Indoor/Outdoor Particulate Matter and Gas Concentration in Library and University Campus

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Abstract Both of indoor and outdoor air pollution levels have considerable negative impacts on human health while people spend over 80% of their time indoors. The main purpose of this paper is to investigate the variability of pollutants on the university campus and the exposure of staff and students to pollutants in buildings and outdoors on campus. Indoor/outdoor (I/O) particulate mass concentration (PM_{10}, $PM_{2.5}$ and PM_1) and gas concentration (CO_2, CO, NO) were measured with QARPEDIEM miniature sensors in the library with mechanical ventilation. The measurement took place during February 2019 on university campus, which belongs to the Université de Lille, in France. First of all, the daily variations and statistical characteristics of particle and gas indoor and outdoor concentration were displayed, which shows higher air pollutants indoor levels during weekdays than weekends. Then, the correlation analysis of CO_2 indoor levels and human presence in the library and the particle mass concentration difference between a small room and balcony in library were present, which indicates particle indoor concentration changing with the number of people occupied. Moreover, the I/O ratio of particles and CO_2 as well as air exchange rate of the library were calculated, and the results show that the coarse particles indoor concentration was associated with indoor resuspension activities.

Key words QARPEDIEM portable sensors; Optical particle counting; Indoor/outdoor air quality monitoring; Particulate matter (PM_1, $PM_{2.5}$, PM_{10}); Gaseous pollutants (CO_2, CO, NO); Atmospheric boundary layer dynamics; Air exchange rate; Urban campus atmospheric environment

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According to recent research, pollution in the air has considerable negative impacts on human health and causes certain diseases including asthma, decreased lung function, respiratory and cardiovascular illnesses[1-4]. Many scientists focus on investigating indoor air quality since people spend most of their time (85% – 90%) indoors[5-7]. A lot of harmful species have been observed indoors and are well known by the public through the media, especially particulate matters (PM), ozone (O_3), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), volatile and semi-volatile organic compounds (VOCs)[8]. Although indoor air pollutants concentration is strongly affected by outdoor air quality, it also can be generated by indoor sources, such as printer operation, human activities and building materials[9]. Consequently, to improve indoor air quality and protect human health, both indoor and outdoor air quality assessment should be studied. In this report, the comparison of indoor and outdoor air quality on university campus and the impact of human presence on indoor air pollutants levels will be discussed.

The main objectives of this work are as the following: firstly, to study the daily variability of particles mass concentration and some gas species concentration measured by four QARPEDIEM sensors; secondly, to evaluate the air pollutants levels of indoors and outdoors on campus; thirdly, to investigate the impact of human presence on indoor air pollutants concentration.

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1 Materials and methods

1.1 Measurement location description Four QARPEDIEM sensors were deployed to monitor outdoor and indoor air pollutants in this study, one in the instrumental platform on the rooftop of the LOA laboratory and three in the library (LILLIAD). The LOA sensor was used to observe the outdoor air quality, while the indoor air quality was measured within the library. The library and LOA laboratory are both located on Université de Lille, Campus Cité Scientifique (Fig. 1a) in a suburban area 6 km southeast of the city of Lille, France. This site is surrounded by streets of medium traffic. In these streets, usually, the peak traffic periods are mainly from 07:00 to 09:00 and from 17:00 to 18:00 on weekdays mainly due to the staff and students driving to the campus in the morning and leaving university to go home in the evening. During the weekends, there are only few vehicles passing through these streets since most of the staff and students don't need to present on campus. A metro run through the area between library and LOA laboratory. Since outdoor air pollutants mainly including NO_x, SO_2, O_3, CO, hydrocarbon (HC), and particulate matters of different particle sizes, not only the on-road and off-road vehicles, artificial road construction activities, but also the industrial boilers in the vicinities of the LOA laboratory can be outdoor air pollutants emission sources on campus, depending on the locations and prevailing winds.

The measurements were performed simultaneously during February 11 – March 2, 2019 in LOA laboratory and library. Fig. 1b provides the floor plan and the location for each instrument within the library: on the balcony (1st floor), second floor and a small room (2nd floor). The library building consists of offices, reading rooms, balcony, cafeteria and small rooms for group working. The balcony and 2nd floor were usually occupied during the opening hours (08:00 – 20:00, 09:00 – 13:00 or 09:00 – 18:00, depending on the schedule of the library) and the positions were selected to perform measurements in an open area. Whereas small room may be occupied or not by multiple persons during the opening hours due to the time period and frequency of students applying to work in the small room is uncertain. Except the air pollutants infiltrated from outdoors to the indoor environment, many studies also found that modern offices environments are mostly affected by the use of office equipment such as printers generate ultrafine particles and volatile organic compound[10 – 11]. As the door usually was closed while the occupants were working and not any printers and other office hardcopy devices that could generate particles were present in the room, thus, the indoor air components concentration of the small room was mainly affected by indoor activities including walking, cleaning, opening the door, *etc*.

Note: a. Map of the Lille campus including the library (red cross) and LOA laboratory (green cross) where the sensors were installed; b. Location of the instruments in library: balcony (blue cross), 2nd floor (green cross) and small room (black cross).

Fig. 1 Location of measurement (a) and instruments (b)

Table 1 presents the opening hours during the working days in library as well as the frequentation. Usually, the library opened for 12 h during 08:00 – 20:00 on Mondays – Fridays and for 4 h during 09:00 – 13:00 on Saturdays, while the library was closed on Sundays. During non-working days, the library was unoccupied at all times. Because of the holidays from 18th to 22nd February 2019, the library opened for 9 h during 09:00 – 18:00 on Mondays – Fridays. At the same time, the frequency and number of persons entering the library were also influenced by holidays, which were about 60% lower than non-holiday opening hours.

In addition, the statistical characteristics of temperature and relative humidity indoor and outdoor were presented in Table 2. It indicated that both the ventilation system and heating devices were working well in the library during all the experiment and the indoor temperature was relatively constant at 24 ℃ and higher than outdoor. The same tendency was observed for relative humidity that was within the library only around 30% and nearly 60% outdoor.

1.2 Experimental set up Particle mass and gas concentrations were measured with four QARPEDIEM portable detectors consisted of a series of ALPHASENCE miniature sensors specified for different particles and gas species. In this report, we mainly focused on PM_1, $PM_{2.5}$, PM_{10}, CO_2, CO and NO, although NO_2, SO_2, VOC and other particles of different sizes were also observed by the sensors.

Table 1 Opening hours and number of persons in library

Date	Day	Opening hours	Number of persons
2019 – 02 – 11	Monday	08:00 – 20:00	2 655
2019 – 02 – 12	Tuesday	08:00 – 20:00	2 692
2019 – 02 – 13	Wednesday	08:00 – 20:00	2 429
2019 – 02 – 14	Thursday	08:00 – 20:00	2 585
2019 – 02 – 15	Friday	08:00 – 20:00	1 805
2019 – 02 – 16	Saturday	09:00 – 13:00	158
2019 – 02 – 17	Sunday	Closed	0
2019 – 02 – 18	Monday	09:00 – 18:00	947
2019 – 02 – 19	Tuesday	09:00 – 18:00	942
2019 – 02 – 20	Wednesday	09:00 – 18:00	904
2019 – 02 – 21	Thursday	09:00 – 18:00	973
2019 – 02 – 22	Friday	09:00 – 18:00	861
2019 – 02 – 23	Saturday	09:00 – 13:00	168
2019 – 02 – 24	Sunday	Closed	0
2019 – 02 – 25	Monday	08:00 – 20:00	574
2019 – 02 – 26	Tuesday	08:00 – 20:00	–
2019 – 02 – 27	Wednesday	08:00 – 20:00	–
2019 – 02 – 28	Thursday	08:00 – 20:00	–
2019 – 03 – 01	Friday	08:00 – 20:00	–
2019 – 03 – 02	Saturday	09:00 – 13:00	–

Note: Number of persons corresponds to the number of people that entering the library through the main entrance at the front. Small rooms are closed 30 min before library closing time.

Additionally, PM_1, $PM_{2.5}$ and PM_{10} represent the particulate matters suspending in the air whose aerodynamic equivalent diameter less than 1, 2.5 and 10 μm, respectively.

NO_2, NO, SO_2 and CO concentrations were measured with gas sensors operated using proven fuel cell technology with diameter around 20 mm. VOCs were measured with metal oxide gas sensor with 10 – 50 ppb limit of detection and CO_2 concentration was measure with infrared sensors. The resolution is respectively about 50 ppb for NO_2, 200 ppb for NO, 1 ppm for SO_2, 5 ppm for CO, while the resolution for CO_2 has not been found. Particle mass concentrations were measured every second by optical particle counters (OPCs) using sample flow rate at 280 ml/min and sorting into 16 size bins between 0.35 and 40 μm. PM_1, $PM_{2.5}$ and PM_{10} were also recorded assuming spherical particles and a constant density. The OPC can measure from clean rooms to pollution levels to 2 000 $\mu g/m^3$.

Table 2 Temperature and relative humidity in library and LOA laboratory

Site		Temperature//℃				Relative humidity//%			
		Mean	Median	Standard deviation	Range	Mean	Median	Standard deviation	Range
Indoor	Balcony	25.08	25.10	0.72	22.32 – 27.61	28.95	28.48	2.51	23.60 – 40.40
	2nd floor	23.59	23.57	0.56	20.42 – 25.08	32.33	31.74	3.45	25.24 – 43.60
	Small room	23.83	23.80	0.88	22.00 – 26.01	32.04	31.41	2.79	26.42 – 39.96
Outdoor	LOA	12.52	12.01	4.72	2.73 – 27.74	59.96	62.23	14.76	17.27 – 86.08

2 Results and analysis

2.1 Indoor and outdoor particle mass concentrations 3-hour average of indoor and outdoor particle mass concentrations of PM_{10}, $PM_{2.5}$ and PM_1 measured in the library and LOA laboratory are showed in Fig. 2. In general, the daily variations of PM_{10} and $PM_{2.5}$ indoor mass concentrations show similar characteristics, especially for 2nd floor and small room. The close vicinity of both measurement locations and the fact that the air from the second floor is constantly injected within the small room explain the similar tendencies. It was noted both of the range and variation characteristics of PM_{10} and $PM_{2.5}$ indoor concentrations were totally different during weekdays and weekends. Fig. 3 compared the daily variations of indoor with the outdoor particle mass concentration for particles PM_1, $PM_{2.5}$ and PM_{10} during weekdays and weekends. The value every hour represents the average concentration at the same hour of a day during 20 d of measurement. For each weekday, PM_{10} indoor concentrations increased first around 08:00, reached a maximum at 50 $\mu g/m^3$ around 10:00 and then decreased, increased second around 11:00, reached a maximum at 60 $\mu g/m^3$ around 13:00 and then decreased, increased third around 14:00, reached a maximum at 48 $\mu g/m^3$ around 15:00 and then decreased and kept stable after 20:00. The $PM_{2.5}$ and PM_1 indoor concentrations on weekdays showed the similar changes except the last maximum was observed around 16:00 and 17:00, respectively. The similar daily change of particle number indoor concentrations in Hanoi households was also fund[12]. According to Table 1, on non-holiday working days, the library usually opened for 12 h from Mondays to Fridays (08:00 – 20:00). The maximum concentration was obtained during the most crowded period in the library between 12:00 and 13:00. Thus, the daily variation of particles indoor concentration corresponded to the changes of the library frequency (number of people entering the library). Besides, library frequency was different during the university holiday period from 18th to 22nd February 2019 (twice lower than usual). These differences could be seen in Fig. 2, PM_{10} and $PM_{2.5}$ indoor concentrations were higher on weekdays than weekends. Moreover, the daily maxima values during February 11 – 15, 2019 were in the range of 30 – 60 $\mu g/m^3$ for PM_{10} and 4 – 10 $\mu g/m^3$ for $PM_{2.5}$. During the vacation, the daily maxima values were lower and around 20 – 33 $\mu g/m^3$ for the PM_{10} and 3 – 7 $\mu g/m^3$ for the $PM_{2.5}$. During February 25 – March 1, 2019, concentrations were at the highest levels: 40 – 80 $\mu g/m^3$ for PM_{10} and 8 – 14 $\mu g/m^3$ for $PM_{2.5}$. In more details, the particle concentrations at the 2nd floor were higher than small room while the particle concentrations in balcony were significantly lower than the former two. The differences were reasonable since the 2nd floor occupied all the time during the opening time while no person in the small room as well as the structure of the balcony was more conducive to the dilution of particles.

On the other hand, average outdoor PM concentrations on weekdays were not always higher than indoor measurements during this field campaign. Especially for PM_{10} concentration during February 25 – March 1, 2019, when indoor PM concentrations were evidently much larger than the usual (more than 50%). One case of high particle levels (PM_{10}: 150 $\mu g/m^3$, $PM_{2.5}$: 50 $\mu g/m^3$ and PM_1: 33 $\mu g/m^3$) was measured outdoors during February 22 – 23, 2019 (on holidays) on Friday and Saturday, whereas the indoor average particle levels in PM_{10} and $PM_{2.5}$ were not higher than the unpolluted weekdays during February 25 – March 1, 2019. As no rainy days in these two periods, the difference was the less people in library during holidays. Indeed, the human presence contribution to indoor particle concentration is essential in the library. In most cases, outdoor PM_1 concentration was higher than indoor concentration. It suggested the infiltration of ultrafine particles was different from coarse particles.

Additionally, a comparison between weekdays and weekends for indoor and outdoor particle concentrations are presented in Fig. 3, where hourly average concentration on 2nd floor represents indoor concentration. A general remark is that the outdoor concentration was higher than the indoor concentration during weekends.

As for weekdays, indoor coarse particle (PM_{10}) level was distinctly higher than outdoor and indoor ultrafine particle (PM_1) levels, showing opposite statistical features. Indeed, the highest indoor $PM_{2.5}$ and PM_{10} mass concentrations were measured during weekdays (16.1 and 104.4 $\mu g/m^3$), whereas the highest outdoor PM_1 mass concentration (6.1 $\mu g/m^3$) occurred during weekends. The numbers suggested higher coarse particles indoor mass concentration during weekdays, probably due to human occupation. Moreover, the low indoor PM_1 mass concentration could be associated with the efficiently removal of outdoor PM_1 by the ventilation systems and the envelop of building. The mechanic ventilation systems working well in buildings can reduce outdoor particles up to 50%, which was also reported in literature[13].

In general, the outdoor PM concentrations were higher than indoor at nighttime during weekdays and weekends. However, the situation became totally different at daytime. The maximum values of indoor concentration were measured at 13:00 for PM_{10} and $PM_{2.5}$ at 60 and 10 $\mu g/m^3$, respectively (Fig. 4), while the cantine in the library opened for lunch during 12:00 – 14:00 on weekdays that corresponded to the most crowded period of each weekday in the library. The revolving door of the library kept open since a lot of people entering the library, the outdoor coarse particles could be transported to library as well as the particles already deposited indoor could be resuspended by human activities. This finding was in agreement with other studies that the human activities indoor was a considerable reason for particle resuspending in modern buildings[14]. It is also interesting to note that outdoor particle concentrations were decreasing during 09:00 – 13:00 on weekdays and then slightly increased during 14:00 – 20:00, whereas indoor particle concentrations were changing in an almost opposite trend (Fig. 4). The reasons for this discrepancy were the changes in meteorological parameters and traffic conditions on campus. Indeed, during the day and due to turbulence effect, the boundary layer height rise and the aerosol concentration is diluted within a larger volume. On the other hand, usually, vehicles on road reduced after 09:00 and increased from 17:00 on weekdays, so that the particles generated in streets would decrease after 09:00 and then increase in the evening.

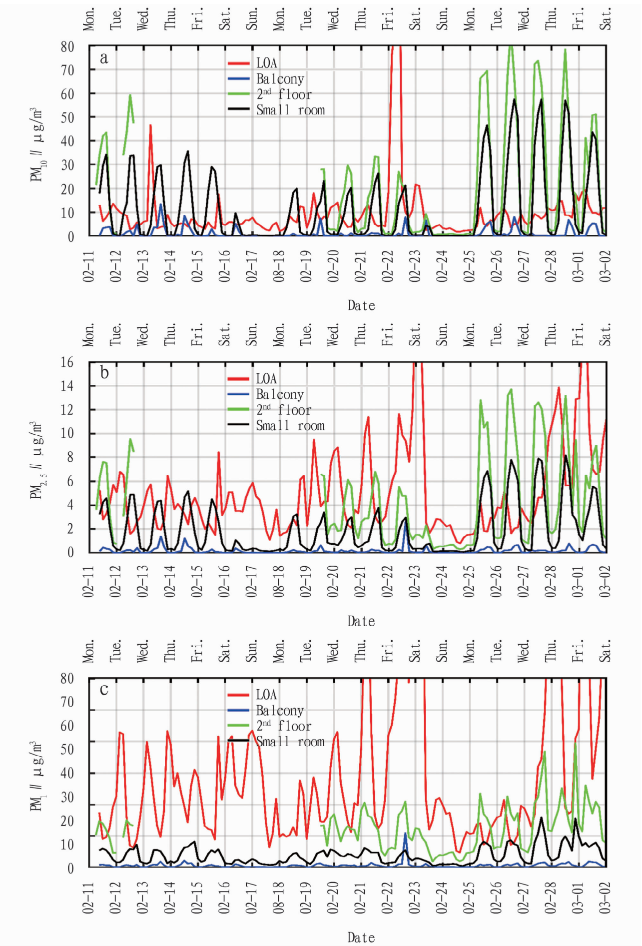
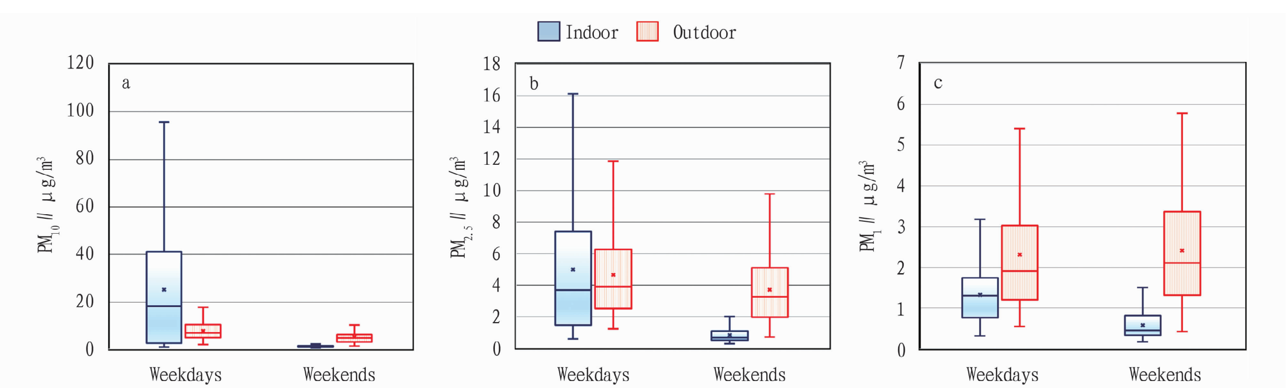


Fig. 2 Indoor and outdoor mass concentrations for particles PM_{10} (a), $PM_{2.5}$ (b) and PM_1 (c) during February 11 – March 2, 2019



Note: The box plots represent the 25th and 75th percentile values, and the horizontal lines represent the median (the 50th percentile) value. The whiskers represent the 10th and 90th percentile values. Outliers are excluded.

Fig. 3 Comparison of indoor and outdoor mass concentrations for particles PM_{10} (a), $PM_{2.5}$ (b) and PM_1 (c) on weekdays and weekends

2.2 Indoor and outdoor gas concentrations In the present study, gas concentrations (CO_2, CO, NO_2, NO, SO_2 and VOC) were also measured simultaneously both indoor and outdoor. Fig. 5 provides average values of indoor and outdoor gas concentrations for CO_2, CO and NO. The values represent the 3-hour average concentration of gases observed during February 11 – March 2, 2019. In general, CO_2 outdoor concentration showed clearly repeatable daily variations while daily change of its indoor concentration distinctly corresponded to whether the day belonged to weekdays or weekends. The variation characteristics of CO_2 indoor concentrations obtained by three sensors were quite consistent, and its average levels during weekdays were distinctly higher than weekends. Obviously, the CO_2 indoor concentration was strongly affected by the presence of people in the library as the peaks of concentration occurred only during opening hours. The CO_2 outdoor concentration ranged from 900 to 1 300 ppm during the experiment, and it had no clear difference between weekdays and weekends. It was notable the trends of CO_2 outdoor and indoor concentrations were almost opposite during weekdays where the highest values indoor and lowest values outdoor were measured almost at the same time. For CO_2 indoor concentration, the maximum observed around 13:00 on weekdays mainly due to a large number of people entering the library during 12:00 – 14:00 as well as producing a lot of carbon dioxide. However, CO_2 outdoor concentration variation was agreement with the diurnal cycles of CO_2 found by other researchers[15].

Additionally, the indoor concentrations of CO and NO were always higher than outdoor. The small room measurements showed lower NO concentration than outdoor sometimes. One possible explanation is that the infiltration rate of NO from 2^{nd} floor to small room was lower than from outdoor to library, since the door of small room closed in most of the time. Similar behavior was found for CO. Indeed, indoor CO concentrations were always higher during the library opening hours. The indoor CO concentrations varied from 120 to 600 ppb during weekdays. No markedly repeatable daily variations of CO outdoor concentrations were observed during the experiment. This result suggested that indoor CO concentration evolution was only linked to indoor sources instead of transport from outdoors. It is necessary to note the high values of outdoor NO concentrations were recorded at daytime on 12^{th}, 20^{th}, 21^{st}, 25^{th}, 26^{th} and 27^{th} February, 2019 which corresponded to high values of indoor NO concentrations. However, indoor NO concentration observed at nighttime was higher than outdoors on February 14, 2019. This suggested that NO could be efficiently transported from outdoor to indoor during daytime, whereas outdoor NO concentration could decrease by NO_x (NO, NO_2) oxidation reactions in the boundary layer during nighttime[16].

Fig. 6 shows the daily variations of indoor (2^{nd} floor) and outdoor CO_2, CO and NO_2 concentrations during weekdays and weekends. As previously said, each dot represents the average concentration at the same hour of a day during 20-day measurement. Daily variations of outdoor CO_2 concentration were similar during weekdays and weekends. Outdoor CO_2 concentration reached a maximum (1 200 ppm) at 08:00, then decreased gradually to reach a minimum (1 000 ppm) at 13:00, and finally increased gradually until 08:00 in the next day. This behaviour was the typically daily changes of CO_2 outdoor background levels noticed by many studies[15].

Indoor CO_2 concentrations were over 1 000 ppm from 10:00 to 18:00 during weekdays. According to the World Health Organization (WHO), indoor CO_2 levels need to be between 350 and 1 000 ppm to prevent any health issues[17]. It could be evidence that indoor air quality in library for most of the day was really poor during the experiment period. However, the indoor CO_2 levels at nighttime were around 800 ppm during weekdays and around 700 ppm during weekends. Moreover, CO_2 indoor levels were always lower than outdoors when people unoccupied the building. Indoor and outdoor CO concentrations showed similar oscillations to CO_2.

2.3 Influence of indoor human presence A linear correlation analysis of CO_2 daily average concentration and visitors entering the library every working day is provided in Fig. 7. The correlation coefficient of CO_2 concentration and the number of people entering library were similar both of balcony and 2^{nd} floor (0.86 and 0.85). It suggested that the high indoor CO_2 concentrations during daytime were caused by the frequency of the library.

Thus, indoor CO_2 concentration could be used as an indicator of human presence. CO_2 sensors are more reliable than the counting sensors. Indeed, the number of entering and exiting person from the library are not consistent, highlighting some sensor defaults. For example, the CO_2 concentration difference between small room and balcony could indicate the number of people in small room. To further verify this idea, CO_2 concentration differences between small room and balcony were displayed in Fig. 8. The sound variation, recorded at the balcony, was added to take into account the number of persons in the surrounding environment and that could locally increase the CO_2 concentration. Zero CO_2 values indicated that the small room was unoccupied while positive CO_2 values meant that small room air showed an excess of CO_2 in comparison to the background (balcony) and therefore highlighted the presence of people within the small room. The negative CO_2 values corresponded to a large excess of CO_2 over the balcony and were associated with large sound anomaly over the balcony. The negative CO_2 values were therefore associated with a large number of people staying close to the balcony sensor. As a result, it is possible to know the human presence in small room using CO_2 concentration difference between small room and balcony. At most of the time, the peak of CO_2 differences were around 200 ppm while some were observed at 300, 400 or even 500 ppm. These larger values were probably due to a larger frequency of this room. Unfortunately, there was no information about the number of person within the small room recorded by Lilliad.

Fig. 9 shows the hourly average PM_{10}, $PM_{2.5}$ and PM_1 and CO_2 concentration differences between small room and balcony. In general, most of the peaks of PM_{10}, $PM_{2.5}$ and PM_1 concentration difference corresponded to the high CO_2 concentration difference when the small room was occupied. Therefore, PM_{10}, $PM_{2.5}$ and PM_1 concentrations in small room were higher than those on the balcony during library opening time due to the human activities indoor. One can see that the activity within the small room had a larger impact on PM_{10} (at least 20 $\mu g/m^3$) and $PM_{2.5}$ (at least 3 $\mu g/m^3$). The presence of people within the small room had a slight effect on PM_1 concentration (0.5 $\mu g/m^3$). However, the ultrafine particles are numerous but are not heavy. The same work needed to be done on particle number concentrations to better understand the influence of human presence on indoor air quality.

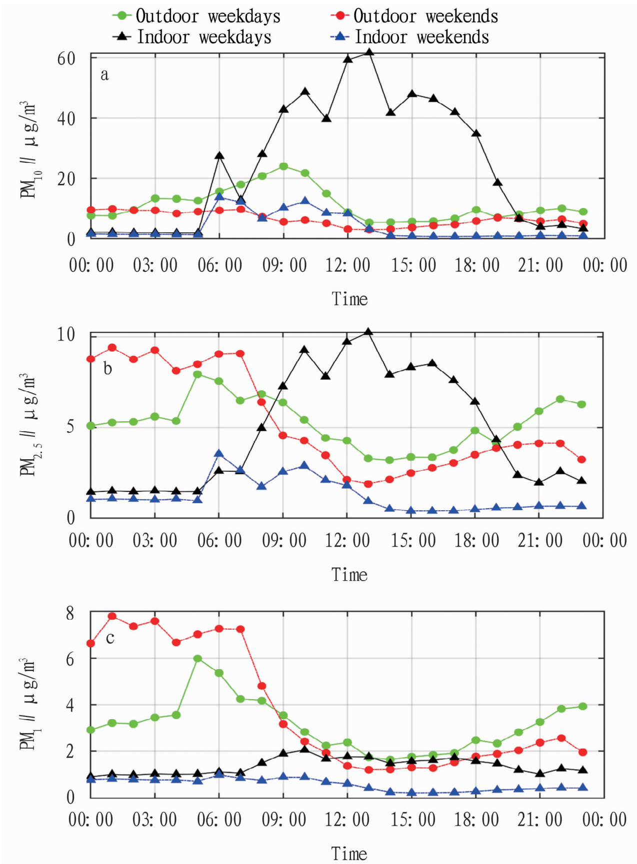


Fig. 4 Daily variations of indoor and outdoor mass concentrations for particles PM_{10} (a), $PM_{2.5}$ (b) and PM_1 (c)

2.4 I/O (indoor/outdoor) ratio and air exchange rate

Indoor to outdoor (I/O) concentration ratio provides a general impression on the transfer rate from outdoor to indoor. I/O ratio is defined as:

$$\text{I/O ratio} = \frac{C_{in}}{C_{out}} \qquad (1)$$

where C_{in} and C_{out} are the indoor and outdoor concentration for one type of air pollutant, respectively. Table 3 presents the I/O ratios of particles mass and CO_2 concentrations during weekdays and weekends. Data observed at 2nd floor represents the indoor data. I/O ratios during weekdays were higher than weekends for both particles and CO_2. This can be explained by the human presence during weekdays because the I/O ratio is easily influenced by indoor sources. The mean values of I/O ratio during weekdays for PM_1, $PM_{2.5}$, PM_{10} and CO_2 were 0.7, 1.45, 4.07 and 0.85, respectively. And the mean values of I/O ratio during weekends for PM_1, $PM_{2.5}$, PM_{10} and CO_2 were 0.26, 0.31, 0.68 and 0.65, re-

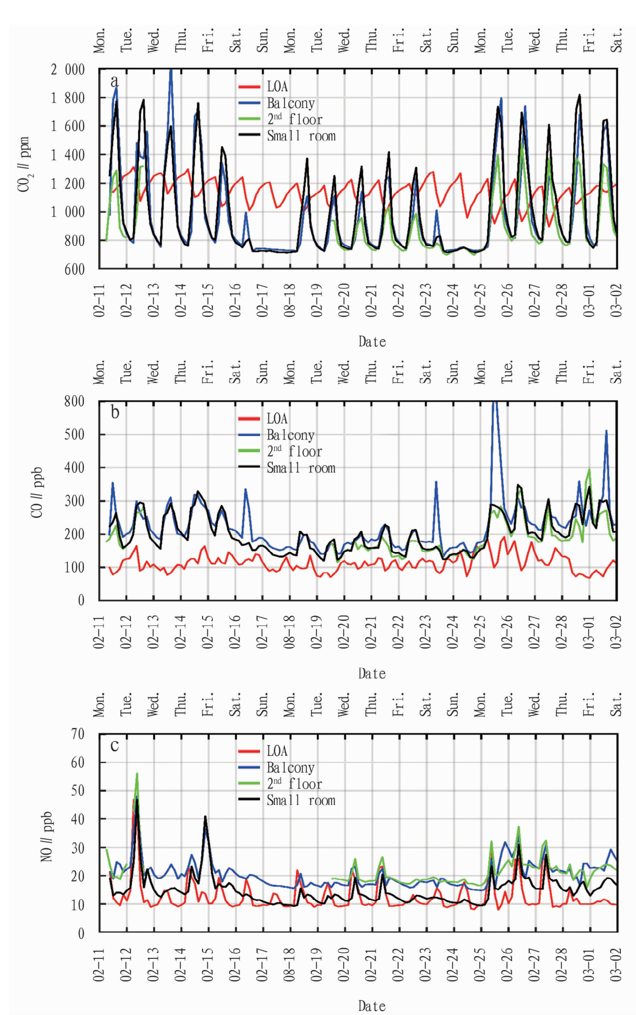


Fig. 5 Indoor and outdoor gas concentrations for CO_2 (a), CO (b) and NO (c)

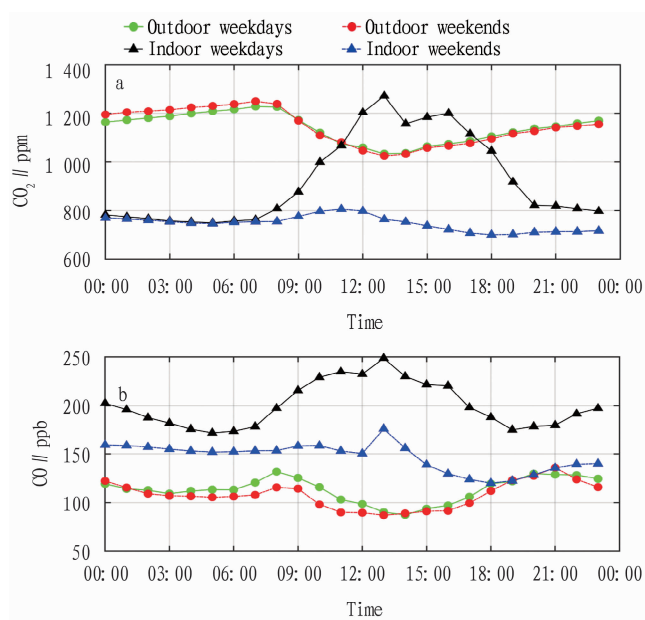
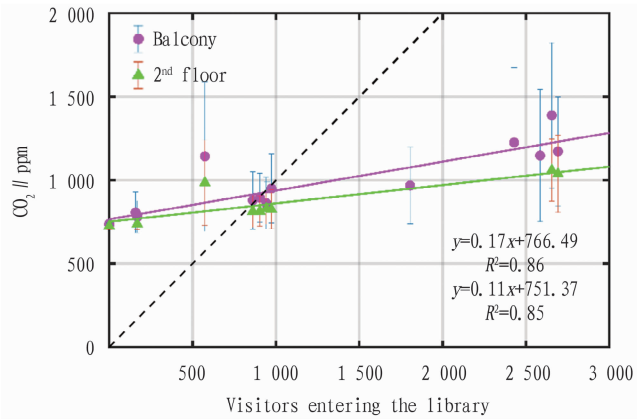


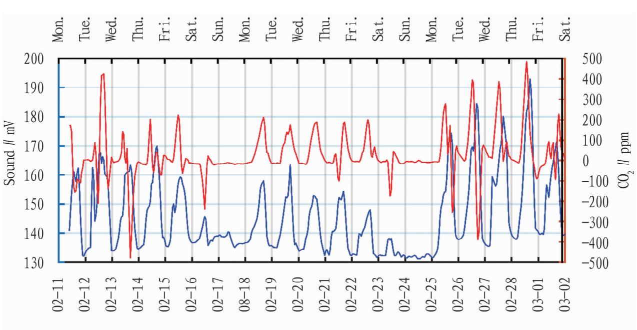
Fig. 6 Daily variations of indoor and outdoor concentrations for gases CO_2 (a) and CO (b)

spectively. The maximum I/O ratio was 37.12 for PM_{10} during weekdays, and it indicated that indoor coarse particle concentrations were associated with indoor sources such as resuspension by people.



Note: The black dash line shows the curve of $y = x$. The magenta solid circles and green solid triangles represent data in the balcony and 2nd floor of the library, respectively. The magenta solid line and green solid line show the fitting curves of data in balcony and 2nd floor of the library, respectively. Error bars represent standard deviation.

Fig. 7 Correlation analysis between indoor CO_2 daily average concentrations and the numbers of people entering the library every day from February 11 to March 2, 2019



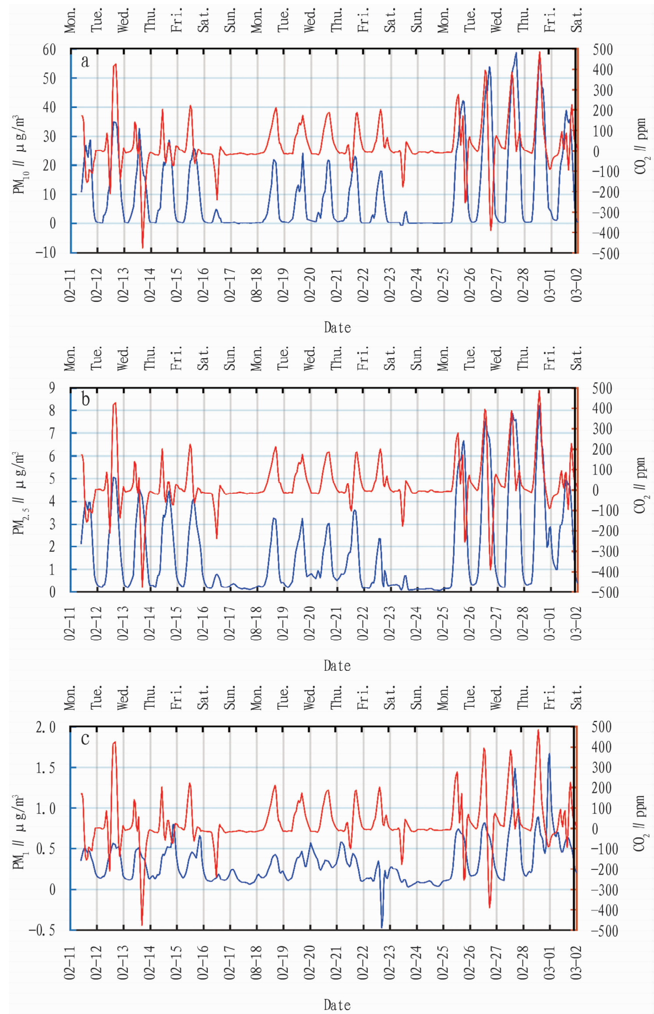
Note: Blue and red lines represent sound and CO_2, respectively.

Fig. 8 The sound in the small room and the CO_2 concentration difference between small room and balcony

Air exchange rate is the rate at which outdoor air replaces indoor air within a room. It is an essential parameter to determine the indoor air quality of any workplace. Air exchange rate to a building can be calculated as:

$$C(t) = C_{max}\exp\left(-\frac{\Delta t}{\tau}\right) + C_{min} \quad (2)$$

where $C(t)$ is the gas concentration at time t. C_{max} and C_{min} are the maximum and background gas concentrations, respectively. Δt is the hours between $C(t)$ and C_{max}. τ is the air exchange rate. These calculations need to be applied to nighttime measurements in order to avoid any influence from natural ventilation from open doors/windows and to avoid the indoor sources due to human presence. The air exchange rate of the library was calculated around 3.97 h^{-1} according to the CO_2 indoor concentration at nighttime (Fig. 10), and the value was close to the minimum air exchange rate at 4 h^{-1} of all kinds of spaces in general including attic spaces for cooling (12–15 h^{-1}), auditoriums (8–15 h^{-1}), bakeries (20 h^{-1}) and banks (4–10 h^{-1}).



Note: Blue solid line and red solid line represent particle [PM_{10} (a), $PM_{2.5}$ (b) and PM_1 (c)] and CO_2, respectively.

Fig. 9 The differences between small room and balcony measurements

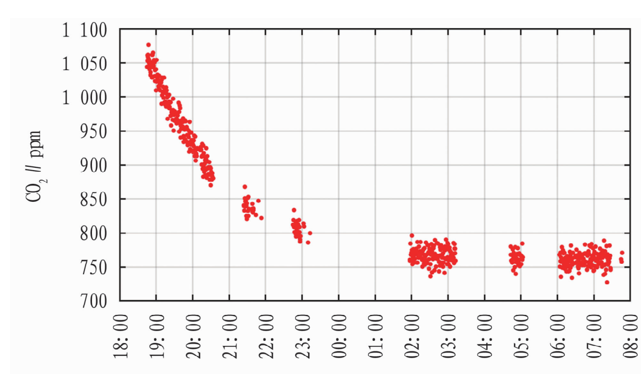


Fig. 10 CO_2 indoor concentration at nighttime during February 22–23, 2019

Table 3 I/O ratios of particles mass concentrations and CO_2 concentration during weekdays and weekends

Pollutant	Weekdays				Weekends			
	Mean	Median	Standard deviation	Range	Mean	Median	Standard deviation	Range
PM_1	0.70	0.46	0.63	0.05 – 3.17	0.26	0.21	0.18	0.06 – 0.98
$PM_{2.5}$	1.45	0.54	1.89	0.06 – 11.87	0.31	0.23	0.29	0.06 – 1.54
PM_{10}	4.07	1.70	5.91	0.01 – 37.12	0.68	0.24	1.21	0.06 – 5.98
CO_2	0.85	0.75	0.25	0.60 – 1.70	0.65	0.64	0.05	0.58 – 0.78

3 Conclusions

The present study focused on PM and gas concentrations measurements within modern library located in university campus and its comparison with outdoor measurements performed on the campus. The objective was to investigate the variability of pollutants and the exposure of library workers and students to pollutants within the library. The results suggested that indoor pollutants varied significantly due to human presence.

In general, indoor CO, NO and NO_2 concentrations were higher than outdoor both on weekdays and weekends. The behavior was slightly different for particle concentrations. The indoor $PM_{2.5}$ and PM_{10} concentration was higher than outdoor on weekdays, and the situation was reversed on weekends. Furthermore, indoor PM_1 concentration was always lower than outdoor PM_1 concentration. As expected, indoor $PM_{2.5}$ and PM_{10} concentrations on weekdays were higher than those on weekends by at least a factor of 2. Daily variations of indoor $PM_{2.5}$ and PM_{10} concentrations were similar to indoor CO_2 concentration with a maximum around 13:00 corresponding to the maximum frequency of the library. According to our results, human presence could be the main indoor source of particulate matter in the small room while the printers and other office equipment generating particles didn't present in the room during the experiment.

The present study also highlighted that the indoor CO_2 concentration was correlated to the number of people in the building. Therefore, CO_2 concentration was really convenient to infer the number of people entering a building. Moreover, using two sensors located in different rooms within the library, we also tried to estimate the number of people entering in the small room. Unfortunately, no information was available to confirm our guess. Nevertheless, the presence of people within the small room was also evidenced through the particle concentration that increased simultaneously with the CO_2. Efficient air filter devices, improved ventilation systems and more reasonable building ventilation design should be concerned to ensure indoor air quality to safeguard people health.

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