Environmental Research 142 (2015) 662–670

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Children's exposure to indoor air in urban nurseries – Part II: Gaseous pollutants' assessment

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ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form
24 August 2015
Accepted 25 August 2015

Keywords:
Indoor air
Nursery school
Children
Exposure
Health risk assessment

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.

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, 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

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http://dx.doi.org/10.1016/j.envres.2015.08.026
0013-9351/

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 Montreal (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 summarised in Table 1. Sampling procedures, periods and duration were fully described in Part I (Branco et al., 2015).

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 n° 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 n° 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 min 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-h 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).

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}