | Burden of Disease from household and ambient air pollution* [WWW Document]. WHO. URL http: //www.who. int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014. pdf. (accessed 5.12.17).

WHO, 2010. *WHO | Guidelines for Indoor Air Quality: selected pollutants* [WWW Document]. URL http: //www.euro. who. int/en/health-topics/environment-and-health/air-quality/publications/2010/who-guidelines-for-indoor-air-quality-selected-pollutants (accessed 5.12.17).

Ye, W., Zhang, X., Gao, J., Cao, G., Zhou, X., Su, X., 2017. *Indoor air pollutants, ventilation rate determinants and potential control strategies in Chinese dwellings: A literature review*. Sci. Total Environ. 586, 696-729. https://doi. org/10.1016/j. scitotenv. 2017.02.047.

Acknowledgements

We express our gratitude to all the workers of the lab and the university departments involved in the study.