Assessment of the indoor/outdoor dynamic of some air pollutants in three buildings located in the valley city of Chambéry, France

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1 INTRODUCTION

In recent years, population exposure to air pollution has been a major concern. Indoor air quality (IAQ) is mainly monitored with CO_2-concentration-based indicators. High levels of CO_2-concentration are avoided in buildings when airing by the windows is done and/or when air exchange rate of the existing ventilation is regulated, based on a CO_2-level-information. However, as contributing to maintain low CO_2-concentration-levels indoors, the increase of outdoor air intake is associated with a more or less important introduction of outdoor air pollutants in the building. Among these pollutants, there are particulate pollutants as $PM_{2.5}$ and there is NO_2 that is a gaseous pollutant mainly emitted by the road-traffic. Many previous papers dealt with the indoor/outdoor dynamics. However, only rare studies, like Bucur et Danet (2019), Bi et al. (2021) or Nezis et al. (2022), were based on outdoor air measurements up to 500 m away from the studied buildings.

The aim of this study is to evaluate such dynamics for $PM_{2.5}$ and NO_2. It was based on a two-months measurements campaign in three buildings presenting different ventilation types. In addition to the reference data of the local air quality monitoring station, an optical particles measurement was introduced on the façade of the buildings.

2 METHODS AND MATERIAL

2.1 Site description

For this study, three public buildings with different ventilation conditions were chosen within a 300 m of an ambient air quality monitoring station. The environment is an urban busy traffic. A short description of the characteristics of these buildings is given in *Table 1**Error! Reference source not found.***

2.2 Sampling methods

Different sensors were used for the campaign to measure the concentrations of particulate matter with an equivalent diameter less than 2.5 $\mu g.m^{-3}$ ($PM_{2.5}$), black carbon (BC), nitrogen oxides (NOx, NO_2, NO). Indoors, there was at least one monitor or sensor for each kind of measurement. And there was one $PM_{2.5}$ sensor on the air intake façade of each building, that also provides air pressure. The technology to measure the particle matter is optical particle counter. A low-cost monitor is used here, that also delivers measurements of CO_2, temperature and relative humidity inside. NOx measurement has been possible in one of the buildings only, using a chemiluminescence-based analyser. The technology used to measure the black carbon is an aethalometer. And Atmo AuRA, the air pollution surveillance actor for the region, delivered data from the nearby station. *Table 2* gives details on the used material in the buildings and on their façades. Prior to the campaign, the eight AirVisual sensors were put under inter-comparison for three months in the laboratory. The installation of $PM_{2.5}$ measurements devices for each building of the campaign was then based on the AirVisual technology version and on the determination coefficient results, as shown in *Table 3*.

Table 1 : Main characteristics of the buildings included in the measurements campaign

Building	**Floors number**	**Façade measurement (campaign)**	**Year of construction**	**Refurbish ment**	**Ventilation type**
School	4	West	1960's	Upcoming	No system, manual airing (windows)
Event center	2	West	1990's	Upcoming	Balanced ventilation (activated when an event is scheduled)
Library	6	East	1990's	No	HVAC system with filters. Turned off at night and on Sundays

Table 2 : Main characteristics of the sampling material for the measurements campaign

Building	**Floor (Nb of rooms)**	**Nb of monitors**	**Brand of monitor/sensor/analyser**			**Building facade**
			$PM_{2.5}$, CO_2, Temp, RH	**BC**	**NOx**	**$PM_{2.5}$**
School	3^{rd} floor (2)	2	AirVisual NODE (IQAir)	AE31 (Magee Scientific)	ENVEA analyser (Atmo AuRA)	AirVisual Outdoor (IQAir)
Event center	Staircase (1)	1	AirVisual PRO (IQAir)	MA300 (Aethlabs)	-	AirVisual Outdoor (IQAir)
Library	2^{d} and 3^{rd} floors (2)	2	AirVisual PRO (IQAir)	MA300 (Aethlabs)	-	AirVisual Outdoor (IQAir)

Table 3 : AirVisual Indoor and Outdoor inter-comparison results (R^2)

AirVisual Indoor device(s)	**Indoor/Indoor R^2**	**Indoor /Outdoor R^2**	**Building destination into the campaign**
Pair of NODE	0.984	0.983 [a]	School
Pair of PRO	0.986	0.981 [a]	Library
Remaining PRO	-	0.966	Event Center

a: This determination coefficient is the average of the determination coefficients of the Outdoor device with each Indoor monitor of the Indoor pair.

2.3 Data Analysis method

The campaign was carried out from January 11^{th} to March 7^{th}, 2024. After collecting the data from the monitors and analysers, a cleaning step was performed, mainly to keep out the temporal discrepancies from the outputs of the AirVisual devices. The cleaned data were then averaged into different time-step levels with the R package openair (Carslaw et al., 2011), i) to match the time step of the data provided by the ambient air quality monitoring station (15 minutes), ii) to determine the European Air Quality Index, EAQI, of the concentrations from the station (respectively 1 hour and 1-day-time steps for NO_2 and $PM_{2.5}$). As the black carbon data treatment is not yet finished, the present summary only covers the $PM_{2.5}$ and NOx analysis.

The data were analysed to get a knowledge of the outdoor-indoor air pollution dynamics: i) at the campaign' scale, and ii) at specific high pollution periods within the campaign. The global study involves several approaches and parameters such as a statistical approach of the distribution of the measurements, the occupation' definition through surveys, etc. Here, the summary presents the results on a daily profile approach, with the 15-minutes I/O ratio of $PM_{2.5}$ and NO_2 concentrations.

3 RESULTS

3.1 Indoor/outdoor dynamics of NO_2

During the campaign, the outdoor NO_2 concentration never exceeded 90 $\mu g.m^{-3}$ per hour, the EAQI upper limit for the Fair class. Indeed, the NO_2 1-hour-step outdoor concentration stayed within the interval of 0.7 to 73.5 $\mu g.m^{-3}$. In the daily-profiled concentrations presented in *Figure 1.a)*, we can observe two peaks in the outdoor concentration, one in the morning and the other at the end of the day, corresponding to the peaks of traffic in urban areas. The indoor concentration curve is rather flat, and the maximum I/O ratio of 0.70 was found at mid-day.

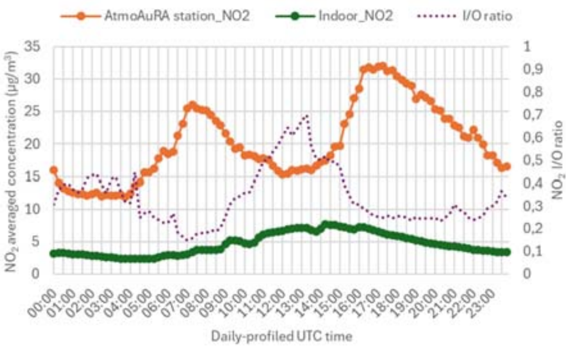
3.2 Indoor/outdoor dynamics of $PM_{2.5}$

We plotted the $PM_{2.5}$ concentration indoors and outdoors and the I/O ratios for the school, the event center and the library within a daily profile, on a 15-minutes time-step level (*Figure 1.b to d)*. Two days in January and two in February, we observed at the station that the outdoor $PM_{2.5}$ concentration did go beyond the value of 25 $\mu g.m^{-3}$ per day, the upper limit of the Moderate class of the European Air Quality Index. In *Table 4* are presented the minimum and maximum I/O ratios representing the indoor averaged concentrations over the station outdoor concentrations during the campaign period. It also gives the detail of the median I/O ratio values in and out of the four dates where the daily concentration is above 25 $\mu g.m^{-3}$. It is noteworthy that, according to the occupation's survey, a window was opened in one of the two monitored rooms of the school at 1.00 PM UTC, on date no. 3, and that no event was mentioned on any of these dates in the monitored room of the event center. There, the ventilation was then off. In the school, the maximum I/O ratio of 5.49 corresponded to a reported combustion activity in one of the classroom, in the beginning of March.

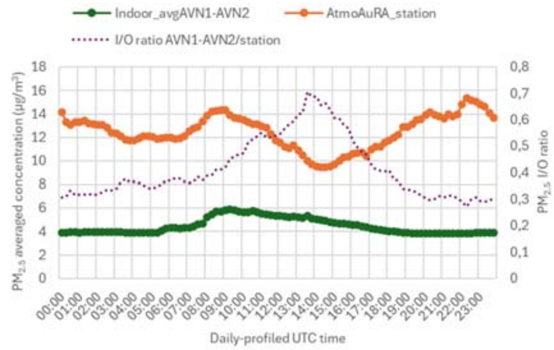
Table 4 : 15-minutes-averaged concentration I/O ratio of PM2.5 during the campaign period ($\mu g.m^{-3}$)

Building	Days where daily concentration is under 25 $\mu g.m^{-3}$			Dates where daily concentration is above 25 $\mu g.m^{-3}$		
	Min.	**Max.**	**Median**	**Min.**	**Max.**	**Median**
School [a]	0.00	5.49	0.34	0.12	0.59	0.29
Event center [b]	0.00	5.35	0.54	0.39	0.85	0.59
Library [a]	0.00	2.05	0.12	0.04	0.33	0.13

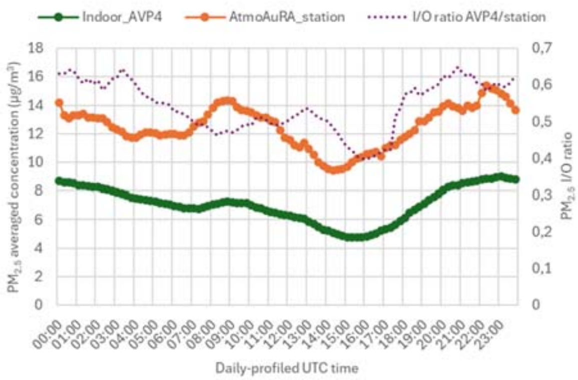
a: Indoor concentration as the average of the values of two sensors.
b: Indoor concentration as the value of one sensor.



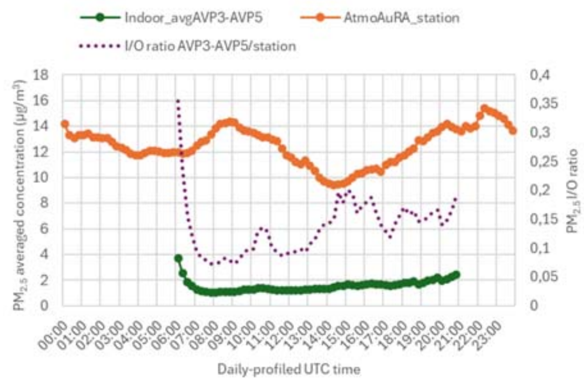
a) NO_2, school building



b) $PM_{2.5}$, school building



c) $PM_{2.5}$, event center



d) $PM_{2.5}$, library

Figure 1 : 15-minutes-averaged concentration in a daily profile of the campaign period

4 DISCUSSION

Considering the daily profile of I/O ratios, having the inside measured concentration above the outside measured concentration never happens for both pollutants. In the case of $PM_{2.5}$, early morning corresponds to the library' highest I/O ratio, when the ventilation is turned on back for the day. Otherwise, the indoor concentration of the library stays far below the outside one during the day. That can be due to the performance of filters. For both pollutants, the peak of I/O ratio for the school is at mid-day, and a weaker one occurs after midnight in the case of NO_2. No clear pattern comes out of the daily profile of the event center, which could be due to an activation of ventilation only when a meeting takes place in the monitored room (seven events reported on seven different dates, four during the day and three at the end of the day or at night). The same can be said of the library, and in this case, it might be due to a random presence of visitors and rooms with a larger volume, but there are two peaks, one in the morning and a wider one in the afternoon. Except for the library, the daily profiles let us guess a transfer of the pollution from the outside to the inside, especially in the case of the event center. Time series give a better indication of potential delays of the transfer, and further analysis will allow an accurate determination. To enhance the knowledge of the air pollution transfer in the building, the impact of different parameters should be further investigated. For example, measurements *in situ*, including air flows of the ventilation systems will be used to characterize the ventilation parameters. The CO_2 concentration decay method could be implemented, like Persily did (Persily, 1997), to determine Air Change Rate (ACR) in the rooms, specifically for the school and its manual airing.

5 CONCLUSION & PERSPECTIVES

The monitored rooms in these three different buildings present specific indoor air pollution temporal evolution, and we observe that the less polluted building is the library (mechanically ventilated with filters), followed by the event center (mechanically ventilated when occupied only) and at last, by the school (manual ventilation). On a daily profile point of view, both NO_2 and $PM_{2.5}$ I/O ratios never exceed the value of 1, but they can be close to it, when considering the school. Looking specifically at the median I/O ratio, higher outdoor pollution seems to rise the $PM_{2.5}$ transfer to the buildings, except for the school, which shows in this study the limit of that indicator and/or which indicates that the data quality step needs to be strengthened if working with I/O ratios. As for NO_2, we found out a daily-profiled I/O ratio under the value of 1 and an hourly-concentration below the EAQI' Fair class upper limit.

As for the experiment method, a configuration where $PM_{2.5}$ sensors are installed on the façade, as near as possible of the air intake, led to similar measurements between the three buildings, that are in the same neighbourhood. Nonetheless, an even greater remarkable point is that the three measurements seem to be well correlated with the ambient air quality monitoring station in their surroundings, excepting when the outside $PM_{2.5}$ pollution rises in a peak.

Thus, this study brings important information for a global comprehensive understanding of the dynamics of outdoor/façade/ indoor concentrations of particulate matter ($PM_{2.5}$) and gaseous pollution (NO_2), because data were produced from different monitored buildings/ventilation systems. A second step in this work will be to characterize the transfer into the buildings, comparing the following results from both points of view of the façades and the station: amount of concentration, time delay. And if possible, the health impact of this transfer will be determined. We will analyse an additional pollutant, measured in each building, that is black carbon, particularly specific to outdoor emissions. A third step will be to conduct a second measurements campaign, in three other public buildings and in the same region. Finally, the results of the experimental phasis will be used in air pollution and aeraulic modelling programs to further investigate the question of the transfer control and its parameters.

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