INRiM Technical Report 26/2020 - Indoor and outdoor measurements of particulate matter concentration in air during wintertime performed in INRiM Campus and in the CNR

Luigi Ribotta

Indoor and outdoor measurements of particulate matter concentration in air during wintertime performed in INRiM Campus and in the CNR Research Area of Turin by using particle counters

T.R. 26/2020 May 2020

INDEX

1. ABSTRACT

ABSTRACT IN ITALIANO

In questo rapporto tecnico viene riportato lo studio della concentrazione di particolato atmosferico eseguito in diversi ambienti (outdoor, indoor e in laboratori sotterranei) mediante l'uso di contatori di particelle. Le misurazioni sono state effettuate per tre settimane in inverno con diverse condizioni climatiche all'interno del Campus INRiM e dell'Area di Ricerca di Torino del CNR.

Al fine di confrontare i risultati ottenuti coi contatori di particelle con i risultati pubblicati da A.R.P.A. Piemonte, è stato implementato un foglio di calcolo per trasformare il numero di particelle in aria misurato in concentrazione di particelle, assumendo una forma sferica delle particelle e una densità $d = 1\ g \cdot cm^{-3}$.

Infine, sono stati confrontati due diversi analizzatori di particelle, ottenendo risultati in accordo entro il 13%.

ABSTRACT IN ENGLISH

This technical report shows the study of the concentration of particulate matter in air performed in different environments (outdoor, indoor and in underground laboratories) by using two particle counters. Measurements were carried out in different climatic conditions during wintertime over three weeks into INRiM Campus and in the CNR Research Area of Turin.

In order to compare the results obtained using portable airborne particle counter with those of A.R.P.A. Piemonte, a spreadsheet for transforming particles number in air into particles concentration was implemented, by assuming a spherical shape of the particles and a density $d = 1\ g \cdot cm^{-3}$.

Finally, two different particle analysers are compared, obtaining a result agreement within 13 %.

2. INTRODUCTION

Particulate Matter (PM) is the set of solid and liquid particles suspended in the atmosphere: it is therefore a heterogeneous pollutant, whose main characteristics are (i) origin, (ii) chemical composition and (iii) dimensions [1].

Atmospheric particulate matter is due both to natural (*e.g.* sea salt, volcanic eruptions, desert sand suspensions) and anthropogenic emissions (fires, industrial emissions, vehicular traffic, friction particles, cigarette smoke, etc.). PM compounds can be classified as primary (the particulate is directly emitted from the natural or anthropogenic source) or secondary (the particulate is formed by the gases present in the atmosphere).

Most of the PM mass in urban and non-urban areas is composed by a combination of the following chemical compounds [2]:

- geological matter, that can be associated to atmospheric dust (oxides of Al, Si, Ca, Ti, Fe, etc.) or to metallic trace elements (Pb, Zn, etc.);
- inorganic ions:
  - sulphates SO_4^{2-}, that derive from the conversion of gaseous sulphur dioxide SO_2 to sulphate-containing particles;
  - nitrates NO_3^-, that derive from reversible gas/particle equilibria between ammonia NH_3, nitric acid HNO_3, and solid ammonium nitrate NH_4NO_3
  - ammonium sulphate $(NH_4)_2SO_4$, ammonium hydrogen sulphate $(NH_4)HPO_4^-$ and ammonium nitrate NH_4NO_3 are the most common;
  - NO_x: nitrogen oxides and their mixtures;
- organic species:
  - Volatile Organic Compounds (VOCs), composed by saturated and unsaturated linear chain acids, aliphatic dicarboxylic acids, aromatic polycarboxylic acids and n-alkanes, which form partially oxidized organic compounds (e.g. acids) that condense;
- carbonaceous fraction:
  - Organic Carbon (OC): consists of thousands of organic compounds of anthropogenic and biogenic origin, including also cancerogenic compounds, such as Polycyclic Aromatic Hydrocarbons (PAH);
  - Elemental Carbon (EC): composed of amorphous carbon or partial graphitic structure, derives from incomplete combustion.

Note that more than the 45 % of the particulate mass is due to the carbonaceous fraction, the 40 % is due to inorganic ions, and the remaining is due to geological matter and organic species.

Particle size and shape can be very different. The size of these particles can be expressed in terms of an equivalent diameter, linked to aerodynamic properties. The aerodynamic diameter D_a is the equivalent diameter defined as the diameter of a sphere ($k = 1$) of unit density (ρ_o = 1 g·cm^{-3}) which has the same deposition speed as the particle in question, that has density ρ_p and geometric diameter D_g.

$$D_a = D_g k \sqrt{\frac{\rho_p}{\rho_o}}$$

The distribution of atmospheric particles is multimodal, and there are generally four modes [3]:

- Coarse particles (> 2.5 μm): biological particles (spores, pollen) or crustal material particles produced through mechanical processes and quickly settle;
- Fine particles (< 2.5 μm):
  - accumulation interval (0.08 μm – 2 μm), that derive from the condensation of low volatility vapours (generated by combustion) and from the coagulation of smaller particles and are made by organic compound and inorganic salts. The particles of this range are a small portion of the total number of particles (5 %), but a significant portion of the mass (50 %);
  - nuclei of Aitken (0.01 μm – 0.08 μm), generated by gas/particle conversion at room temperature and in combustion processes, that function as nuclei for the condensation of low vapor pressure gaseous (*e.g.* PAH, partially oxidized compounds);
  - ultra-fine particles (< 0.01 μm), generated by particle/gas conversion processes not yet well understood at the molecular level.

Particulate matter has an important effect on visibility (PM scatter the light), formation of mists, on chemical atmosphere, and on health. Scientific studies show a causal link between the levels of fine PM and a series of effects on health (carbonaceous fine particles are vehicle within the respiratory tract of toxic compounds, such as some VOCs, PAHs, etc.). For this reason, particulate concentration is regulated by the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe [4], implemented at national level. In Italy, according to the D.Lgs 155/2010 [5], the threshold concentration of PM 10 or PM_{10} (set of all the particles with diameter smaller than 10 μm) is 40 $mg \cdot m^{-3}$. The most dangerous are the fine particles $PM_{2.5}$ (set of all the particles with diameter smaller than 2.5 μm) because (i) they derive from sources such as combustion processes and from the transformation of gaseous emissions such as SO_2, NO_x, and VOCs, and because (ii) they can penetrate into bronchi (dimensions between 3.3 μm and 1.1 μm) and alveoli (dimensions between 1.1 μm and 430 nm), spreading toxic compounds. Epidemiologic studies demonstrate that a 10 $\mu g \cdot m^{-3}$ increment in $PM_{2.5}$ was associated with a 1.04 % increase in the risk of death, with an increase of 3.3 % deaths due to obstructive lung diseases and 2.1 % deaths due to cardiac ischemia [6].

Given the importance of the PM diameter in determining its sources, the deposition in the respiratory system and the removal processes, in addition to the study of average parameters such as PM_{10}, an important characterization is given by the size distribution. If a particulate composed of a trimodal distribution of spherical particles with density 1 $g \cdot cm^{-3}$ is supposed, the classes are made by 1 $particle \cdot cm^{-3}$ of 100 μm, 10 $particles \cdot cm^{-3}$ of 10 μm and 100 $particles \cdot cm^{-3}$ of 1 μm. Fine and ultrafine particles generally represent the greatest quantity of particles in number, so these dominate the number distribution. Gravimetric methods are more sensitive to coarse particles, while measurement systems that count individual particles (e.g. differential mobility analysers) are more sensitive to fine and ultrafine particles.

3. INSTRUMENTATIONS

The study reported in this technical report is made using a portable airborne particle counter Hach Ultra Met One 2400 [7], bought in 2002. The counter uses a laser-diode light source and collection optics for particle detection. The light scattered from the particles is focused by collection optics onto a photodiode that converts the bursts of light into electrical pulses. Pulses are counted and their amplitude is proportional to particle size. Results are displayed as particle cumulative count or differential count in six particle size ranges of 0.3 µm, 0.5 µm, 1 µm, 3 µm, 5 µm, 10 µm. The number of particles given by the instruments refers to the volume flow of one cubic foot of air in one minute (28.32 $L \cdot min^{-1}$), according the ISO 14644-1:1999 written standard [8].

The results obtained with the Hach Ultra Met One 2400/2408 are compared with another particle counter, a Grimm Aerosol Mini-WRAS 1371 [9], bought in 2016. This instrument is a combination of an aerosol spectrometer and a Grimm NanoSizer. The aerosol spectrometer is an optical particle counter, in which particles pass through an optical beam generated by a laser diode source. It measures the size distribution from 250 nm to 32 µm in 31 size channels by means of a fast and robust photodiode, that detect perpendicular scattered light, and a wide field reflector, that improves the detection limit for small particles and reduces sizing effects due to the refractive index. The Grimm NanoSizer is an electrical sensor made by a unipolar electrical diffusion charger, a time multiplexed electrode and a Faraday cup electrometer. In this NanoSizer, (i) the particles are extracted from the aerosol flow with a unipolar electrical diffusion charger, (ii) the charged aerosol impact the multiplexed electrode as a function of the electric voltage, the charge of the particle and the particle diameter, and finally (iii) particles with the right electrical mobility (from 10 nm to 250 nm) are counted by the Faraday cup electrometer.

The particle counter Grimm Aerosol Mini-WRAS 1371 permits the analysis of particles from 10 nm to 32 µm in 41 size channels, measuring an air volume flow of 1.2 $L \cdot min^{-1}$. Under the estimation of particles of spherical shape, the mass distribution is calculated, and it is subsequently converted into the PM fractions.

4. MEASUREMENTS

4.1 Indoor and outdoor environments

Airborne particle measurements are performed in wintertime during a period of three weeks, from Monday to Friday in the period 14 January 2019 – 01 February 2019. Measurements are carried out in different environments, both outdoor and indoor. Indoor measurements are performed in office 17 (mezzanine floor) in INRiM building 7, and in four underground laboratories (laboratories 15, 16, 20, 21 in Figure 1) in the “impianto Galleria Metrologica delle Lunghezze” (INRiM building 8) with the portable airborne particle counter Hach Ultra Met One 2400. Moreover, in order to compare the two particle counters, outdoor and indoor measurements are performed at CNR – IMAMOTER.

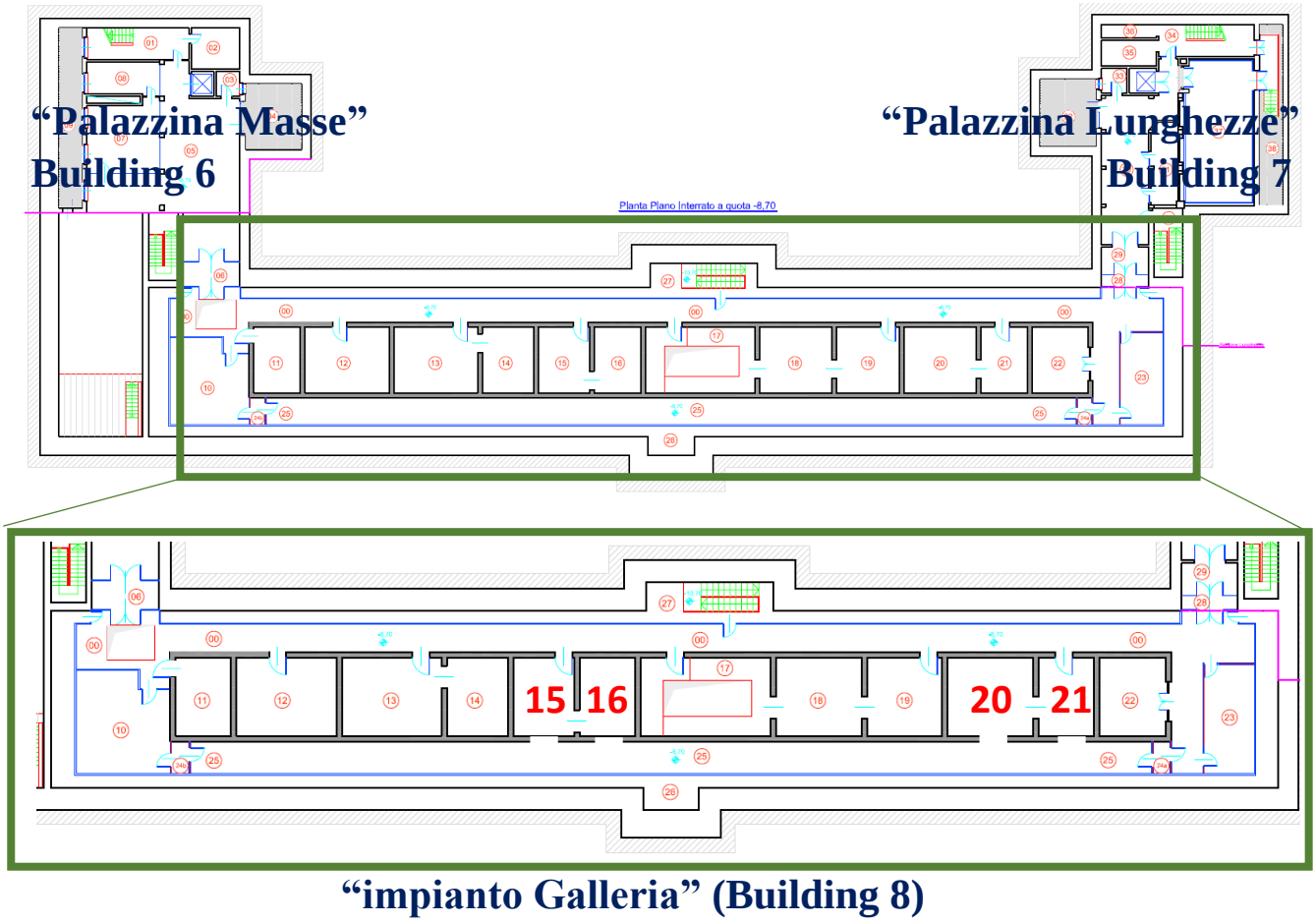


Figure 1 Map of “impianto Galleria”

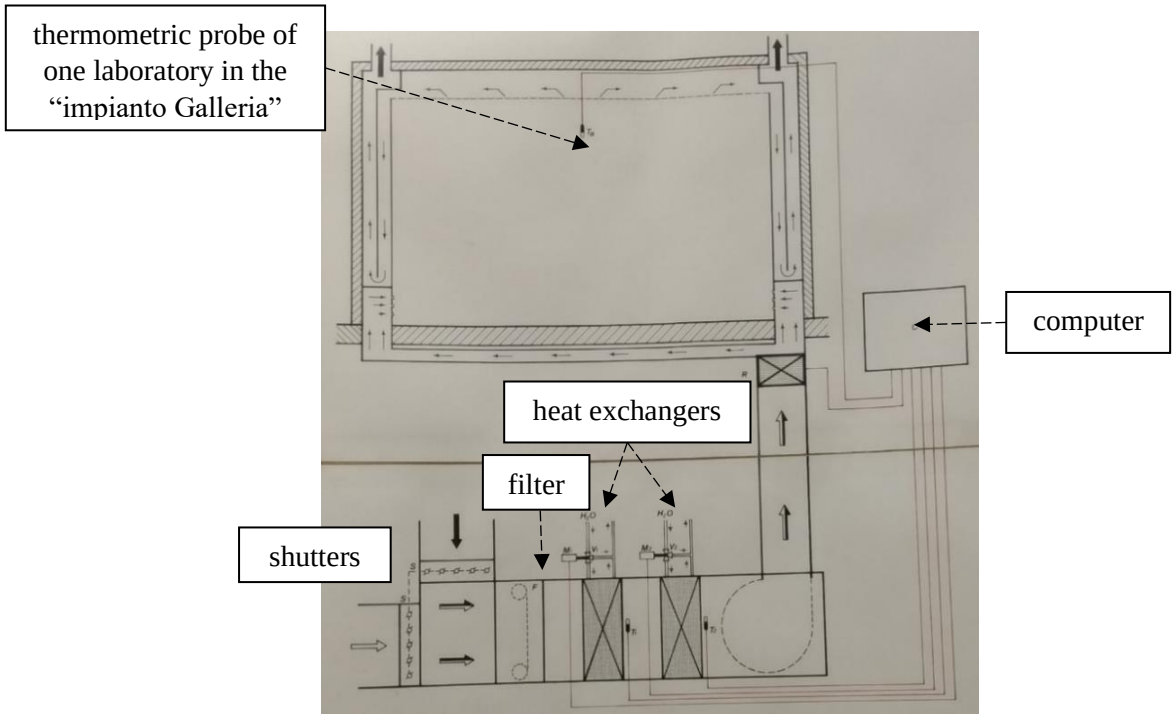


Figure 2 Thermal-hygrometric scheme of “impianto Galleria”. The solid arrows show the direction of the air flow.

The “impianto Galleria” is a completely underground building that houses INRiM laboratories of Length and Mass Metrology. This building conditioning plant was designed by professors V. Ferro, A. Sacchi and G. Saggese of “Politecnico di Torino” in 1970 [10], and the peculiarity is that the underground building is less affected by environmental vibrations due to city traffic and local noisy plants if any, and that the temperature can be easily controlled to be T = (20.0 ± 0.1) °C, while the humidity is RH ~ (50 ± 15) %. As shown in Figure 2, the temperature and humidity of each laboratory is controlled by a thermal-hygrometric plant, in which the external air pass through a filter, then through two heat exchanger and finally arrives into the laboratory. It is worth noting that the filter is 1 µm, so particles belonging to the PM_1, PM_3, PM_5 and PM_{10} are abated; besides, the laboratories air is changed every two hours.

4.2 Measurements performed with portable airborne particle counter Hach Ultra Met One 2400

As explained in paragraph 3 and in Figure 3, the results obtained by the Hach Ultra Met One 2400 are displayed as cumulative and differential particle number in one cubic foot of six particle size classes (0.3 µm, 0.5 µm, 1 µm, 3 µm, 5 µm, 10 µm) present in air.

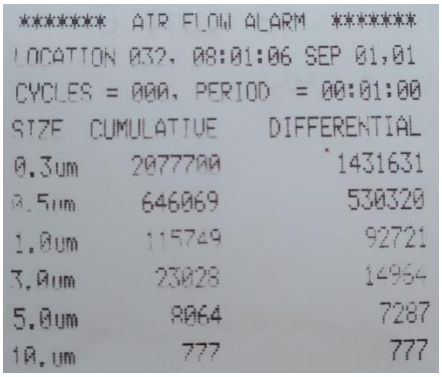


Figure 3 Measurement output using a Hach Ultra Met One 2400 portable airborne particle counter

In order to compare our results from the Hach Ultra Met One 2400 portable airborne particle with the results from A.R.P.A. Piemonte, described in paragraph 5, a spreadsheet for transforming particles number in air into particles concentration is implemented. The calculations performed consist in the following steps:

1- Calculation of the particles volume $V\ [cm^3]$, by using the size $s\ [\mu m]$ of each class of particles, that are assumed as spherical:

$$V\ [cm^3] = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{\frac{s}{2}[\mu m]}{10^{-4}\frac{\mu m}{cm}}\right)^3$$

2- Calculation of the weight $w\ [g]$ of each class, by assuming a density $d = 1\ g \cdot cm^{-3}$ for the particulate matter, and so assuming a hydrodynamic diameter of the PM (see definition in paragraph 2):

$$w\ [g] = V\ [cm^3] \times d\ [g \cdot cm^{-3}]$$

3- Transformation of the particles count experimentally measured, reported from the instrument as differential particle number per cubic feet $N\ [ft^{-3}]$, into differential number of particles analysed per square meter $N\ [m^{-3}]$:

$$N\ [m^{-3}] = \frac{N\ [ft^{-3}]}{0.02832\ \left[\frac{m^3}{ft^{-3}}\right]}$$

4- Calculation of the particle concentration for each class C_{class}, according to the measurement unit reported by the national and international laws for the atmospheric pollutant monitoring:

$$C_{class}\ [\mu g \cdot m^{-3}] = w\ [g] \times 10^6\ \frac{\mu g}{g} \times N\ [m^{-3}]$$

5- Sum of the concentration for each of the six classes C_{class} in order to obtain the PM_{10} concentration $C_{PM_{10}}\ [\mu g \cdot m^{-3}]$:

$$C_{PM_{10}}\ [\mu g \cdot m^{-3}] = \sum_{class\ =0.3\ \mu m}^{10\ \mu m} C_{class}\ [\mu g \cdot m^{-3}]$$

As mentioned above, indoor measurements are performed in office 17 in INRiM building 7 and in the laboratories 15, 16, 20 and 21 for dimensional measurements in building 8.

Figure 4 reports the variation of particles concentration according to the diameter, showing an increment while increasing the dimension; besides, the same trend can be noticed for the different days sampled.

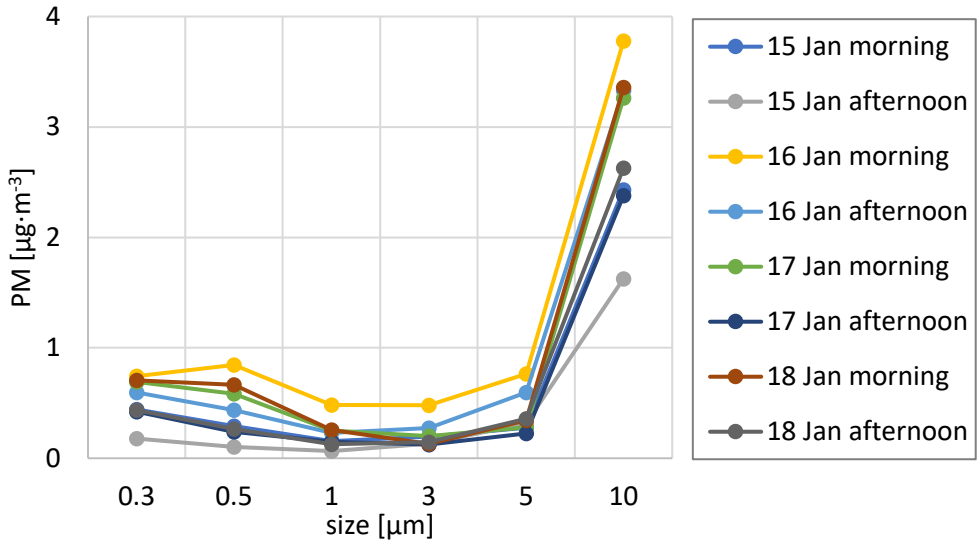


Figure 4 Difference in particle distribution in different measurements in laboratory 21 of INRiM building 8

The particle concentration measured in different days and laboratories is shown in Figure 5. A different behaviour is reported for particles of different size: small particles (Figure 5 (a)) show a constant trend in all environments, while large particles (Figure 5 (b)) show a significant decrement passing from the office to the laboratories due to the presence of the filters for air conditioned laboratories situated into the "impianto Galleria".

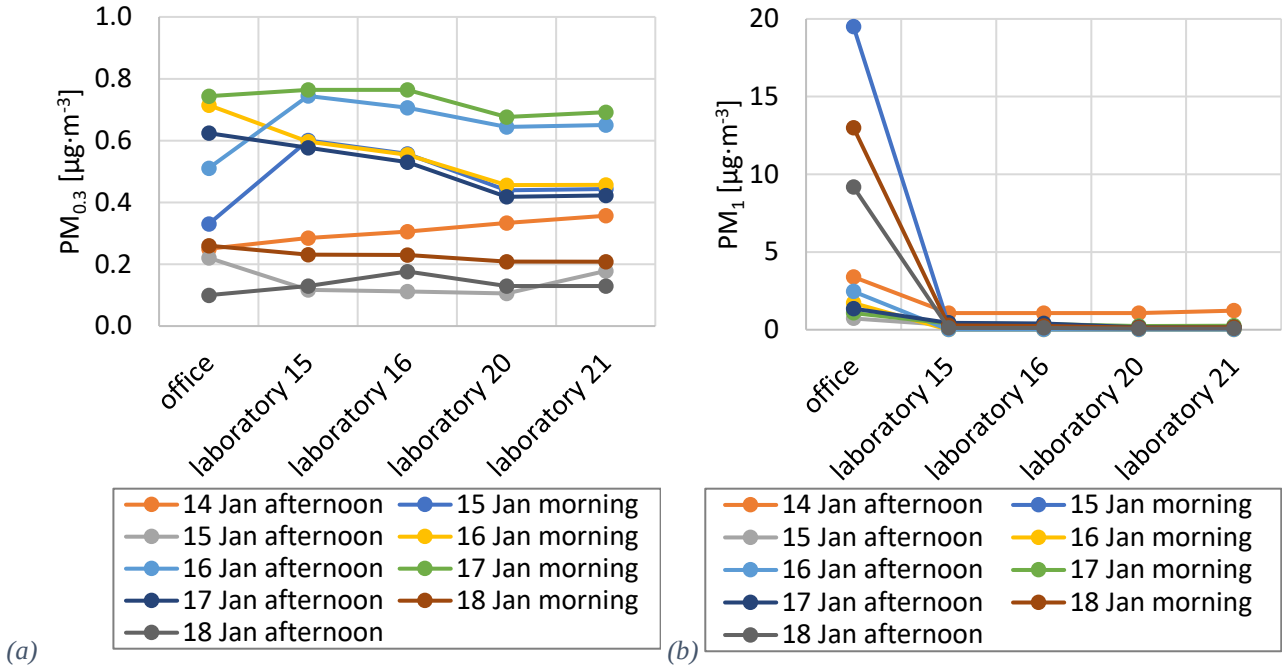
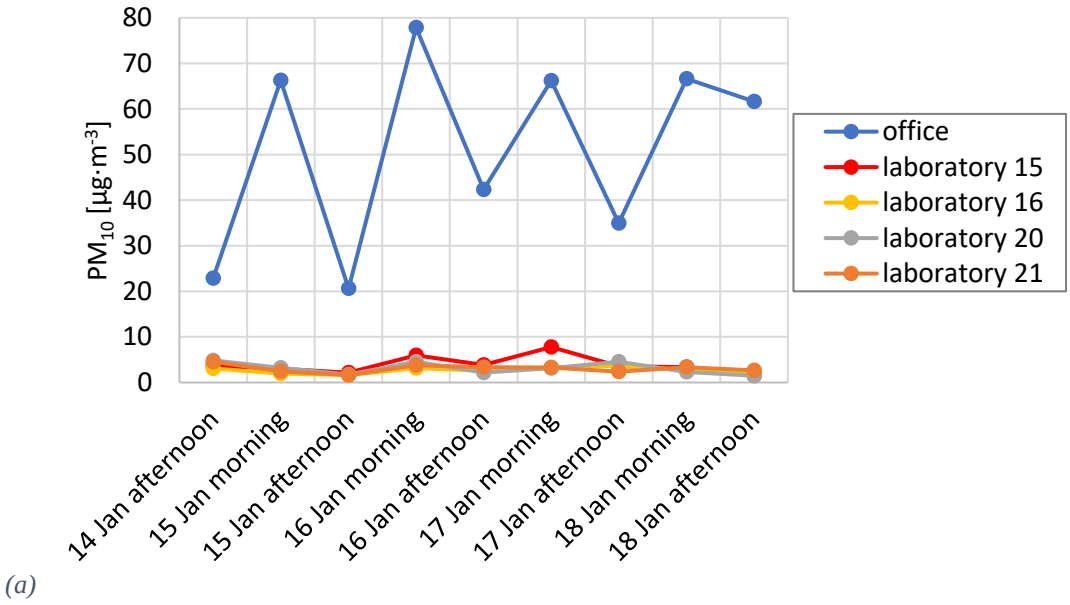


Figure 5 Concentration along different day in different environment of particles with diameter of (a) 0.3 µm and (b) 1 µm

Figure 6 (a) shows the PM_{10} concentration along the day during the week; the same trend can be noticed both in office (Figure 6 (b)) and in the underground laboratories (Figure 6 (c)). Please note that particles concentration in office is higher in the morning.

It is worth noting that Figure 4, Figure 5, and Figure 6 are related to the first week of measurements, but the trends reported are well representative of all the three weeks measured (average results day by day in Table 4 and atmospheric conditions in Table 5). Moreover, several repetitions in the same room within 5 minutes are made, showing a measurement repeatability of 4 %.



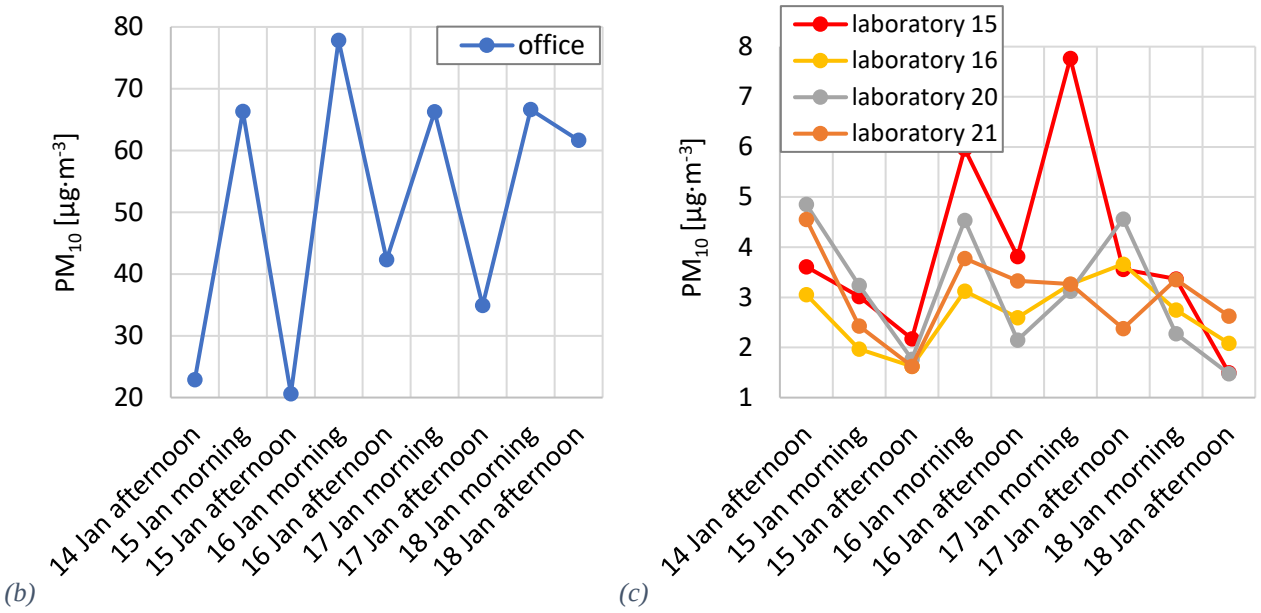


Figure 6 (a) PM10 variation of the concentration during morning and afternoon. The same trend is better shown by the zoom of figures (b) and (c) for the different rooms.

An uncertainty estimation regarding the particles concentration by measurements performed with the portable airborne particle counter Hach Ultra Met One 2400 is reported in Table 1, for a coverage probability of 95 % (k = 2). Please note that the major contributions are due to the repeatability of measurements and to the assumption made on the particulate matter, in particular to the variation of density and the variation from the spherical shape. Minor contribution is due to the instrument digits and to the presence of one person in laboratory.

Table 1 Uncertainty budget of the particle concentration by measurements performed with Hach Ultra Met One 2400 particle counter.

quantity X_i	**probability distribution function**	**type**	**uncertainty contribution** $u_i(\#)$	**degrees of freedom** υ_i	**sensitivity coefficient** $c_i = \partial d/\partial x_i$	**uncertainty** $u\ (x_i)$
measurements repeatability	N	A	1.8 %	5	1	1.8 %
presence of one person in the laboratory	R	A	0.2 %	50	0.58	0.1 %
particle density	N	B	5.0 %	10	1	5.0 %
particle shape	R	B	5.0 %	10	0.58	2.9 %

combined standard uncertainty $u_c(\#)$ = 6.0 %

effective degree of freedom $\upsilon_{eff}(\#)$ = 19

expanded uncertainty (k = 2) = 12.1 %

4.3 Comparison between the measurements with Hach Ultra Met One 2400 and Grimm Aerosol Mini-WRAS 1371

In order to compare the two particles analysers, measurements analysis inside the laboratory and outside the building of the CNR – IMAMOTER are performed. The Grimm Aerosol Mini-WRAS 1371 give as measurements output two files, one with PM_{10}, $PM_{2.5}$ and PM_1 values in $\mu g \cdot m^{-3}$, and the other with the number of particles per cm^3 for each of the 41 categories that range from 10 to 35150 nm of diameter, as reported by Figure 7.

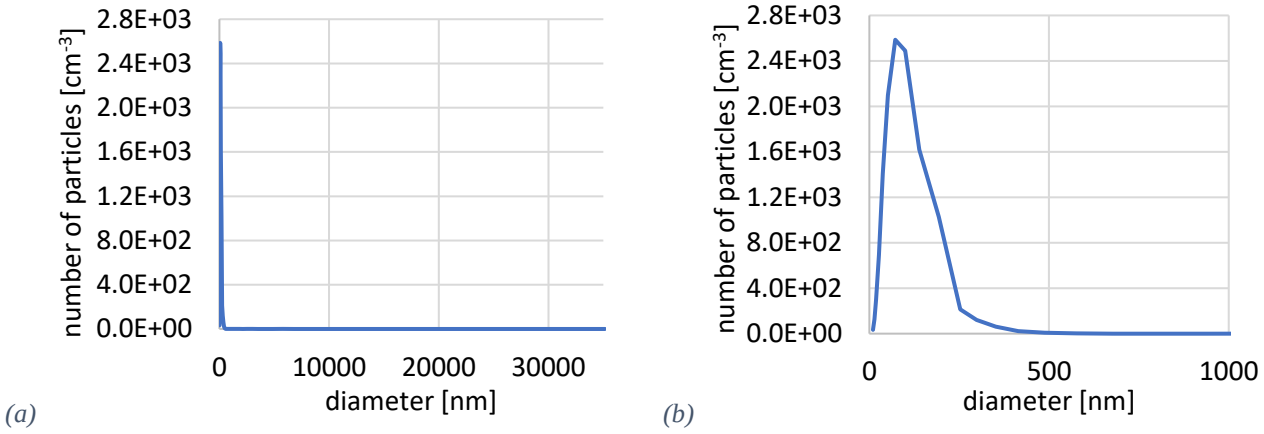


Figure 7 (a) Cumulative plot of particles analysed in outdoor environment and (b) its zoom until PM 1. These data come from the second output file of measurements performed by Grimm Aerosol Mini-WRAS 1371.

In Table 2 the PM_{10} concentration results from the two instruments are compared, obtaining an agreement within 13 %.

Table 2 Comparison between data from the two particle counters

	average value of PM_{10} [$\mu g \cdot m^{-3}$] from measurements performed with Grimm Aerosol Mini-WRAS 1371	**average value of PM_{10} [$\mu g \cdot m^{-3}$] from measurements performed with Hach Ultra Met One 2400**	**difference between the two instruments [%]**
outdoor	36.4	31.8	12.8
laboratory	10.5	11.8	11.1

5. COMPARISON OF RESULTS WITH A.R.P.A. Piemonte

Results obtained by the Hach Ultra Met One 2400 particle analyzer are compared with the results from A.R.P.A. Piemonte [11]. In the bulletins are reported the municipal estimates of PM_{10} for the cities of Torino, Borgaro Torinese, Beinasco, Collegno, Grugliasco, Moncalieri, Nichelino, Orbassano, Rivoli, San Mauro Torinese, Settimo Torinese and Venaria Reale. These data are

calculated from the results produced by the modelling chemistry and transport system used operationally by A.R.P.A. Piemonte, and by the air quality data observed by the stations of the Regional Air Quality Detection System. The two information are integrated with a statistical methodology of data assimilation. The concentration values thus calculated are then assigned to the municipal territory, taking into consideration the urbanization characteristics.

In Table 4 are compared the average values of the cities of Torino and Nichelino, that are nearby INRiM Campus, with the average results obtained from punctual measurements that are performed in the morning and in the afternoon using our laser particle analyzer. It is worth noting that some differences between INRiM experimental results and A.R.P.A. Piemonte data can be observed, due to (i) the different methods used to evaluate the particle concentration, and (ii) comparison between punctual measurements in an area of woods and parks and measurements averaged through an urban context. The results in Table 4 are reported by classifying the PM_{10} concentration according to the 5 classes of the European Air Quality Index (EAQI) [12] reported in Table 3.

Table 3 Classes of the European Air Quality Index (EAQI)

Air Quality	Index EAQI	PM_{10} Concentration [$\mu g \cdot m^{-3}$]
Good	1	0 – 25
Fair	2	26 – 35
Moderate	3	36 – 50
Poor	4	51– 100
Extremely Poor	5	> 100

Furthermore, in Table 5 are reported the atmospheric conditions in which the measurements are performed.

Table 4 Comparison of the concentration of PM_{10} reported by A.R.P.A. Piemonte and measured at INRiM

	14 Jan 2019	**15 Jan 2019**	**16 Jan 2019**	**17 Jan 2019**	**18 Jan 2019**	**21 Jan 2019**	**22 Jan 2019**	**23 Jan 2019**	**24 Jan 2019**	**29 Jan 2019**	**30 Jan 2019**	**31 Jan 2019**	**1 Feb 2019**
PM_{10} EAQI in Turin by A.R.P.A. Piemonte [11]	2	3	4	4	4	4	4	4	3	3	3	4	1
PM_{10} EAQI in Nichelino by A.R.P.A. Piemonte [11]	1	3	4	4	3	4	4	4	3	2	3	3	1
PM_{10} EAQI in INRiM Campus	1	3	4	4	4	4	3	3	3	3	3	3	1

Table 5 Outdoor atmospheric condition and gallery plant environmental parameters for the measurements performed in the morning (mn) and in the afternoon (an)

	14 Jan 2019 an	**15 Jan 2019 mn**	**15 Jan 2019 an**	**16 Jan 2019 mn**	**16 Jan 2019 an**	**17 Jan 2019 mn**	**17 Jan 2019 an**	**18 Jan 2019 mn**	**18 Jan 2019 an**	**21 Jan 2019 mn**	**22 Jan 2019 mn**	**22 Jan 2019 an**	**23 Jan 2019 mn**	**23 Jan 2019 an**	**24 Jan 2019 mn**	**24 Jan 2019 an**	**29 Jan 2019 mn**	**29 Jan 2019 an**	**30 Jan 2019 mn**	**30 Jan 2019 an**	**31 Jan 2019 mn**	**1 Feb 2019 an**
EXTERNAL WEATHER CONDITIONS																						
weather conditions	windy and sunny	windy and sunny	windy and sunny	sunny	sunny	partly cloudy	mostly sunny	foggy	sunny	sunny	sunny	sunny	partly cloudy	light snow	sunny	sunny	partly cloudy	sunny	partly cloudy	mostly cloudy	foggy	snow
temperature [°C]	17	12	13	10	12	8	8	3	11	4	3	8	1	1	8	7	3	7	2	5	3	1
precipitation [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82
humidity [%]	20	31	27	45	39	56	63	65	26	61	60	51	77	87	45	50	47	50	69	61	76	88
wind [km/h]	13	8	6	2	5	3	5	8	8	2	2	3	10	11	5	3	8	3	5	10	3	5
"IMPIANTO GALLERIA"																						
pressure [kPa]	97.95	99.14	98.96	99.22	99.02	98.76	98.38	98.56	98.58	99.03	98.26	97.72	97.34	96.83	97.34	98.64	97.99	97.99	97.37	97.25	97.59	-
CO_2 [ppm]	485	475	475	480	480	505	515	515	515	490	500	505	500	500	500	505	480	480	485	485	485	-
RH [%]	33.5	33	32.5	33	33	34	35	35	34	33.5	32.5	33.5	34	34	34	33	31	32.5	33	34	34	-
temperature [%]	varies for each laboratory (~ 20.0 ± 0.1 °C)																					

6. CONCLUSIONS

This technical report deals with airborne particle measurements in indoor and outdoor environments, carried out during wintertime using particle counters. The PM_{10} concentration from two different particles counters, one of them equipped with a laser counter and an electrical sensor, are compared showing an agreement within 13 %.

A simple method to correlate the number of particles measured with the Hach Ultra Met One 2400 particle counter to the concentration of particles in air is used, by assuming a spherical shape of the particles and a density $d = 1\ g \cdot cm^{-3}$. Particle concentration show an expanded uncertainty of about 12 %, with major contributions due to the measurement repeatability and particulate matter density and shape variations.

Finally, the measurements results are compared with data provided by A.R.P.A. Piemonte. Some differences in the results can be due to the different methods used to evaluate the particle concentration, and to the fact that punctual measurements performed in INRiM Campus are compared to measurements averaged through an urban context.

7. AKNOWLEDGMENTS

The author thanks Prof. Valter Maurino from Università degli Studi di Torino for having provided the Grimm Aerosol Mini-WRAS 1371 particle counter. Furthermore, the author wish to thank Dr. Maria Giulia Faga and Dr. Giovanna Gautier from CNR – IMAMOTER (Consiglio Nazionale delle Ricerche – Istituto per le Macchine Agricole e Movimento Terra) for the permission and the help in performing analysis in the CNR Research Area of Strada delle Cacce 73 in Turin. Finally, the author thanks Dr. Maria Giulia Faga for the text revision.

8. REFERENCES

[1] Colin Baird, Michael Cann, Environmental Chemistry, W. H. Freeman & Co Ltd, 2012, ISBN-13: 978-1464113499

[2] W.H. Schlesinger, Emily Bernhardt, Biogeochemistry - An Analysis of Global Change, Elsevier Academic Press, 2013, ISBN: 978-0-12-385874-0

[3] Barbara J. Finlayson-Pitts, James N. Pitts, Jr., Chemistry of the Upper and Lower Atmosphere, Elsevier Academic Press, 2000, ISBN 978-0-12-257060-5

[4] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008L0050

[5] Decreto Legislativo 13 agosto 2010, n.155 , Attuazione della direttiva 2008/50/CE relativa alla qualità dell'aria ambiente e per un'aria più pulita in Europa, https://www.camera.it/parlam/leggi/deleghe/testi/10155dl.htm

[6] R. W. Atkinson, S. Kang, H. R. Anderson, I. C. Mills, H. A. Walton, Epidemiological time series studies of PM 2.5 and daily mortality and hospital admissions: a systematic review and meta-analysis, *Thorax*, 2014, 69, 660-665, DOI: 10.1136/thoraxjnl-2013-204492

[7] Met One 2400/2408 Portable Airborne Particle Counter Operator Manual, Hach Ultra, 2002

[8] ISO 14644-1:1999, Cleanrooms and associated controlled environments Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness, International Organization for Standardization, Geneva, web site https://www.iso.org/standard/25052.html

[9] Andreas Jaksch, The MINI-WRAS, Grimm Aerosol Technik GmbH&Co. K G, 2016

[10] V. Ferro, A. Sacchi, G. Saggese, Impianti straordinari di condizionamento per Galleria misure di Lunghezze, Consiglio Nazionale delle Ricerche – Istituto di Metrologia "Gustavo Colonnetti", 6 febbraio 1970

[11] Bollettini A.R.P.A. Particolato atmosferico, web site access in January 2019 – February 2019, http://www.arpa.piemonte.it/bollettini/elenco-bollettini-1/bollettino-dei-dati-settimanali-di-pm10

[12] European Air Quality Index, European Environment Agency, https://airindex.eea.europa.eu/#