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Children's exposure to indoor air in urban nurseries - Part II: gaseous pollutants' assessment

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Abstract

This study, Part II of the larger study “Children’s exposure to indoor air in urban nurseries”, aimed to: i) evaluate nursery schools’ indoor concentrations of several air pollutants in class and lunch rooms; and ii) analyse them according to guidelines and references. Indoor continuous measurements were performed, and outdoor concentrations were obtained to determine indoor/outdoor ratios. The influence of outdoor air seemed to be determinant on carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3) indoor concentrations. The peak concentrations of formaldehyde and volatile organic compounds (VOC) registered (highest concentrations of 204 and 2320 $\mu g\ m^{-3}$ respectively), indicated the presence of specific indoor sources of these pollutants, namely materials emitting formaldehyde and products emitting VOC associated to cleaning and children’s specific activities (like paints and glues). For formaldehyde, baseline constant concentrations along the day were also found in some of the studied rooms, which enhances the importance of detailing the study of children’s short and long-term exposure to this indoor air pollutant. While CO, NO_2 and O_3 never exceeded the national and international reference values for IAQ and health protection, exceedances were found for formaldehyde and VOC. For this reason, a health risk assessment approach could be interesting for future research to assess children’s health risks of exposure to formaldehyde and to VOC concentrations in nursery schools. Changing cleaning schedules and materials emitting formaldehyde, and more efficient ventilation while using products emitting VOC, with the correct amount and distribution of fresh air, would decrease children’s exposure.

Keywords

Indoor air, nursery school, children, exposure, health risk assessment

1. Introduction

Exposure to air pollutants in indoor environments may lead to health effects, from discomfort symptoms to the prevalence of respiratory or even cardiovascular diseases and/or carcinogenic effects, mainly lung cancer and childhood leukaemia (Franklin, 2007; Jones, 1999; Lin et al., 2013). The World Health Organization (WHO) selected particulate matter (PM) and some gaseous compounds as crucial to verify Indoor Air Quality (IAQ), namely radon, carbon monoxide (CO), nitrogen dioxide (NO_2), polycyclic aromatic hydrocarbons, formaldehyde and other volatile organic compounds (VOC) as benzene, naphthalene, trichloroethylene, and tetrachloroethylene (WHO, 2010). The increasing concern about those pollutants led WHO and national governmental organizations, like the United States Environmental Protection Agency (USEPA) and Health Canada, to define guidelines and standards to protect people's health by ensuring a better IAQ.

There were found some studies on children's exposure to indoor air in nursery schools, but some of them were merely focusing on ventilation, CO_2 and/or comfort parameters, PM or even biological compounds (Branco et al., 2014; Branco et al., 2015; Carreiro-Martins et al., 2014; Fonseca et al., 2014; Gładyszewska-Fiedoruk, 2011; Madureira et al., 2015; Nunes et al., 2015; Theodosiou and Ordoumpozanis, 2008). Nevertheless, Zuraimi and Tham (2008) investigated indoor concentrations of several air pollutants, evaluating their sources in child care centres in the tropical region of Singapore. Despite the large number of child care centres and air pollutants assessed, samplings were only conducted in the middle of the week and during occupation periods, which did not allow understanding potential differences between occupation and non-occupation periods. Yoon et al. (2011) measured indoor air concentrations of several chemical compounds (including TVOC and formaldehyde) besides PM in Korean pre-schools. However, NO_2 (also considered crucial to IAQ by WHO) was not considered in that study. Roda et al. (2011) investigated IAQ of Paris child care centres to compare it with dwellings by measuring biological and chemical pollutants, besides comfort parameters. However, chemical pollutants were measured passively during an entire week (except the weekend), which did not allow to understand pollutants variations along the day. St-Jean et al. (2012) also studied IAQ in day care centres of Montréal (Canada) to determine its associations with building characteristics. Despite considering a few different chemical compounds as well as a VOC selection, passive sampling was also used for formaldehyde and VOC sampling, which did not allow understanding pollutants variations along the day, and no outdoor measurements were used to understand the outdoor influence on nursery schools' indoor air. Also in the AIRMEX study (Geiss et al., 2011), in which 23 different VOC were measured in public buildings including schools and kindergartens in eleven European cities, passive sampling was used with the duration of a full 7-days week, not allowing to understand variations along the day and between occupation and non-occupation periods.

Accordingly, following the study already reported focusing on the PM assessment (Branco et al., 2014) in the scope of INAIRCHILD project (Sousa et al., 2012), and aiming to reduce the lacks above referred, this study aims to assess children's exposure to indoor air pollution in urban nursery schools. To meet this goal, the study was divided in two parts: i) Part I – CO_2 and comfort assessment; and ii) Part II (the present study) which aimed to: i) evaluate indoor concentrations of several gaseous air pollutants in different microenvironments of urban nursery schools in Porto city; and ii) analyse those concentrations according to guidelines and references for IAQ and children's health.

2. Materials and methods

2.1. Sites description, sampling and analysis

This study was carried out in the city of Porto (Portugal) on four different nursery schools located at urban sites influenced by traffic emissions (N_URB1, N_URB2, N_URB3 and N_URB4), from March to June 2013 in N_URB1, N_URB2 and N_URB3, and in November 2013 in N_URB4. Its main characteristics (including occupation, ventilation and cleaning habits and other specific activities), indoor microenvironments considered, and sampling periods were fully described in Part I of the present study (Branco et al., 2015).

Indoor gaseous air compounds, namely CO, formaldehyde, NO_2, O_3, and total volatile organic compounds (TVOC), were continuously measured using an Haz-Scanner IEMS Indoor Environmental Monitoring Station (SKC Inc., USA), equipped with high sensitive sensors. Sampling methods and main characteristics of each sensor are summarized in Table 1. Sampling procedures, periods and duration were fully described in Part I (Branco et al., 2015).

Table 1 – Sampling methods and main characteristics of each sensor.

Sensor	Detection methods	Sensor minimum resolution	Sensor accuracy	Measurement range
CO	Electrochemical detection	< 1746 μg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-58200 μg m^{-3}
Formaldehyde	Electrochemical detection	62.5 μg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-5000 μg m^{-3}
NO_2	Electrochemical detection	41 μg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-41000 μg m^{-3}
O_3	Electrochemical detection	2.14 μg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-1070 μg m^{-3}
TVOC	Photoionization detection (PID)	230 μg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-115385 μg m^{-3}

The mean values were compared with reference standards and guidelines aiming to evaluate exceedances and/or non-compliances. Comparisons were performed considering national and international reference values for general indoor environments, namely: i) Portuguese 2006 legislation (hourly means) (*Decreto-Lei nº 79/2006*) for CO (12 500 μg m^{-3}), O_3 (200 μg m^{-3}), formaldehyde (100 μg m^{-3}), and TVOC (600 μg m^{-3}); ii) Portuguese 2013 legislation (Portaria nº 353-A/2013) for CO (10 000 μg m^{-3}), formaldehyde (100 μg m^{-3}), and TVOC (600 μg m^{-3}, plus 100% of margin of tolerance (MT) if no mechanical ventilation system was working in the room); iii) WHO guidelines (WHO, 2010) for CO (35000 μg m^{-3} for hourly mean), NO_2 (200 μg m^{-3} for hourly mean) and formaldehyde (100 μg m^{-3} for 30 minutes mean); and iv) Health Canada guidelines (HealthCanada, 2013) for NO_2 (480 μg m^{-3} for hourly mean) and formaldehyde (123 μg m^{-3} for hourly mean). For the Portuguese 2013 legislation, 8-hour running means were calculated and the daily maximum was compared with the reference value. Although Portuguese 2006 legislation was officially replaced by the new Portuguese 2013 legislation, comparisons were made with both due to the clear differences between them, which allowed concluding on the expected impacts from the application of the new one.

Simultaneously, hourly NO_2 and O_3 outdoor concentrations were obtained from the nearest air quality station, classified as urban traffic and representative of the area (CCDR-N, 2011), because only one equipment was available inhibiting simultaneous measurements outside the nursery schools. These measurements were conducted by the Air Quality Monitoring Network of Porto Metropolitan Area, managed by the Regional Commission of Coordination and Development of Northern Portugal (*Comissão de Coordenação e Desenvolvimento Regional do Norte*) under the responsibility of the Ministry of Environment. These concentrations allowed calculating the correspondent indoor/outdoor (I/O) ratios.

2.2 Statistical analysis

Data were tested for normality with both Shapiro-Wilk and Anderson-Darling tests. If normal, the differences between hourly mean concentrations in different sampling days for each microenvironment were analysed by a parametric unpaired *t*-test; in the other cases, the non-parametric Kruskal-Wallis test was used for the microenvironments where there were more than two complete sampling days, and the Wilcoxon Rank Sum Test (also called Mann-Whitney *U* test) was used for those where there were only two complete sampling days.

The one-sample parametric *t*-test was used to analyse if the differences along the day were significant for normal distributions; for other distributions, the non-parametric Wilcoxon Signed Rank Test was used.

To analyse other differences, namely between weekdays and weekends, as well as between different microenvironments and nursery schools, the parametric unpaired *t*-test or the non-parametric Wilcoxon Rank Sum Test was used, respectively when distributions were normal or not. In all cases, a significance level (α) of 0.05 was considered. Descriptive statistics was calculated using MS Excel® (Microsoft Corporation, USA), and other statistical analyses were determined using R software, version 3.1.2 (R Development Core Team, 2014).

3. Results and discussion

Table 2 summarizes the main statistical parameters (minimum, maximum, mean, median and standard deviation) of the hourly mean for each room of the four nursery schools.

When comparing two or more consecutive sampling days of the studied microenvironments, statistically significant differences were found ($p < 0.05$) in 83.3%, 50% and 75% of the cases regarding CO, NO_2 and O_3, respectively. For formaldehyde and TVOC, it was not possible to make these statistical comparisons because concentrations were usually specific in time. Despite this, a daily mean scenario in each microenvironment was assumed for the following analyses of all the studied pollutants.

Table 2 – Statistical parameters of the hourly mean data for each room studied in the four nurseries.

	Nursery	**N_URB1**				**N_URB2**				**N_URB3**			**N_URB4**		
	Room	**A**	**B**	**C**	**LR**	**A**	**B**	**C**	**LR**	**A**	**B**	**LR**	**A**	**B**	**LR**
CO ($\mu g\ m^{-3}$)	Min	913	1577	0	0	1498	1996	0	1949	1240	3077	734	0	0	0
	Max	4956	4347	2578	2879	3711	3902	2689	3211	2618	3916	2544	1972	89.9	1165
	Mean	2599	2765	463	1230	2359	2786	971	2552	1960	3477	1513	604	4.2	83
	Median	2476	2571	158	1152	2297	2723	893	2511	1984	3487	1438	669	0.00	0
	StDev	940	1043	608	531	521	520	577	333	329	224	541	444	15.7	221
Formaldehyde ($\mu g\ m^{-3}$)	Min	0	0	0	0	0	0	0	0	0	0	0	0	12	0
	Max	146	0	0	9	0	0	204	0	2	0	6	50	87	77
	Mean	2	-	-	0	-	-	8	-	0	-	0	35	35	2
	Median	0	-	-	0	-	-	0	-	0	-	0	38	35	0
	StDev	12	-	-	1	-	-	33	-	0	-	1	9	18	11
NO_2 ($\mu g\ m^{-3}$)	Min	0	-	1	0	87	49	36	57	80	109	114	-	-	-
	Max	57	-	75	84	148	131	171	142	138	189	155	-	-	-
	Mean	6	-	40	22	121	73	62	93	113	136	138	-	-	-
	Median	0	-	41	18	124	72	58	90	115	133	140	-	-	-
	StDev	13	-	19	21	15	15	16	22	13	20	9	-	-	-
O_3 ($\mu g\ m^{-3}$)	Min	0	15	2	4	1	8	1	9	9	10	17	7	5	12
	Max	20	32	53	49	23	39	28	61	48	25	57	27	13	32
	Mean	13	24	18	23	13	17	20	26	18	16	38	9	10	19
	Median	15	23	14	22	12	15	20	20	16	15	40	8	10	18
	StDev	5	5	10	9	3	7	4	14	7	4	7	3	2	5
TVOC ($\mu g\ m^{-3}$)	Min	0	0	0	0	0	52	0	0	0	0	0	0	0	0
	Max	354	54	373	132	202	276	2320	197	307	20	388	0	0	12
	Mean	17	3	8	8	92	141	104	8	5	2	12	-	-	0
	Median	0.00	0	0	0	90	115	0	0	0	0	0	-	-	0
	StDev	59	10	42	27	54	62	310	36	31	6	58	-	-	1

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room

3.1 TVOC and formaldehyde

TVOC mean concentrations from the studied class and lunch rooms in N_URB1, N_URB2 and N_URB3 are represented in Figure 1 a), b) and c), respectively. N_URB4 is not represented in Figure 1 because concentrations were zero or very close to zero (maximum concentration observed equal to 4 µg m^{-3}) (Table 2).

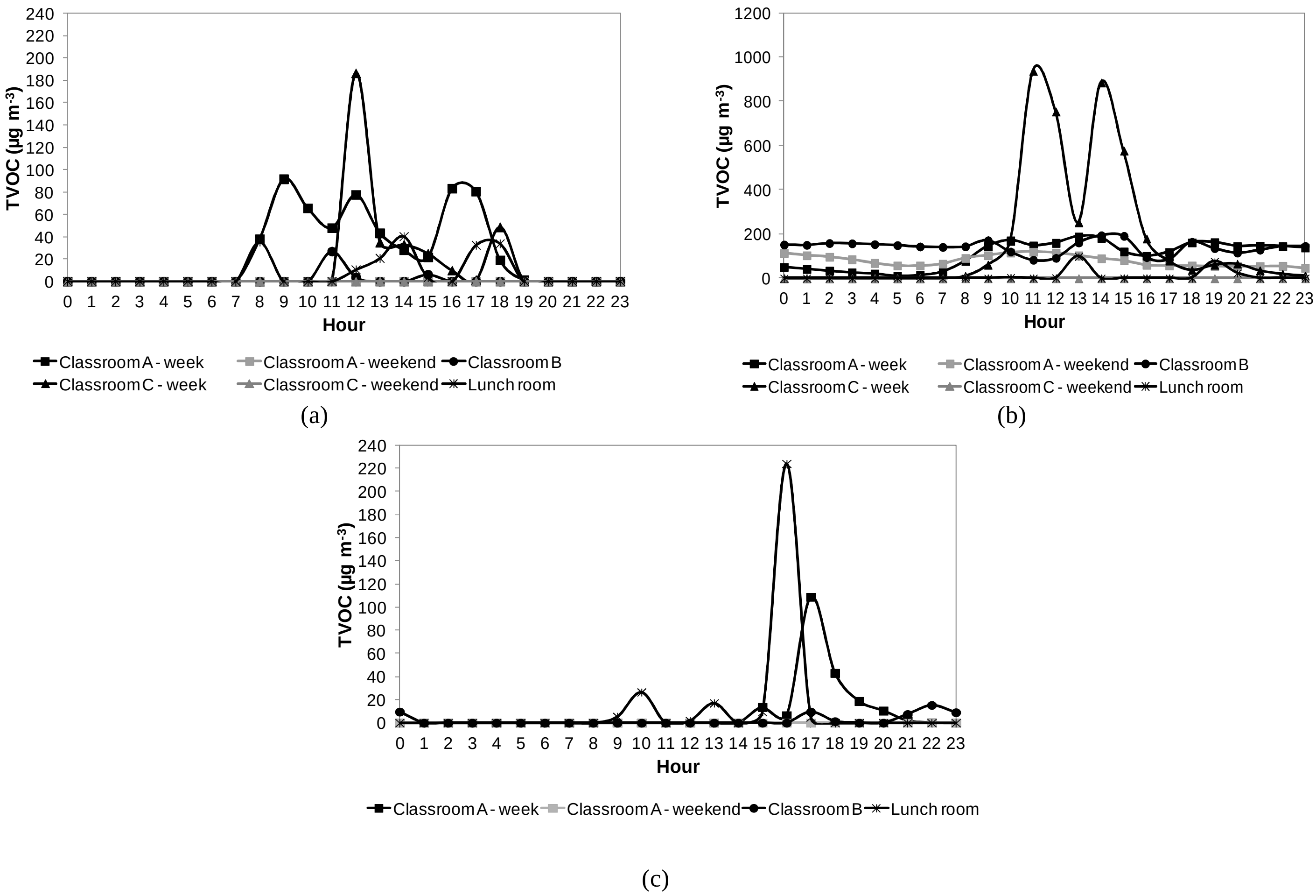


Figure 1 - Daily profile of TVOC mean concentrations registered indoors of a) N_URB1, b) N_URB2, and c) N_URB3.

Although different concentrations and daily profiles were observed, it is clear that the presence of TVOC occurred mainly during occupation periods, which seemed to be result of typical children activities associated with the use of paints and glues. The concentrations measured while the nursery schools were closed (night and weekend) were very close to zero, with exception of classrooms A (both on weekdays and weekend), B and C (on weekdays) of nursery school N_URB2 (Table 2) in which it seemed to exist a continuous source of VOC. Additionally, peak concentrations were observed in the beginning of the morning, during or immediately after lunch time and in the afternoon. These TVOC concentrations in the indoor air immediately before and/or after the occupation periods in the classrooms were associated with the cleaning activities using products that emitted VOC.

Figure 2 shows the formaldehyde mean concentrations for a) classroom A (weekdays) and lunch room of N_URB1, classroom C (weekdays) of N_URB2 and classroom A (weekdays) and lunch room of N_URB3, and b) N_URB4. The formaldehyde concentrations for the remaining studied rooms are not represented because concentrations were close to zero (Table 2) in all those cases, except for weekend on classroom A of N_URB4 which was due to instrument error. No daily profile was found for formaldehyde concentrations on the different studied rooms. The highest concentrations were observed in classroom C of N_URB2 during weekdays, where there was a peak in the morning (after the opening hour), which decreased through the morning until the period after lunch and a second peak (lower) was found about 5 p.m.. These peaks matched the periods of entrance and exit from the classroom. In the other rooms represented in Figure 2 a) concentrations were close to zero. Regarding N_URB4, in the lunch room, concentrations were close to zero, except at the beginning of the morning, during and after lunch, also periods of entrance and exit. Indoor formaldehyde concentrations seemed to indicate the presence of specific indoor sources for this pollutant, namely the use of materials emitting formaldehyde (mainly furniture). The higher concentrations during occupation periods, characterized by some peaks, seemed to be mainly related to entrance and/or exit periods, associated with moving the furniture (tables and chairs).

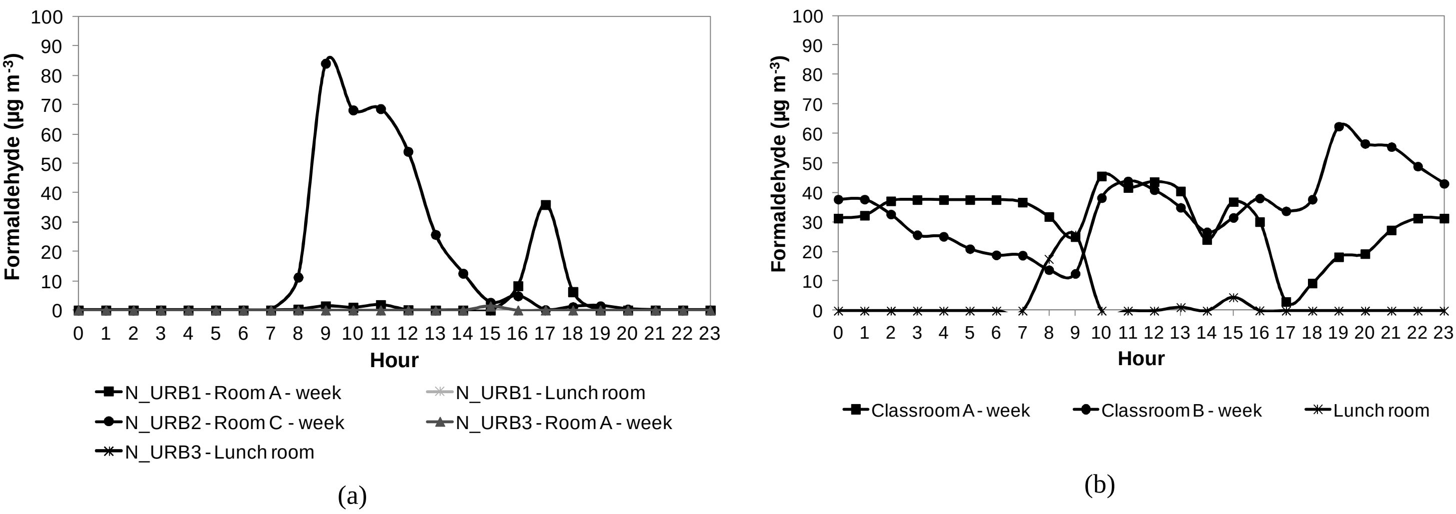


Figure 2 – Daily profile of formaldehyde mean concentrations registered indoors in a) classroom A (weekdays) and lunch room of N_URB1, classroom C (weekdays) of N_URB2, classroom A (weekdays) and lunch room of N_URB3; and b) N_URB4.

Table 3 – Exceedances (%) to WHO guidelines and Portuguese legislation (2006 and 2013) reference values of formaldehyde and TVOC measured on weekdays and only during occupation periods.

Nursery	Room	Weekdays					During occupation		
		Portuguese 2006 legislation		WHO	Portuguese 2013 legislation		Portuguese 2006 legislation		WHO
		Formaldehyde[a]	TVOC[b]	Formaldehyde[c]	Formaldehyde[d]	TVOC[e]	Formaldehyde[a]	TVOC[b]	Formaldehyde[c]
N_URB1	A	1	0	1	0	0	2	0	2
	B	0	0	15	0	0	0	0	22
	C	0	0	0	0	0	0	0	0
	LR	0	0	0	0	0	0	0	0
N_URB2	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	C	6	11	6	33	33	18	29	17
	LR	0	0	0	0	0	0	0	0
N_URB3	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	LR	0	0	0	0	0	0	0	0
N_URB4	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	LR	0	0	1	0	0	0	0	0

a) % of the hourly mean concentrations above the reference value of 100 µg m^{-3}; b) % of the hourly mean concentrations above the reference value of 600 µg m^{-3}; c) % of the 30-min mean concentrations above the reference value of 100 µg m^{-3}; d) % of 8-hour running mean concentrations above the reference value of 100 µg m^{-3} ; e) % of 8-hour running mean concentrations above the reference value of 600 µg m^{-3}.

Table 3 shows the number of non-compliances and exceedances (%) to the standards and guidelines referred in section 2.2. The values presented on the table are the percentage (%) of the measured hourly means which were above the Portuguese 2006 reference values, the percentage (%) of the 30-min means which were above the WHO reference value (only for formaldehyde), and the percentage (%) of the daily maximum 8-hour running means which were above the Portuguese 2013 reference values.

In few situations the recommended standard and guideline values for formaldehyde and TVOC were exceeded. In the case of formaldehyde, the exceedances were mainly found during occupation periods and mainly for the WHO reference value (WHO, 2010). A health risk assessment approach could be important to assess the children's health risks of short-term exposure to those high concentrations, and to confirm if they are expected to cause mild or moderate eye irritation.

Formaldehyde concentrations in N_URB4 were similar to those registered by Yoon et al. (2011) in Korean urban pre-schools (45.27 $\mu g\ m^{-3}$), but far from those registered in Korean kindergartens (162.69 $\mu g\ m^{-3}$) (Yang et al., 2009). Both of those studies found much higher TVOC concentrations (591.2 $\mu g\ m^{-3}$ and 642.11 $\mu g\ m^{-3}$ respectively), and both also concluded that those problems in indoor air were caused by emissions from building materials and furnishing, worsened by insufficient ventilation as concluded in Part I (Branco et al., 2015). Formaldehyde concentrations found in classroom C of N_URB2 and in N_URB4 were often found higher than those reported by Roda et al. (2011), both in hot and cold season (10.7 and 14.8 $\mu g\ m^{-3}$, respectively), and higher than those reported by St-Jean et al. (2012) (22.9 $\mu g\ m^{-3}$). The selection of classroom materials to use in nursery schools' indoor environments should be performed with extreme caution by choosing formaldehyde-free materials to safeguard children's health. Moreover, better ventilation (amount of fresh air and its distribution) could help to reduce indoor formaldehyde and TVOC concentrations. It is important to notice that the analysis performed in the present study were made for TVOC, but further investigations in specific VOC are needed, as made in previous studies (Pegas et al., 2012; Roda et al., 2011; St-Jean et al., 2012) which reported considerable indoor concentrations in nursery and primary schools. That will allow comparing the results to better understand sources and pathways of children's exposure to specific VOC inside nursery schools.

3.2 CO, NO2 and O3

Figure 3 shows the CO mean concentrations in all the studied rooms of the four nursery schools ((a) N_URB1, (b) N_URB2, (c) N_URB3, and (d) N_URB4). It is possible to distinguish a similarity in the daily profile, especially during weekdays, in all the studied rooms – an increase in CO concentrations in the early morning and a decrease starting at the evening. During weekend, CO concentrations seemed to have an almost constant profile along the day. In general, CO concentrations were significantly lower ($p < 0.05$) in N_URB4 than in the other three nursery schools. The highest concentrations were found on weekdays in classrooms A and B of N_URB1 (respectively 4956 and 4347 $\mu g\ m^{-3}$) and the lowest were found in classroom B of N_URB4 (close to zero) (Table 3). In N_URB2, CO concentrations in classroom C were significantly lower ($p < 0.05$) than in the remaining rooms of that nursery school. In N_URB3, CO concentrations in classroom B were significantly higher ($p < 0.05$) than in the other rooms of that nursery school. As there were not found any indoor sources, outdoor CO concentrations were expected to be the main determinant of the indoor concentrations registered.

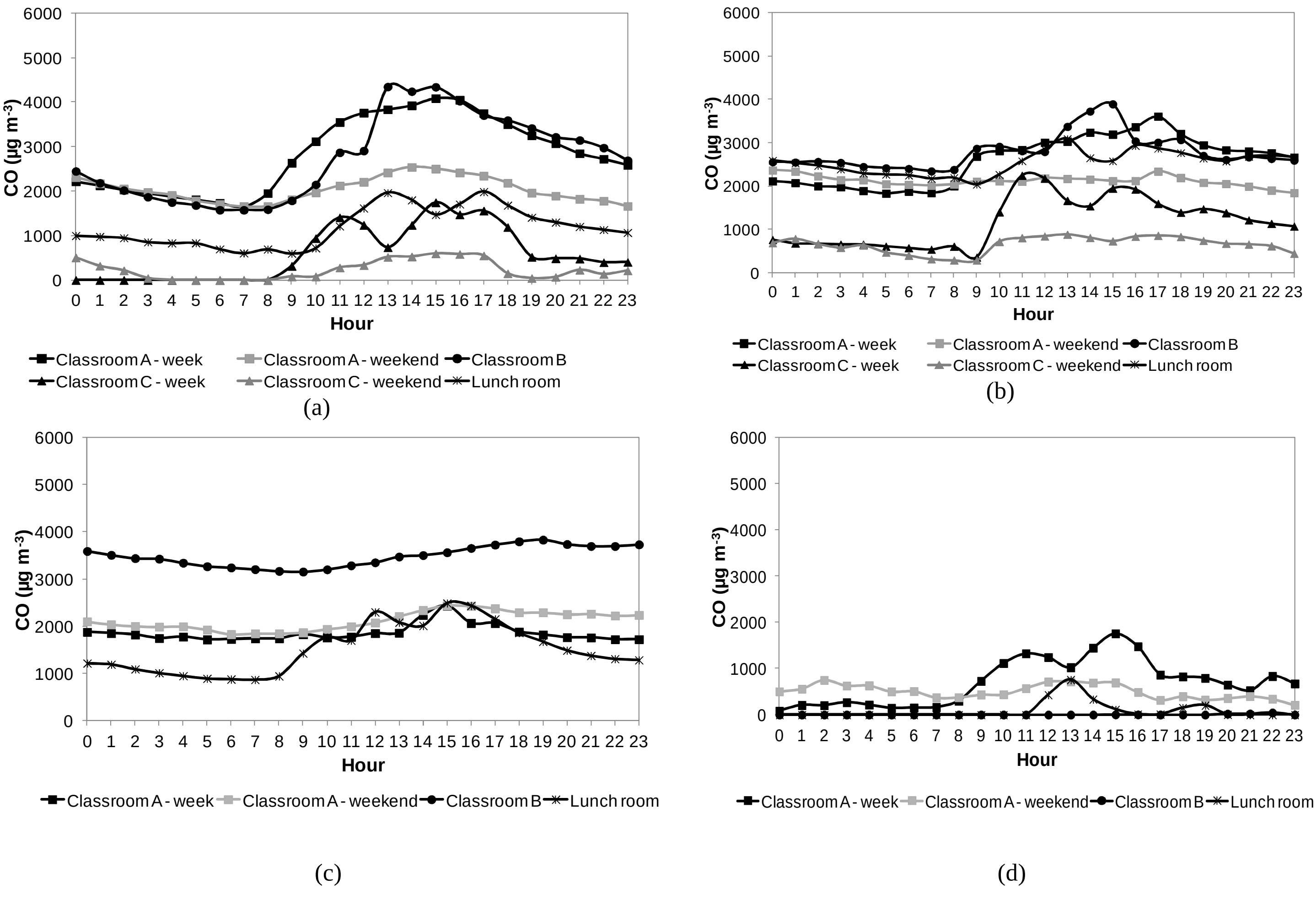
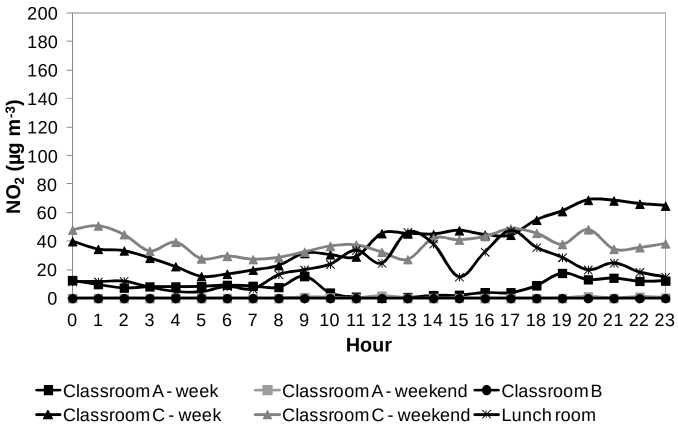
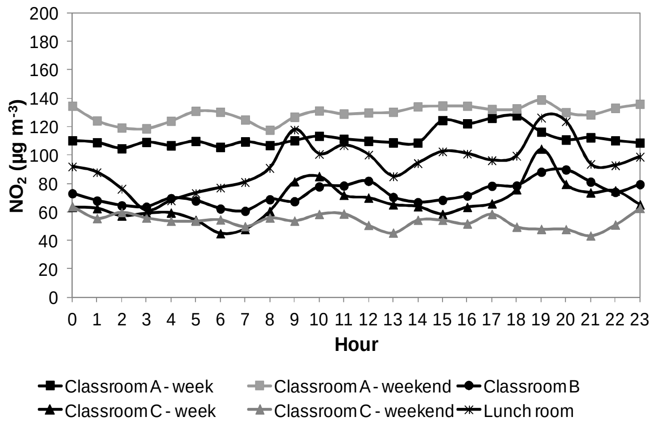


Figure 3 – Daily profile of CO mean concentrations registered indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

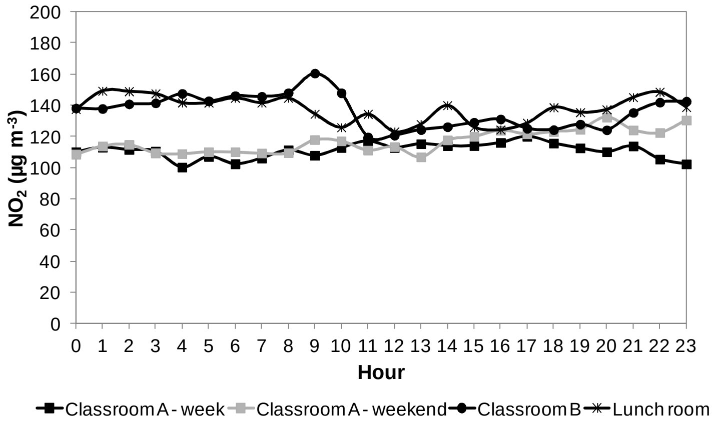
NO_2 mean concentrations registered in N_URB1, N_URB2 and N_URB3 are represented in Figure 4 a), b) and c), respectively. NO_2 mean concentrations in N_URB4 and in classroom B of N_URB1 are not represented due to instrument error. The lowest concentrations were found in N_URB1 and the highest in N_URB3 (Table 2). In fact, in classrooms A (both weekend and weekdays) and B of N_URB1 concentrations were always very close to zero. Although with significant differences amongst them (p = 0.06), classrooms of N_URB2 (weekdays), as well as the studied rooms of N_URB3, showed higher values and significantly different profiles ($p < 0.05$) than those observed in N_URB1. All of these three buildings were located in a busy traffic street (N_URB1 and N_URB2 were located in the same street), but N_URB2 and N_URB3 had a road junction with traffic lights next to the front façade of the building, which could indicate higher NO_2 emissions from the vehicles exhaust and consequently higher concentrations of this compound entering into the building. In classroom A of N_URB2, both in weekdays and weekend, there were found significantly higher values ($p < 0.05$) than in the rest of that building, probably due to the location of this classroom (in the ground floor and with windows in the front façade of the building). In the weekend at some classrooms, indoor NO_2 concentrations were higher than in weekdays because as there was no ventilation during the weekend, the high concentrations observed in Friday did not decrease maintaining a high and almost constant daily profile during the whole weekend.



(a)



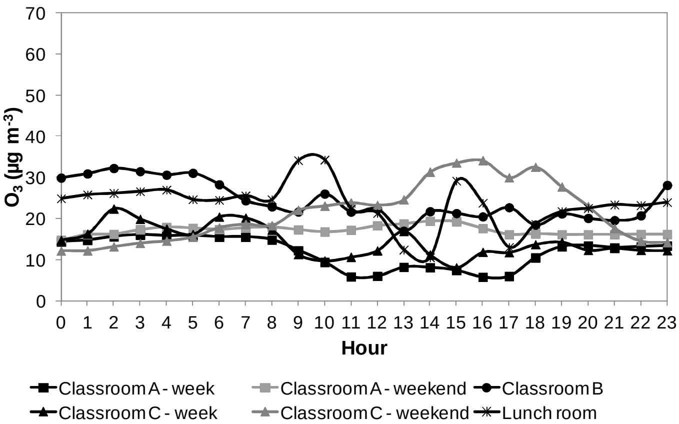
(b)



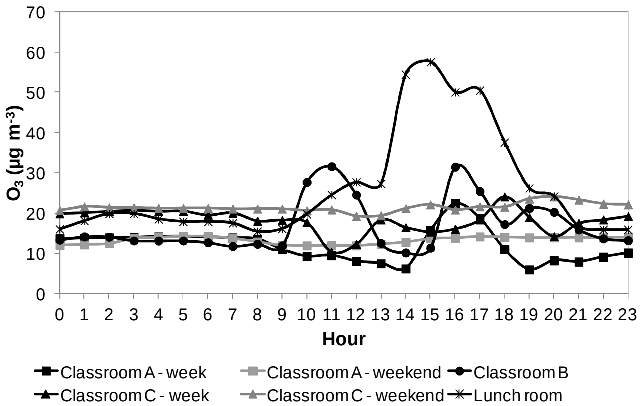
(c)

Figure 4 – Daily profile of NO_2 mean concentrations registered indoors of a) N_URB1, b) N_URB2, and c) N_URB3.

Figure 5 a), b) c) and d) shows the O_3 mean concentrations determined in the studied rooms of N_URB1, N_URB2, N_URB3 and N_URB4, respectively. It is possible to observe O_3 concentrations with a similar order of magnitude among the different studied rooms in the four nursery schools, and with no relevant variations along the day in all the studied classrooms. The highest values were often found in the lunch rooms (Table 2) during or immediately after lunch time, which in the absence of indoor sources might be associated with higher ventilation to outdoors during daytime. The accumulation in those indoor microenvironments led to the O_3 highest concentrations during the night and dawn found in the lunch rooms of N_URB3 and N_URB4. In N_URB4, no relevant variations in O_3 concentrations were found in the classrooms. As there are no indoor sources, O_3 concentrations indoors seemed to be associated with outdoor concentrations.



(a)



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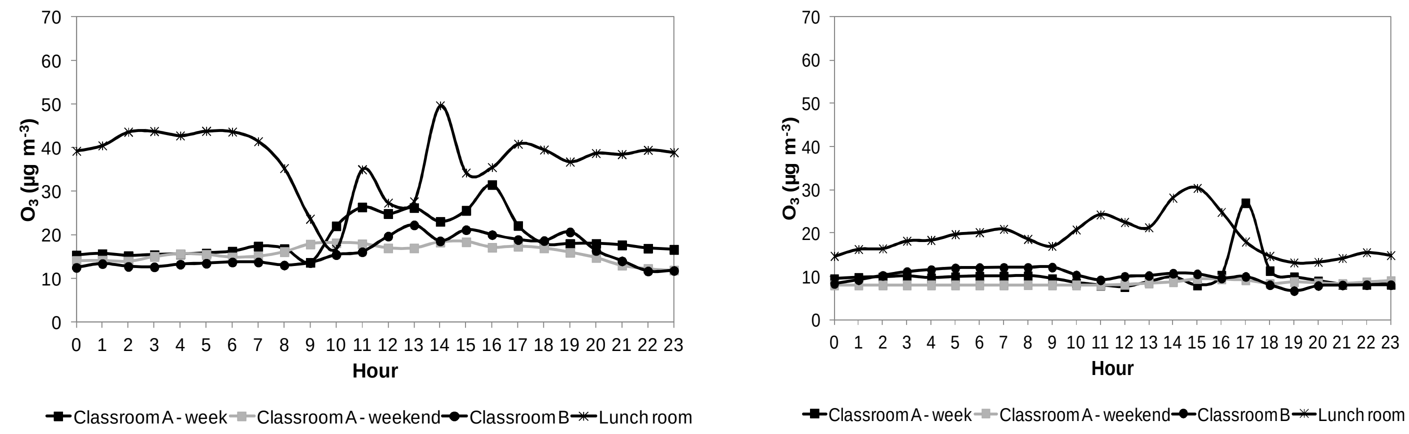
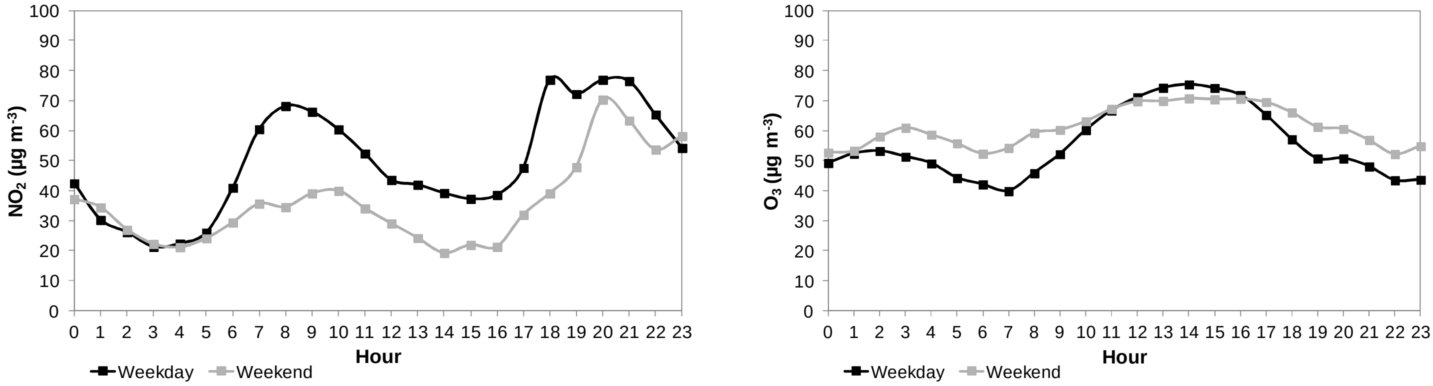


(c) (d)

Figure 5 – Daily profile of O_3 mean concentrations registered indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

The outdoor mean concentrations of NO_2 and O_3 allowed obtaining a mean daily profile, represented in Figure 6 a) and b) respectively. In both NO_2 and O_3 profiles a similar pattern was found between weekdays and weekend with NO_2 concentrations usually higher on weekdays and with O_3 concentrations usually higher on weekend. Daily variations in NO_2 concentrations boiled down to two significant peaks – one in the morning and another at the end of the afternoon, matching the two traffic rush periods, as expected for urban areas (Wichmann et al., 2010). From the O_3 outdoor profiles, it is possible to observe the highest concentrations along the afternoon, as expected (Sousa et al., 2009). These profiles were generally similar to those typically found indoors, thus outdoor air seemed to be the main contributor to those concentrations found indoors.



(a) (b)

Figure 6 – Daily profile of outdoors mean concentrations for a) NO_2 and b) O_3.

Table 4 – I/O ratios for NO_2 and O_3: median values observed in each studied site for weekdays and weekends, and respective minima (min) and maxima (max) values.

Nursery	Room	NO_2		O_3	
		Weekday	Weekend	Weekday	Weekend
N_URB1	A	0.02 (min-max: 0.00-2-26)	0.00 (min-max: 0.00-0.23)	0.16 (min-max: 0.00-1.15)	0.19 (min-max: 0.16-0.22)
	B	0.00 (min-max: 0.00-0.00)	-	0.33 (min-max: 0.21-0.50)	-
	C	1.88 (min-max: 0.50-4.41)	1.50 (min-max: 0.42-4.88)	0.24 (min-max: 0.03-6.11)	0.22 (min-max: 0.14-0.62)
	LR	0.41 (min-max: 0.00-3.43)	-	0.31 (min-max: 0.05-1-78)	-
N_URB2	A	3.80 (min-max: 1.18-7.88)	6.19 (min-max: 1.63-13.73)	0.25 (min-max: 0.06-0.99)	0.20 (min-max: 0.16-0.50)
	B	2.94 (min-max: 0.93-7.67)	-	0.30 (min-max: 0.10-1.70)	-
	C	2.33 (min-max: 0.36-5.11)	2.42 (min-max: 0.71-4.68)	0.28 (min-max: 0.01-1.07)	0.27 (min-max: 0.18-0.65)
	LR	1.98 (min-max: 0.79-4.20)	-	0.42 (min-max: 0.11-2.49)	-
N_URB3	A	4.20 (min-max: 1.46-15.93)	4.08 (min-max: 1.25-9.77)	0.33 (min-max: 0.17-1.08)	0.30 (min-max: 0.17-3-97)
	B	2.70 (min-max: 1.07-5.65)	-	0.22 (min-max: 0.14-1-07)	-
	LR	6.79 (min-max: 2.99-17.49)	-	0.57 (min-max: 0.26-1.07)	-
N_URB4	A	-	-	0.15 (min-max: 0.13-0.64)	0.19 (min-max: 0.12-0.53)
	B	-	-	0.79 (min-max: 0.12-8.03)	-
	LR	-	-	2.53 (min-max: 0.30-19.88)	-

Indoor concentrations were compared with those obtained outdoors using the I/O ratio. Outdoor concentrations were obtained from an air quality station instead of measured simultaneously outside each nursery school. Although the air quality station was representative of the study area (CCDR-N, 2011), this might be a study limitation and results should be interpreted with care. Table 4 shows mean I/O ratios (and minima and maxima) for NO_2 and O_3 in each studied room. In N_URB1, NO_2 I/O ratios were usually below 1, showing indoor concentrations lower than outdoors, with the exception of classroom C, both in weekdays and weekend, although there were ratios below 1 in these cases. In the case of N_URB2 I/O median ratios were often above 1, and in N_URB3 all the I/O ratios were also above 1, which might be due to the steep decrease of outdoor concentrations which were not followed by the same decrease indoors. As indoor concentrations of NO_2 in N_URB4 were usually zero, I/O ratios were not represented. O_3 I/O ratios in N_URB1, N_URB2 and N_URB3 were usually below 1 both during weekdays and weekend. In N_URB4, the same was found in classroom A and B, but different results were found in the lunch room (2.53), which might be also due to the steep decrease of outdoor concentrations which were not followed by the same decrease indoors as referred for NO_2.

Table 3 shows the exceedances (%) to the standards and guidelines referred in the section 2.2. When there were more than one standard or guideline for the same pollutant, like in the case of CO and NO_2, Table 4 reports the most restrictive one (Portuguese 2006 legislation for CO and WHO guideline for NO_2). Although influenced by outdoor concentrations, the indoor O_3, CO and NO_2 concentrations did not exceed the standards and guidelines used for comparison referred in section 2.2. Zuraimi and Tham (2008) found much higher O_3 concentrations (62.65 $\mu g\ m^{-3}$), mainly determined by outdoor concentrations, shelf area and table cleaning, but CO concentrations observed in classrooms A and B of N_URB1, classrooms A, B and lunch room of N_URB2 and in N_URB3 were higher than those found in that study (1266.38 $\mu g\ m^{-3}$ only determined by outdoor air). On the opposite, lower CO concentrations were found by Yang et al. (2009) (524.42 $\mu g\ m^{-3}$) and by Yoon et al. (2011) (812.89 $\mu g\ m^{-3}$). Roda et al. (2011) registered indoor NO_2 concentrations comparable to those found in N_URB1 but much lower than those detected in N_URB2 and N_URB3, ranging between 9.0 and 41.0 $\mu g\ m^{-3}$, which were determined by outdoor air influence in the absence of indoor sources, mainly due to the proximity to roadways with heavy traffic and by the fact that most of nursery schools' classrooms were located on the ground floor. There were not found exceedances to the Portuguese 2006 and 2013 standards for CO, O_3 or NO_2, which indicates that the registered concentrations of those pollutants are not expected to cause health effects on children attending these nursery schools. As expected, it is possible to observe from the results that the new Portuguese legislation is less restrictive. Exceedances to Portuguese 2006 standards were always higher during occupation periods than on weekdays in general. Moreover, it is also important to refer that the results here presented were similar to those obtained in Portuguese primary schools by Pegas et al. (2012) for NO_2 and VOC. School activity and indoor sources were also identified as increasing loadings of air pollutants in those primary schools, being inadequate ventilation, specific indoor sources (especially for VOC) and outdoor influence (NO_2) the main determinants of IAQ.

4. Conclusions

This study allowed a better understanding of the behaviour of several indoor air pollutants in the studied nursery schools, with and without occupation. The influence of outdoor air seemed to be determinant on O_3, CO and NO_2 indoor concentrations, and the observed formaldehyde and TVOC peak concentrations indicated the presence of specific indoor sources for these pollutants, namely materials emitting formaldehyde (mainly furnishing) and products emitting VOC associated to cleaning and children's specific activities (like paints and glues). For formaldehyde, baseline constant concentrations along the day were also found in some of the studied rooms, which enhances the importance of detailing the study of short and long-term children's exposure to this indoor air pollutant.

While CO, NO_2 and O_3 never exceeded the national and international reference values for IAQ and health protection, exceedances were found for formaldehyde and TVOC. For this reason, a health risk assessment approach could be interesting for future research to assess the children's health risks of short-term exposure to formaldehyde and to VOC concentrations.

Thus, improving IAQ is needed in the studied nursery schools. Besides the measures proposed in Part I of this study, others like changing cleaning activities schedule (after the occupation period), changing materials emitting formaldehyde and better ventilation while using products emitting VOC (amount of fresh air and its distribution), could also be applied to reach the same goal. It is important to take into consideration when applying these changes the conclusions reported by Branco et al. (2014) concerning the concentrations of PM in the rooms. The study of individual VOC should be done to better understand IAQ inside these nursery schools. These recommendations can also be applied in a broader perspective, as the problems found in these nursery schools are similar to others being reported in other nursery and even in primary schools. Additionally, it could be also important to study other nursery schools to help supporting these findings, not only considering urban traffic influence, but also including suburban and rural contexts for comparison.

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