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Gaseous pollutants on rural and urban nursery schools in Northern Portugal

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Abstract

Indoor air quality in nursery schools is different from other schools and this has been largely ignored, particularly in rural areas. Urban and rural nursery schools have different environmental characteristics whose knowledge needs improvement. Thus, this study aimed to evaluate continuously the concentrations of CO_2, CO, NO_2, O_3, CH_2O and total VOC in three rural nursery schools and one urban, being the only one comparing urban and rural nurseries with continuous measurements, thus considering occupation and non-occupation periods. Regarding CO_2, urban nursery recorded higher concentrations (739-2328 mg m^{-3}) than rural nurseries (653-1078 mg m^{-3}). The influence of outdoor air was the main source of CO, NO_2 and O_3 indoor concentrations. CO and NO_2 concentrations were higher in the urban nursery and O_3 concentrations were higher in rural ones. CH_2O and TVOC concentrations seemed to be related to internal sources, such as furniture and flooring finishing and cleaning products.

Capsule: Gaseous pollutant levels were higher in the urban nursery than in rural ones, except for O_3. High concentrations were due to lack of ventilation, outdoor air and internal sources.

Keywords

Indoor air, nursery, children, rural, urban, gaseous

1. Introduction

In recent years, numerous scientific studies highlighted that citizens spend most of their time in indoor environments (Jenkins et al., 1992; Silvers et al., 1994; Klepeis et al., 2001; Schweizer et al., 2007; de Gennaro et al., 2014; Wu et al., 2015). The largest part of human exposure to air pollution occurs in indoor environments, commonly considered non-polluted such as homes, offices and schools (WHO 2006; de Gennaro et al., 2014; Branco et al., 2014). Nevertheless, it is actually known that indoor air pollution has equal or even greater impact on human health than outdoor pollution. This occurs because time spent indoor is usually higher than time spent outdoor; also, there is a great variety of indoor sources, that include outdoor and specific indoor sources associated with formaldehyde and volatile organic compounds (VOC) emissions, leading frequently to higher concentration than outdoor (Franklin 2007; Faustman et al. 2000; Sofuoglu et al. 2011). Furthermore, children are more vulnerable to air pollution exposure than adults, being considered a risk group (Sousa et al., 2012). Exposure to indoor air pollution has been related to long and short-term health problems. Respiratory, cardiovascular and central nervous systems are the most affected, leading also to adverse effects on children's productivity and academic performance (Jones 1999; Wang et al., 2015; Annesi-Maesano et al., 2013, Mohai et al., 2011).

Indoor pollutant sources are related to structural conditions of buildings (interior finishes, coverings and furniture), occupants' activities (heating, cooling and cooking habits, metabolism, hygiene, cleaning and disinfection products) and outdoor pollution (Jones, 1999). The control and analysis of indoor air quality (IAQ) assume an extremely important role because indoor pollutants' concentrations may vary significantly with location and time (de Gennaro et al., 2014). Studies of IAQ in schools have been performed mainly in primary or secondary schools. Nevertheless, IAQ in nursery schools is different from other schools and this has been largely ignored, particularly in rural areas (Ashmore and Dimitroulopoulu, 2009). IAQ studies comparing urban and rural contexts are relevant because there are evident environmental and social differences. On the environmental level this idea is supported essentially by the influence of traffic emissions. On the social level, habits and life styles in these two contexts are significantly different. Studies already made in nursery schools were essentially of three types: i) only focusing on comfort parameters (Gladyszewska-Fiedoruk 2013), and/or on CO_2 concentration as global IAQ indicator (Theodosiou and Ordoumpozanis, 2008; Carreiro-Martins, 2014); or ii) focusing on the study of one specific pollutant such as PM, allergens or phthalates (Arbes, et al., 2005; Fromme, et al., 2013). As far as known there are only five studies focussing on various gaseous pollutants in nursery schools' indoor air, from which one was in rural areas. Zuraimi and Tham (2008) investigated comfort parameters, air velocity and air exchange rates, as well as concentrations of several pollutants in nursery schools of Singapore, concluding that outdoor concentrations and occupant density were the main determinants for CO_2 concentrations. For indoor CO and O_3 levels, outdoor concentrations were the main precursors. Yang et al. (2008) characterized the concentrations of different indoor air pollutants in Korean nursery schools and compared them according to age and characteristics of buildings. The main problems reported in that study were caused by chemicals emitted from building materials or furnishing, and insufficient ventilation rates. Yoon et al. (2011) measured IAQ in rural and urban preschools in Korea, by investigating the indoor air concentrations of PM and several chemical compounds, and they found evidences that pollutant concentrations were in general higher in urban context and indoors than in rural context and outdoors. However, indoor/outdoor (I/O) ratios of CH_2O, CO and total volatile organic compounds (TVOC) were higher in rural schools.

Cano et al. (2012) studied IAQ in nursery schools in Lisbon and Porto (Portugal) considering various chemical pollutants, comfort parameters and microbiological parameters. The results of that study demonstrated an association between CO_2 concentrations and the number of children present in classrooms, as well as the need to improve ventilation and comfort of the spaces to promote healthier indoor environments.

Despite considering a large number of nursery schools, gaseous compounds, comfort parameters and comparisons between rural and urban nursery schools, in the above mentioned studies, samplings were only conducted during weekdays and during occupation periods. That did not allow understanding differences in IAQ between occupation and non-occupation periods (including nights and weekends), which permit to better understand sources of indoor air pollution, as well as the baseline room scenario. Additionally, some chemical compounds were measured by passive sampling and not continuously. Moreover, some important compounds were missing as for example NO_2, which is an important traffic marker.

Following Nunes et al. (2015) study that focused on the PM assessment, and in the scope of INAIRCHILD project (Sousa et al., 2012), the present study is the only one comparing urban and rural nurseries with continuous measurements considering the comparison of occupation and non-occupation periods, thus aiming to reduce the above referred gaps. Therefore, the continuous evaluation of the indoor concentrations of CO_2, CO, ozone (O_3), NO_2, TVOC and formaldehyde (CH_2O) on different indoor microenvironments, namely classrooms and lunch rooms was performed. Furthermore, gaseous concentrations were compared with Portuguese legislation and WHO guidelines for IAQ and children’s health.

2. Materials and methods

IAQ measurements were made in three different rural nursery schools (RUR1, RUR2 and RUR3) located in *Bragança* district and without significant influence of traffic emissions and in one urban nursery (URB) located in *Porto* and influenced by traffic emissions.

Table 1 shows a general description of each studied microenvironment of RUR1, RUR2, RUR3 and URB, namely regarding the type of use, children's age, building floor, area, number of occupants, period of occupation, ventilation routines and sampling time.

Measurements were performed in two classrooms in RUR1 and RUR3, one classroom in RUR2, and three classrooms in URB, as well as in the lunch rooms of all nursery schools. Indoor air gaseous compounds, namely CO_2, CO, NO_2, O_3, CH_2O and TVOC, were continuously measured (at least 24 h in each ME) using an Haz-Scanner IEMS Indoor Environmental Monitoring Station (SKC Inc., USA), equipped with high sensitive sensors using the following methods: i) CO_2 – nondispersive infrared (NDIR) detection; ii) CO, O_3, NO_2 and CH_2O – electrochemical detection; iii) VOC – photoionization detection (PID). All concentrations were converted from ppb and ppm (units from data log), to ease the comparisons with legislation and guidelines using conversion factors (Nota Técnica NT-SCE-02 2009; Tiwary and Colls, 2010). These conversion factors are normalized to 293 K and 101.3 kPa, therefore concentrations were corrected for temperature, using the values measured, and admitting an atmospheric pressure of 1 atm.

The equipment was submitted to a standard zero calibration (available in the equipment) and data were validated prior to each new measurement (in each new room). Indoor measurements were performed in each room studied, and, in some cases, both on weekdays and weekends, between April and June 2014. Measurements were recorded each minute and hourly means were calculated. In RUR1 measurements were made in full occupation and partial occupation for one of the classrooms and in the lunch room. Full occupation concerned the usual period of nursery attendance and partial occupation concerned to one week before the period of the Easter holidays, where the classroom's occupation was reduced.

The indoor hourly mean values were compared with reference standards and guidelines for general indoor environments, aiming to evaluate exceedances. Comparisons were performed considering national and international reference values for general indoor environments, namely: i) Portuguese legislation (8 hour means) (Portaria nº353-A/2013) for CO_2 (2250 mg m^{-3}, plus 30% of margin of tolerance (MT) if no mechanical ventilation system was working in the room), CO (10 000 µg m^{-3}), CH_2O (100 µg m^{-3}), and TVOC (600 µg m^{-3}, plus 100% of MT if no mechanical ventilation system was working in the room); ii) WHO guidelines (WHO, 2010) for CO (35000 µg m^{-3} for hourly mean), NO_2 (200 µg m^{-3} for hourly mean) and CH_2O (100 µg m^{-3} for 30 minutes mean). For the Portuguese legislation, 8-hour running means for all pollutants were calculated and the daily maximum was compared to the standard.

Hourly O_3 and NO_2 outdoor concentrations were obtained to calculate I/O ratios for rural nursery schools in the subsequent days after indoor measurements and with the same equipment used indoors; for the urban nursery outdoor concentrations were monitored at the nearest air quality station from the Air Quality Monitoring Network of the 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. This station is classified as urban traffic and is representative of the urban area studied.

Mean, minimum, maximum, median and standard deviation (SD) values were calculated for the hourly mean data of indoor air pollutants' concentrations in occupation and non-occupation periods and weekend periods. Data was tested for normality using both the Shapiro-Wilk and Anderson-Darling tests. Whenever measurements were performed for more than one day differences between mean hourly concentrations measured in different sampling days were tested using *t*-test for normal distributions and Mann–Whitney's *U* test for the other distributions. Differences between weekdays and weekends as well as between rural and urban context were also studied using *t*-test for normal distributions and Mann–Whitney *U* test for the other distributions. For all analyses a significance level of 0.05 was considered. Descriptive statistics for the parameters were calculated using MS Excel® (Microsoft Corporation, USA), and other statistical analyses were computed using R software, version 3.1.2 (R Foundation for Statistical Computing, 2014).

3. Results and Discussion

Tables 2, 3 and 4 summarize the main statistical parameters (minimum, maximum, mean, median and standard deviation) of the hourly mean data for each room considering the entire sampling period for weekdays occupation periods, weekdays non-occupation periods and weekends, respectively. Mean daily profiles were performed to represent mean IAQ scenarios for weekdays and weekends. When comparing two or more consecutive sampling days (weekdays and weekends), statistical differences regarding CO_2 ($p > 0.05$ in all cases) were not found; however, for CO, NO_2, O_3, CH_2O and TVOC statistical differences ($p < 0.05$) were found in 50, 75, 50, 25 and 50% of the cases, respectively. Nevertheless, similarly to what was performed by Branco et al. (2015), a daily mean scenario was assumed for all pollutants allowing the following analyses.

3.1 Average daily profiles

3.1.1 Ventilation indicator - CO_2

Average daily profiles of CO_2 for all the studied nursery schools are represented in Figure 1: a) RUR1, b) RUR2, c) RUR3 and d) URB.

Two peaks of CO_2 concentrations were observed in the classrooms: i) during morning - rising in early morning and decreasing before lunch time; and ii) during afternoon - rising after lunch time and decreasing until the end of the afternoon. In lunch rooms, three peaks were observed corresponding to the breakfast, lunch and snack times in RUR1 and RUR2, and two peaks corresponding to the lunch and snack times in the remaining nursery schools. Consequently, all these peaks were found during occupation periods.

A large difference was found between daily profiles on weekdays and weekends. For the latter, concentrations were usually found bellow 1000 mg m^{-3} in all studied nursery schools. During meals lower concentrations were observed in the classrooms, although never lower than in non-occupation periods (night, dawn and weekends).

Exceptions for the general profiles above described were found for: i) classroom B of RUR3, characterized by a small increase during the occupation period, which might have been due to the usage of this room as a support room, namely for material storage and for only one baby sleeping period, thus having low occupation for a short period; ii) classroom B of URB, characterized by a continuous increase of CO_2 concentrations throughout the day from early morning until late afternoon. This was probably due to the lack of ventilation (closed windows) during the morning and sleeping period (12h to 15h), leading to the highest concentrations (7448 mg m^{-3}). Before the sleeping period the windows were opened and CO_2 concentrations started to decrease until the early evening when they stabilized close to the minimum value (708 mg m^{-3}).

Windows and doors closed during classrooms' occupation periods (to avoid noise and reducing/increasing indoor temperatures) also caused the highest CO_2 concentrations found by Yang et al. (2009) (5813 mg m^{-3}) and by Yoon et al. (2011) (3088 mg m^{-3}) for urban nursery schools, although lower than those reported for classrooms B and C of URB. The same was verified by Branco et al. (2015) for urban nursery schools. Gładyszewska-Fiedoruk (2011) reported similar CO_2 concentrations in a nursery school at north-eastern Poland, and also highlighted the importance of good natural ventilation. Classroom C of URB that had natural ventilation, recorded on average, for occupation periods, higher concentrations (mean ± SD: 2087±971 mg m^{-3}) than the rooms of rural nursery schools also naturally ventilated, which might have been due to the occupational densities. This is in fact another determining factor for the indoor air concentrations of CO_2 in classrooms. Therefore, it was possible to observe that classroom C of URB had higher occupation density than the above referred rural classrooms. In general, the occupational densities were found higher in the urban nursery school than in the rural ones (Table 1).

Global concentrations found in rural nursery schools were on average lower than those in the urban nursery school during occupation periods (mean ± SD: 1408 ± 388 mg m^{-3} and 2273 ± 943 mg m^{-3}, respectively), non-occupation periods (mean ± SD: 795 ± 97 mg m^{-3} and 976 ± 83 mg m^{-3}, respectively) and weekends (mean ± SD: 676 ± 14 mg m^{-3} and 799 ± 60 mg m^{-3}, respectively). Yoon et al. (2011) reached the same conclusion in their study, reporting higher concentrations of CO_2 in urban pre-schools (1525 mg m^{-3}) than in rural ones (995 mg m^{-3}). Theodosiou and Ordoumpozanis (2008) that studied the thermal environment and IAQ in kindergartens and primary schools in Kozani (Greece) and Carreiro-Martins (2014) that evaluated the association between reported wheezing and measured indoor CO_2 and other environmental comfort parameters in day care centres of

Porto and Lisbon, reported higher mean concentrations (2700 mg m^{-3} and 2592 mg m^{-3}, respectively) than those recorded in all nursery schools in this study. Cano et al. (2012) reported for urban pre-schools of Porto a higher mean concentration (3145 mg m^{-3}) than that registered in URB (mean ± SD: 2273 ± 943 mg m^{-3} for occupation periods). Zuraimi and Tham (2008) reported for nursery schools in Singapore concentrations similar to those found in classrooms A and B of URB. Yoon et al. (2011) reported for rural nursery schools similar concentrations to those found in classrooms A of RUR1 (full occupation) and RUR2 and in classroom B of RUR3.

3.1.2 Traffic related pollutants - CO, NO_2 and O_3

Figures 2, 3 and 4 show CO, NO_2 and O_3 hourly mean concentrations in: a) RUR1, b) RUR2, c) RUR3 and d) URB. For O_3, daily distributions of hourly mean concentrations were only represented for a) RUR1 – Classroom A in full occupation (week), Classroom A in partial occupation, Classroom B (week and weekend) and lunch room in full occupation and partial occupation; b) RUR2 – Classroom A (week) and lunch room; c) RUR3 – Classroom A (week) and d) URB. The remaining profiles were not represented because O_3 concentrations were below or very close to the minimum detection limit of the equipment (1 ppb).

Regarding CO concentrations, it was possible to distinguish a similar daily profile in all the studied buildings, especially on weekdays, when concentrations increased early in the morning until the end of the afternoon, matching with anthropogenic activities mainly related with work/school-to-home-to-work/school routes, thus showing the probable outdoor influence. During night and early morning concentrations tended to decrease.

For NO_2 concentrations, statistically different average daily profiles were found for all nursery schools ($p < 0.05$). Oscillations might have been related with ventilation (door and /or windows opening), reducing NO_2 concentrations, and with accumulation (in RUR2 for example), increasing NO_2 concentrations. In RUR3, slight increases were only verified in occupation periods; however, concentrations were on average significantly higher ($p < 0.05$) than in RUR1 and RUR2. In URB, NO_2 daily profiles corresponded to the daily traffic patterns, where there were increases in the morning and late afternoon. The major cause for the increase of indoor NO_2 concentrations was the exhaust gases' emission from outdoors, which was very clear in classroom A of RUR3, with windows facing the parking area, recording 291.66 μg m^{-3} at 18h (time of parents' arrival). Nevertheless, in some cases the accumulation of this pollutant and lack of rooms' ventilation were the factors that contributed the most to the concentrations recorded (as in classroom B in RUR1).

CO and NO_2 concentrations obtained in URB for occupation, non-occupation and weekend periods were on average higher (CO - 3608.7 ± 1175.1 μg m^{-3}, 3053.0 ± 1024.0 μg m^{-3} and 3218.4 ± 669.5 μg m^{-3}, respectively; NO_2 – 63.87 ± 43.21 μg m^{-3}, 62.99 ± 45.40 μg m^{-3} and 104.80 ± 47.61 μg m^{-3}, respectively) than those registered in rural nursery schools (CO – 3109.3 ± 830.5 μg m^{-3}, 2817.5 ± 863.9 μg m^{-3} and 2439.8 ± 195.6 μg m^{-3}, respectively; NO_2 – 47.13 ± 43.04 μg m^{-3}, 44.96 ± 41.59 μg m^{-3} and 61.51 ± 39.95 μg m^{-3}), which can be explained by the influence of road traffic from outdoor air, as no indoor sources were present. Yang et al. (2009) and Wichmann et al. (2010) also pointed to road traffic as responsible for high concentrations of CO and NO_2 in South Korean urban pre-schools and in Sweden homes, pre-schools and schools, respectively. In the lunch rooms, CO and NO_2 concentrations were on average lower than those recorded in the classrooms, except for RUR1, probably due to emissions from gas stoves in the lunch room of this school.

Regarding weekend periods, CO and NO_2 daily profiles seemed almost constants throughout the day, however, CO concentrations in URB showed a similar profile to that recorded for weekdays. Despite this, in all nursery schools concentrations on weekends were significantly lower ($p < 0.05$ in all cases) than those recorded on weekdays, once the nursery schools were closed being the influence from outdoors restricted. For NO_2, all nursery schools showed profiles with the same order of magnitude as those recorded on weekdays. CO concentrations obtained in the four nursery schools studied, both for weekdays and weekends, were substantially higher than those reported by Yoon et al. (2011) (1512.0 µg m^{-3}). Cano et al. (2012) reported much lower concentrations in Porto pre-schools (478 µg m^{-3}) than those recorded in the nursery schools here studied; however, for Lisbon pre-schools the reported concentrations (3888 µg m^{-3}) were similar to some of those here recorded (classrooms A of RUR2 and RUR3 and in classrooms A and C of URB). Wichmann et al. (2010) reported for kindergartens in Stockholm, Sweden, similar NO_2 concentrations (12.4 µg m^{-3}) to some of those here stated (classroom A in full occupation and in the lunch rooms in full occupation of RUR1, and RUR2 and RUR3).

Regarding O_3, concentrations were higher during the afternoons in all nursery schools. The maxima concentrations were recorded between 16h and 19h related with cleaning activities and windows opening. The peak observed in RUR3 was similar to that recorded for NO_2, and the outdoor air appeared to be the main cause for the O_3 indoor air concentrations. In RUR2 and URB, the maximum concentrations were recorded in lunch rooms during clean-up activities, which were frequently associated with windows opening and consequent influence of outdoor air. Rural nursery schools recorded significantly higher ($p < 0.05$) concentrations than URB. In the inexistence of indoor sources, which happened in all nursery schools of this study, outdoor air is expected to have been the main determinant of indoor O_3 concentrations, as already identified in several studies (Sousa et al., 2009; Bayer-Oglesby et al., 2004; Duenas et al., 2004; Syri et al., 2001). O_3 outdoor concentrations are clearly higher in rural areas than urban ones, thus reproducing the same behaviour indoors. Generally, O_3 concentrations were lower on weekends than on weekdays, being zero in most cases, which reinforces the influence of outdoor air.

Zuraimi and Tham (2008) reported higher O_3 concentrations (59 µg m^{-3}) than those in the nursery schools of this study, probably due to cleaning routines and outdoor air contributions.

In general, the influence of outdoor air could be associated with the observed indoor concentrations of CO, NO_2 and O_3, which could be supported by the inexistence of indoor sources (in majority of cases) as well as by the I/O ratios results (presented in Section 3.4).

3.1.3 TVOC and CH_2O

Figure 5 shows TVOC hourly mean concentrations determined for all the studied class and lunch rooms of the four nursery schools: a) RUR1, b) RUR2, c) RUR3, and d) URB).

RUR1 and RUR2 showed a nearly constant profile throughout the day; in RUR3 maxima concentrations were found during dawn and in URB occurred mainly during occupation periods. In lunch rooms, the highest concentrations were recorded immediately after lunch and snack times. Although it was not possible to find a typical profile for TVOC concentrations in the studied nursery schools, all recorded peaks seemed to be related with: i) the cleaning activities (products emitting VOC), which were performed mostly in the late afternoon in the classroom and after lunch in the lunchrooms; ii) with the accumulation phenomenon caused by the lack of ventilation after these activities; for partial occupation period in RUR1, a deeper cleaning was performed, thus higher concentrations of TVOC were recorded in the lunch room as well as in classroom A; and iii) in URB, the frequent peaks during occupation periods seemed to be related with insufficient ventilation, boosting accumulation during sleeping time (12h to 15h). After sleeping time concentrations decreased, as the room was ventilated.

The concentrations recorded on weekends, when above the detection limit, seemed to be constant and almost the same as those recorded for non-occupation periods (night and dawn) during the week, except for RUR3. In this nursery school there were probably specific indoor sources of those pollutants, namely building materials such as wood clusters, plywood and furniture materials, because besides increasing during weekends (classroom A), a progressive increasing from the end of the day until the following morning on weekdays was observed in classrooms A and B. Classroom A of RUR2 and Classroom C of URB reported concentrations for occupation periods (mean ± SD: 117.66 ± 17.59 µg m^{-3} and mean ± SD: 124.58 ± 89.62 µg m^{-3}, respectively), similar to those reported by Yang et al. (2009) (123.00 µg m^{-3}). Classroom B of RUR1 reported concentrations for occupation periods (mean ± SD: 155.22 ± 115.11 µg m^{-3}) similar to those reported by Cano et al. (2012) (181.00 µg m^{-3}). Roda et al. (2011) that investigated IAQ in Paris child day care centers and St-Jean et al. (2012) that studied IAQ in Montréal reported lower TVOC concentrations than those reported for nursery schools in this study (12.75 µg m^{-3} and 22.90 µg m^{-3}, respectively). In these two studies, the authors concluded that indoor TVOC concentrations were caused by emissions from building materials and furniture, worsened by insufficient ventilation rates.

TVOC mean concentrations recorded for occupation periods in rural nursery schools were lower (mean ± SD: 145.18 ± 128.15 µg m^{-3}) than those reported by Yoon et al. (2011) (351.00 µg m^{-3}) and similar to those reported by Yang et al. (2009) (162.69 µg m^{-3}).

However, both these studies concluded that those concentrations were caused by emissions from building materials and furnishing. Cano et al. (2012) reported in Lisbon much higher concentrations (3339.00 µg m^{-3}) than those found in this study. In general, for occupation periods the urban nursery recorded higher mean TVOC concentrations (mean ± SD: 271.66 ± 216.42 µg m^{-3}) than rural ones (mean ± SD: 145.18 ± 128.15 µg m^{-3}), and Yoon et al. (2011) found the same for the South Korean nursery schools.

Figure 6 shows CH_2O hourly mean concentrations for: a) classroom A (weekend), classroom B (weekdays) and the lunch room in full occupation of RUR1; b) the lunch room of RUR2; c) the lunch room of RUR3; and d) URB. CH_2O concentrations for the remaining studied rooms are not represented because they were below the minimum detection limit of the equipment (0.05 ppm).

For CH_2O concentrations a daily pattern was found in URB. In this nursery school it was possible to identify three concentration peaks in classrooms A and B and in the lunch room, recorded on weekdays. In classroom A the peak was between 11h and 13h, corresponding to the lunch and cleaning time as well as to the preparation for the sleeping period (children were less than 2 years old and spent the entire school day inside the classroom). CH_2O concentrations' increase might have been related with the products used for cleaning. Furthermore, certain activities such as dragging wood furniture (scraping the floor) to prepare the classroom for sleeping time could be connected with the emission of this pollutant. The other two peaks corresponded to the cleaning periods in the lunch room (before lunch) and cleaning before sleeping time and children's hygiene in classroom B. Besides the recorded peaks, concentrations increased at the end of the day, in agreement with the period of general cleaning of the entire building. After that, the building was closed and the concentrations of CH_2O increased due to the accumulation at the end of the night, and gradually decreased throughout the morning. In

RUR1 (full occupation), RUR2 and RUR3 two concentrations peaks were recorded in the lunch rooms at lunch time probably related with furniture dragging (furniture finishing - varnished wood). On average, URB registered higher CH_2O concentrations for occupation and non-occupation periods (44.19 ± 42.99 μg m^{-3} and 60.63 ± 60.83 μg m^{-3}, respectively) than those registered in rural nursery schools (18.42 ± 34.03 μg m^{-3} and 1.54 ± 2.77 μg m^{-3}, respectively) and lower for weekend periods (1.33 ± 1.15 μg m^{-3} and 3.68 ± 6.37 μg m^{-3}, respectively). CH_2O mean concentrations recorded for occupation periods in URB were much higher than those reported by the European Commission in AIRMEX project (European Indoor Air Monitoring and Exposure Assessment) (2003-2008) for schools and kindergartens (the maximum mean value recorded was 31.9 μg m^{-3} in Leipzig during July). For Athens, Budapest and Helsinki schools and kindergartens, (20.2 μg m^{-3}, 18.23 μg m^{-3} and 21.23 μg m^{-3}, respectively) (Kotzias et al., 2009) as well as in the kindergartens analysed in the SINPHONIE project (Schools Indoor Pollution and Health: Observatory Network in Europe) (15 ± 10 μg m^{-3}) (Jantunen et al., 2008), concentrations were similar to those recorded in occupation periods of rural nursery schools. Furthermore, CH_2O mean concentrations in schools of Nijmegen, Catania, Thessaloniki and Nicosia (6.1 μg m^{-3}, 13.0 μg m^{-3}, 13.8 μg m^{-3}, 12.0 μg m^{-3}, respectively), also reported in AIRMEX project, were lower than those reported in this study (Kotzias et al., 2009).

Concluding, TVOC higher concentrations in RUR1, RUR2 and URB were mainly caused by cleaning activities (products used). In RUR3 internal sources, namely building materials and furniture finishing, were the probable causes for the concentrations recorded. The lack of ventilation increased even more significantly the concentrations recorded. Regarding CH_2O, dragging of furniture in RUR1, RUR2 and RUR3 lunch rooms during meal time appeared to have been the main responsible for the CH_2O

concentrations recorded. In URB, concentrations seemed to have been related with cleaning activities and poor ventilation.

A careful choice of materials which do not emit VOC must be prioritized to improve IAQ and to protect children's health. Furthermore, improved ventilation rates will allow the reduction of indoor concentrations of these pollutants.

3.3 Comparison with standards and guidelines

Table 5 shows the number of non-compliances and exceedances (%) to the standards and guidelines referred to in the Material and methods section.

WHO guidelines for CO, NO_2 and O_3 concerning 1h, 8h and 24h means were never exceeded. However, WHO guideline for 30 minutes CH_2O mean was always exceeded during occupation periods in the lunch rooms of RUR1, RUR2 and RUR3, probably due to furniture dragging (tables and chairs) during meal times. In URB, exceedances were around 28% in all the studied rooms during occupation periods, being lower than in rural nursery schools. Classrooms A and B also recorded CH_2O exceedances for the Portuguese legislation (100% in both classrooms). These values were probably due to emissions from cleaning products, furniture and flooring which were varnished wood. Missia et al. (2010) reported CH_2O concentrations (5.8-62.6 μg m^{-3}) below the WHO guideline. CH_2O concentrations reported in AIRMEX and SINPHONIE projects could not be compared with the WHO guideline (30 minutes), because measurements were one week long. Exposure to CH_2O concentrations may cause inflammation of the airways and adverse pulmonary effects (Venn et al., 2003, Jones, 1999). To minimize the concentrations recorded, higher ventilation in the rooms with the highest concentrations should be implemented, and materials free from CH_2O emissions should be preferred whenever possible.

According to Portuguese legislation for CO_2, exceedances were recorded in classrooms A and B of URB (50% and 100%, respectively). Classrooms A of RUR3 and C of URB had natural ventilation so the margin of tolerance was applied, thus no exceedances were observed. A determining factor for the indoor air concentrations of CO_2 that is not taken into account by the Portuguese legislation is the occupation density of the classrooms. In fact, Portuguese legislation regarding the number of children per classroom for infants under 3 years old (Portaria nº 262/2011) and for pre-schoolers (Despacho nº 5048-B/2013) which only considers educational and economic criteria, legislate for infants, groups aged 1 to 2 year old (until the acquisition of march) and groups aged 2 to 3 years old, a maximum of, respectively, 10, 14 and 18 children per group. For pre-schoolers a minimum of 20 and a maximum of 25 children per classroom is legislated. Beyond that, there is a guideline recommended by ASHRAE for classrooms (for children between 5 and 8 years old) that considers the density of occupation (25 occupants per 100 m^2) (ASHRAE, 2007). Although only classroom C of URB has exceeded the value of the Portuguese legislation regarding the number of children per classroom for pre-schoolers (Despacho nº 5048-B/2013), all classrooms of this study exceeded ASHRAE recommended guideline. Branco et al. (2015) also found exceedances to ASHRAE recommended guideline for all urban nursery schools analysed. This circumstance as well as ventilation habits referred in Section 3.1, led to the increase of CO_2 concentrations in classrooms to values above the Portuguese legislated standards. Theodosiou and Ordoumpozanis (2008) and Zuraimi and Tham (2008) also pointed out the higher occupation densities as an important factor for the increase of indoor CO_2 concentrations. St-Jean et al. (2012) also referred a high occupational density when comparing with ASHRAE recommendation and indicated high occupation density as an important factor for the increase of CO_2 concentrations.

Headache, nausea, breathlessness and loss of concentration are possible health symptoms for children attending these nursery schools (USEPA 2009; Griffiths and Eftekhari, 2008).

For TVOC, exceedances were recorded in classroom A of RUR3 (33%) and in classrooms A and B of URB (50% and 100%, respectively). According to the analysis previously performed, these exceedances may have been caused by specific point activities performed in the classrooms (A and B of URB), associated with the use of paints and glues, as well as by the probable existence of internal sources of these pollutants such as furniture materials, finishing (paints and varnishes), decoration and construction products (classroom A of RUR3). Missia et al. (2010) and Zhang and Niu (2003) also associated finishing products, coatings and building materials (carpets, acoustic and thermal insulation) as sources of TVOC. These high concentrations may result in irritation of the upper airways and/or the lower respiratory tract and adverse lung effects (Rumchev et al., 2004; Nurmatov et al., 2013).

On weekends, no exceedances were observed. In general, most exceedances and non-compliances were registered in the urban nursery school.

3.4 Indoor/Outdoor ratios

The concentrations measured indoors were compared with those outdoors using the I/O ratio for NO_2 and O_3. Median, minimum (min) and maximum (max) I/O ratios were obtained for each studied room in the four nursery schools and are presented in Table 6.

Median I/O ratios of NO_2 were lower than 1 in classroom A in full occupation and for RUR1 lunch room in full occupation and partial occupation, meaning that lower concentrations were observed indoors. In classrooms A during partial occupation and B, both for weekdays and weekends, indoor air concentrations of NO_2 were higher than outdoors, which was probably due to accumulated indoor concentrations that did not decrease as fast as the outdoor concentrations, leading to ratios higher than 1. Whichmann et al. (2010) that studied indoor-outdoor relationships at homes, pre-schools and schools in Stockholm (Sweden) also reported mean I/O ratio for pre-schools higher than 1.

I/O ratios found during the weekend were higher than those on weekdays, once again demonstrating the contribution of accumulation observed in non-occupation periods resulting from the lack of proper ventilation.

Maxima values of NO_2 I/O ratios in URB were higher than in rural nursery schools. This was expected since URB was strongly affected by traffic emissions and it is known that NO_2 is one of the main components of exhaust gases. Furthermore, the accumulation phenomenon (lack of proper ventilation) increased even more the already high indoor concentrations (influenced by outdoor air) in URB.

Concerning O_3, I/O median ratios calculated for all microenvironments were lower than 1. This behaviour was expected, because in the absence of indoor sources, indoor O_3 concentrations are mainly due to outdoor air. On average, I/O ratios were higher in rural nursery schools than in the urban one.

4. Conclusions

Indoor concentrations of CO_2, CO, CH_2O, NO_2, O_3 and TVOC were monitored in rural nursery schools and in one urban nursery school allowing a better understanding of the effect that those two different contexts have on IAQ.

Regarding CO_2, the urban nursery recorded, on average, higher concentrations than rural nursery schools, reaching maxima peaks in occupation periods of around 7500 mg m^{-3}.

The Portuguese legislation reference value was exceeded only in the classrooms from the urban nursery, which was due to the higher occupation densities than in rural nursery schools. CO and NO_2 concentrations obtained in URB for occupation periods were on average higher than those registered in rural nursery schools, which can be explained by the influence of road traffic from outdoor air. The inexistence of indoor sources as well as I/O ratio results indicated that the influence of outdoor air was the main determinant NO_2 and O_3 indoor concentrations. Regarding O_3, rural nursery schools registered higher indoor concentrations than the urban nursery school. Several studies have concluded that the outdoor O_3 concentrations are clearly greater in rural areas than in urban ones (Sousa et al., 2008). Thus, as no indoor sources were present (referred above) the higher rural indoor concentration were due to the outdoor contribution.

High concentrations of CH_2O and TVOC were occasionally observed associated mainly to cleaning activities and in some cases indicating the presence of internal sources of these pollutants, such as furniture finishing (emission of CH_2O).

From this study it is possible to conclude that there is a need to implement measures to reduce critical situations regarding IAQ and consequent children's risk of exposure, mainly in the urban context. Measures such as changing materials and consumer products that emit VOC can be applied to promote children's and childcare workers overall life quality. More efficient ventilation (by mechanical or natural systems) could also be applied to reach the same goal. Besides that, it could also be necessary to review the Portuguese legislation on the number of children per classroom, having into account the occupation density and children's health issues.

The study allowed to communicate the results to the staff of the nursery schools involved as well as to provide mitigation measures when necessary. The authors believe that these findings may be useful to improve IAQ in other nursery schools and to support future research. More nurseries need to be studied to help supporting these findings.

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Figure captions

Figure 1. Daily profile of CO_2 concentrations registered indoors for a) RUR1, b) RUR2, c) RUR3, and d) URB.

Figure 2. Daily profile of CO concentrations registered indoors for a) RUR1, b) RUR2, c) RUR3, and d) URB.

Figure 3. Daily profile of NO_2 concentrations registered indoors for a) RUR1, b) RUR2, c) RUR3, and d) URB.

Figure 4. Daily profile of O_3 concentrations registered indoors in a) classroom A in FO (week), classroom A in PO, classroom B (week and weekend) and lunch room in FO and PO of RUR1, b) classroom A (week) and lunch room of RUR2, c) classroom A (week), and d) URB.

Figure 5. Daily profile of TVOC concentrations registered indoors for a) RUR1, b) RUR2, c) RUR3, and d) URB.

Figure 6. Daily profile of CH_2O concentrations registered indoors in a) classroom A (weekend), classroom B (weekdays) and lunch room in FO of RUR1, b) lunch room of RUR2, c) lunch room of RUR3; and d) URB.

Table 1 – Summary of the main characteristics of each studied microenvironment and sampling periods.

Nursery	Room	Type of use	Children's age (years)	Floor	Area (m^2)	Occupation (Children + staff)	Period of occupation	Ventilation	Sampling time (weekdays + weekend days)
RUR1	A	Classroom	4-5	Ground floor	63	FO[a] : 25+2 PO[b] : 6 + 2	09h – 12h 14h – 15h30	DNV [c] (Door to inner corridor frequently closed; Windows frequently open; AVAC system off)	2 + 2
	B	Classroom	5	Ground floor	48	20+2	09h – 12h 14h – 15h30	DNV (Door to inner corridor frequently closed; Windows frequently open; AVAC system off)	3 + 2
	LR	Lunch room	3-5	Ground floor (back)	56	FO : ~200 PO : ~21	12h – 14h	DNV (Open to kitchen and to inner corridor; Windows open during the occupation; AVAC system off	1 + 0
RUR2	A	Classroom	3-6	Ground floor (back)	32.5	14+2	09h – 11h30 12h15 – 16h	DNV (Door to inner corridor always open; Windows frequently closed; A/C[d] and heating off)	4 + 2
	LR	Lunch room	3-6	Ground floor	26	14+2	11h30 – 12h15	DNV (Door to inner corridor always open; Windows open during the occupation)	3 + 0
RUR3	A	Classroom	<1-2	Ground floor	23.5	23+2	08h – 11h30 13h30 – 18h 12h30 – 15h30 (sleeping time)	DNV (Door to inner corridor frequently closed; Windows frequently open; AVAC system off)	4 + 2
	B	Classroom	2-3	Ground floor	37.5	1 (Functioned as support room)	8h – 11h30 12h30 – 18h	DNV (Door to inner corridor always closed; Windows always closed; AVAC system off)	3 + 0
	LR	Lunch room	<1-3	Ground floor (back)	104	24	11h30 – 12h30	DNV (Door to inner corridor always open; Windows always closed; AVAC system off)	3 + 0

URB1	A	Classroom	<2	1st floor (back)	38	23+2	07h30 – 19h30 12h – 13h (sleeping time)	DFV [e] (Door to inner corridor always closed; A/C and dehumidifier frequently used)	4 + 2
	B	Classroom	2-3	1st floor (back)	21	23+2	08h30 – 10h50 11h45 – 18h30 12h – 15h (sleeping time)	DFV (Door to inner corridor always closed. Windows sometimes open; A/C and dehumidifier frequently used)	4 + 0
	C	Classroom	4	2nd floor (front)	59	29+2	09h – 11h30 14h – 18h	DNV (Door to inner corridor always closed; Windows sometimes open)	3 + 2
	LR	Lunch room	2-5	Ground floor (back)	38	21 to 74	11h30 – 13h30	DNV (Opening to the kitchen and to the inner corridor; No direct opening to the outside)	3 + 0

[a] FO – full occupation; [b] PO – partial occupation; [c] DNF – Dominate natural ventilation; [d] A/C – Air Conditioner; [e] DNF – Dominate forced ventilation.

Note: adapted from Nunes et al. (2005)

Table 2 – Statistical parameters of the hourly mean data for each room studied at all nursery schools in weekdays for occupation periods.

	Nursery	RUR1					RUR2		RUR3			URB			
	Room	**A_{FO} [a]**	**A_{PO} [b]**	**B [c]**	**LR_{FO} [d]**	**LR_{PO} [e]**	**A**	**LR [f]**	**A [g]**	**B**	**LR**	**A**	**B**	**C**	**LR**
CO_2 (mg m^{-3})	Min	700	701	728	1092	885	953	1195	691	695	1622	823	715	773	1002
	Max	2288	1490	1418	2431	1178	2398	1484	3490	1375	2513	3171	7448	4571	1331
	Mean	1391	951	981	1808	1054	1565	1340	1883	1035	2068	2010	3791	2087	1202
	Median	1397	828	932	1901	1068	1436	1340	1680	1021	2068	1940	4237	2126	1237
	SD [h]	535	248	209	550	107	467	144	873	215	445	635	1938	971	122
CO (µg m^{-3})	Min	3293.0	3496.6	1761.5	3172.2	2976.8	2772.5	1919.3	2667.2	2595.5	1535.7	2512.6	1646.7	1534.0	1591
	Max	5972.0	4861.0	3206.3	3410.2	3515.8	3809.4	2259.8	3912.0	3109.9	1654.7	6686.5	6216.7	5386.6	1838
	Mean	4417.7	4273.7	2583.9	3322.5	3309.6	3298.7	2089.5	3329.9	2872.0	1595.2	5031.7	3940.7	3692.4	1770
	Median	3907.0	4319.6	2714.5	3385.2	3317.6	3285.6	2089.5	3344.2	2917.3	1595.2	5065.4	3609.8	4176.6	1824
	SD	1030.0	441.8	431.9	106.8	175.5	261.5	170.3	325.6	141.1	59.5	1064.3	1167.6	1165.1	103
CH_2O (µg m^{-3})	Min	0.00	0.00	0.00	21.92	0.00	0.00	3.12	0.00	0.00	12.65	0.00	0.00	0.00	0.00
	Max	0.00	0.00	61.79	233.76	0.00	0.00	72.95	0.00	0.00	42.94	653.44	697.74	0.00	12.21
	Mean	0.00	0.00	5.62	112.80	0.00	0.00	38.03	0.00	0.00	27.79	99.32	72.94	0.00	4.50
	Median	0.00	0.00	0.00	82.74	0.00	0.00	38.03	0.00	0.00	27.79	30.52	19.89	0.00	2.90
	SD	0.00	0.00	17.76	89.06	0.00	0.00	34.91	0.00	0.00	15.14	162.55	126.91	0.00	5.04
NO_2 (µg m^{-3})	Min	0.00	5.99	56.14	0.00	9.20	38.26	0.00	72.79	82.84	2.22	98.58	0.64	15.15	6.32
	Max	34.46	137.52	143.86	2.82	29.29	94.54	24.86	291.66	113.82	9.51	146.27	143.40	82.09	20.92
	Mean	16.67	41.18	96.48	0.94	15.71	55.54	12.43	125.17	101.32	5.87	125.57	79.40	40.07	10.45
	Median	17.07	24.26	94.11	0.00	13.42	50.67	12.43	117.77	101.65	5.87	127.74	89.26	35.52	7.27
	SD	13.03	39.33	21.42	1.33	6.42	16.76	12.43	44.06	7.32	3.65	13.84	38.23	21.32	6.07
O_3 (µg m^{-3})	Min	2	0	6	0	1	0	0	0	0	0	0	0	0	2
	Max	32	38	29	0	10	17	3	27	0	0	6	1	2	6
	Mean	11	8	18	0	4	3	1	2	0	0	0	0	0	4
	Median	8	4	16	0	3	1	1	0	0	0	0	0	0	4
	SD	10	11	7	0	3	5	1	5	0	0	1	0	0	2

TVOC (µg m^{-3})	Min	142.01	182.75	79.23	0.00	201.00	77.55	0.00	0.00	0.00	0.00	87.10	139.39	0.00	0.00
	Max	174.17	325.63	488.33	0.00	450.12	140.20	0.00	1927.18	702.71	0.00	1245.68	1321.37	337.04	0.00
	Mean	159.40	229.27	155.22	0.00	329.70	117.66	0.00	379.14	81.38	0.00	434.90	527.14	124.58	0.00
	Median	160.44	219.66	100.47	0.00	357.65	118.04	0.00	0.00	0.00	0.00	295.23	527.21	118.05	0.00
	SD	9.49	39.62	115.11	0.00	98.53	17.59	0.00	540.50	215.88	0.00	314.98	257.12	89.62	0.00

[a] A_{FO} – Classroom A in full occupation; [b] A_{PO} – Classroom A in partial occupation; [c] B – Classroom B; [d] LR_{FO} – Lunch Room in full occupation; [e] LR_{PO} – Lunch Room in partial occupation; [f] LR - Lunch Room; [g] A – Classroom A; [h] SD – Standard Deviation

Table 3 – Statistical parameters of the hourly mean data for each room studied at all nursery schools in weekdays for non-occupation periods.

	Nursery	**RUR1**					**RUR2**		**RUR3**			**URB**			
	Room	**A_{FO} [a]**	**A_{PO} [b]**	**B [c]**	**LR_{FO} [d]**	**LR_{PO} [e]**	**A**	**LR [f]**	**A [g]**	**B**	**LR**	**A**	**B**	**C**	**LR**
CO_2 (mg m^{-3})	Min	684	653	633	700	700	647	645	622	695	697	778	708	727	766
	Max	1077	1051	869	1068	987	1718	2437	873	1080	2582	1835	1202	3127	1718
	Mean	723	715	700	806	787	753	921	728	796	1023	1059	866	1052	925
	Median	694	696	689	785	785	695	703	727	780	784	1031	789	819	848
	SD [h]	94	71	49	98	67	176	401	54	95	471	259	162	591	214
CO (µg m^{-3})	Min	3313.8	3700.5	1846.9	2058.1	2364.1	2461.2	891.6	2514.5	2537.7	1034.0	2545.4	1635.5	1576.8	704.22
	Max	5624.7	4627.8	2871.1	3474.3	3474.3	3366.2	3511.4	3397.1	2967.4	1945.8	5808.0	4101.2	4612.3	2301.91
	Mean	4294.5	4068.6	2418.8	2846.9	2879.0	2983.6	1660.8	2928.9	2749.3	1344.1	4347.4	3100.1	3281.5	1483.11
	Median	4212.1	4040.5	2422.6	2854.9	2854.9	3032.9	1700.4	2966.9	2749.6	1336.0	4463.4	3194.8	3530.7	1358.22
	SD	603.0	221.4	289.7	282.4	281.5	185.2	498.6	206.4	112.4	207.9	918.0	788.8	941.3	452.88
CH_2O (µg m^{-3})	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max	0.00	0.00	2.08	54.47	0.00	0.00	178.13	0.00	0.00	34.88	158.14	703.33	219.29	332.57
	Mean	0.00	0.00	0.06	3.54	0.00	0.00	8.94	0.00	0.00	2.87	23.59	165.78	31.71	21.42
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.04	0.00	0.00
	SD	0.00	0.00	0.36	11.70	0.00	0.00	28.70	0.00	0.00	7.63	44.07	199.73	57.11	54.55
NO_2 (µg m^{-3})	Min	0.00	1.58	44.10	0.00	0.32	11.38	0.00	91.06	92.64	0.00	102.73	5.13	17.77	1.26
	Max	34.25	66.58	126.06	52.21	52.21	92.01	39.05	224.80	115.40	26.65	173.62	107.88	65.90	37.12
	Mean	4.36	26.78	85.56	22.50	24.49	48.42	5.24	123.27	103.69	5.31	136.48	60.40	40.25	14.82
	Median	0.00	21.40	87.22	23.96	27.92	48.54	0.00	120.15	103.39	2.55	133.02	68.20	41.09	12.98
	SD	8.62	19.35	20.20	15.49	14.31	19.22	9.06	21.17	5.89	6.38	17.60	34.27	13.83	9.96
O_3 (µg m^{-3})	Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Max	23	16	19	20	20	23	22	5	0	0	6	3	6	14
	Mean	3	1	2	1	2	2	3	0	0	0	1	0	0	2
	Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SD	6	3	5	4	5	4	5	1	0	0	2	1	1	4

	Min	138.20	183.51	74.23	0.00	162.86	91.61	0.00	0.00	0.00	0.00	86.72	64.68	0.00	0.00
	Max	174.75	274.50	112.69	431.92	431.92	180.69	0.00	1827.79	535.84	0.00	460.00	1329.23	567.03	187.34
TVOC (µg m^{-3})	Mean	156.62	240.18	101.71	288.37	330.12	116.10	0.00	530.06	103.25	0.00	224.79	542.80	159.32	8.60
	Median	160.44	245.34	101.58	349.63	359.23	114.60	0.00	46.03	0.00	0.00	210.81	622.90	144.45	0.00
	SD	8.96	24.39	9.06	136.36	84.26	14.21	0.00	683.31	167.83	0.00	90.52	349.42	147.17	38.48

[a] A_{FO} – Classroom A in full occupation; [b] A_{PO} – Classroom A in partial occupation; [c] B – Classroom B; [d] LR_{FO} – Lunch Room in full occupation; [e] LR_{PO} – Lunch Room in partial occupation; [f] LR - Lunch Room; [g] A – Classroom A; [h] SD – Standard Deviation

Table 4 – Statistical parameters of the hourly mean data for each room studied at all nursery schools in weekends.

	Nursery	RUR1		RUR2	RUR3	URB	
	Room	**A**	**B**	**A**	**A**	**A**	**B**
CO_2 (µg m^{-3})	Min	638	616	629	621	756	699
	Max	700	685	781	780	962	790
	Mean	684	653	680	688	859	739
	Median	694	656	684	695	863	721
	SD[a]	18	26	29	43	61	38
CO (µg m^{-3})	Min	2059.1	1765.4	2174.7	2429.8	2713.0	1699.4
	Max	2688.0	2600.4	2865.3	2936.5	4984.2	3530.0
	Mean	2340.7	2179.1	2547.3	2692.2	3887.8	2548.9
	Median	2333.6	2185.7	2529.2	2700.5	3940.2	2582.7
	SD	160.5	236.1	199.6	132.5	586.5	468.5
CH_2O (µg m^{-3})	Min	0.00	0.00	0.00	0.00	0.00	0.00
	Max	24.92	0.00	0.00	0.00	84.39	8.51
	Mean	14.71	0.00	0.00	0.00	2.48	0.18
	Median	12.46	0.00	0.00	0.00	0.00	0.00
	SD	6.00	0.00	0.00	0.00	12.92	1.22
NO_2 (µg m^{-3})	Min	0.00	58.57	24.11	76.20	126.14	45.40
	Max	16.50	124.79	64.08	141.01	171.21	77.94
	Mean	4.50	89.16	45.04	107.32	152.40	57.19
	Median	3.17	81.96	46.00	111.61	155.71	55.52
	SD	4.71	19.55	8.45	15.90	13.66	7.38
O_3 (µg m^{-3})	Min	0	0	0	0	0	0
	Max	0	10	0	1	10	2
	Mean	0	2	0	0	2	0
	Median	0	0	0	0	0	0
	SD	0	12	0	0	2	0

	Min	0.00	56.92	92.31	0.00	118.44	0.00
	Max	0.00	116.53	115.76	579.55	384.97	86.30
TVOC (μg m^{-3})	Mean	0.00	96.41	105.12	64.90	169.78	6.80
	Median	0.00	100.58	107.84	0.00	159.90	0.00
	SD	0.00	16.25	8.75	148.63	44.77	18.55

[a] SD - Standard Deviation

Table 5 - Non-compliances and exceedances (%) of values to ASHRAE and WHO guidelines. as well as to Portuguese legislation. on weekdays and only during occupation periods.

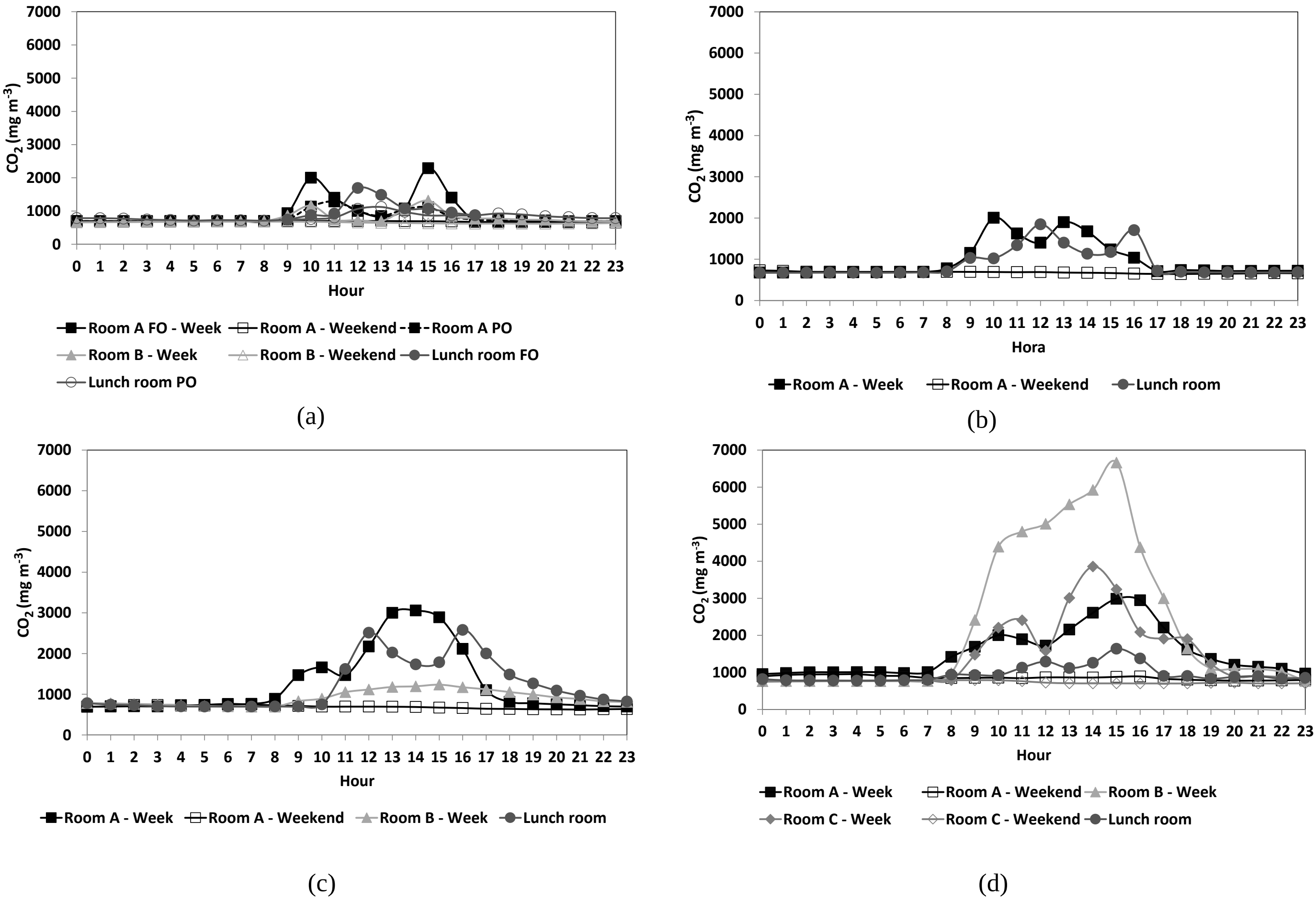
Nursery	Room	Weekdays						During occupation
		WHO	Portuguese Legislation					WHO
		CH_2O [30 min] [a]	CO_2 [b]	CO_2 MT [c]	CH_2O [d]	TVOC [e]	TVOC MT [f]	CH_2O [30 min]
RUR1	A_{FO} [g]	bdl [h]	0%	na [i]	bdl	0%	na	0%
	A_{PO} [j]	bdl	0%	na	bdl	0%	na	bdl
	B	0%	0%	na	0%	0%	na	bdl
	LR_{FO} [k]	93%	na	na	na	na	na	100%
	LR_{PO} [l]	bdl	0%	na	bdl	0%	na	bdl
RUR2	A	bdl	0%	na	bdl	0%	na	bdl
	LR [m]	4%	0%	na	0%	0%	na	100%
RUR3	A	bdl	33%	0%	bdl	67%	33%	bdl
	B	bdl	0%	na	bdl	0%	na	bdl
	LR	19%	0%	na	0%	0%	na	100%
URB	A	17%	50%	na	100%	50%	na	28%
	B	37%	100%	na	100%	100%	na	28%
	C	7%	50%	0%	0%	0%	na	0%
	LR	4%	0%	na	0%	0%	na	29%

[a] % of 30 minute mean concentrations above the reference value of 100 µg m^{-3}; [b] % of 8-hour running mean concentrations above the reference value of 2250 mg m^{-3}; [c] % of 8-hour running mean concentrations above the reference value of 2925 mg m^{-3} (2250 mg m^{-3}+ 30% of margin of tolerance (MT)); [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}; [f] % of 8-hour running mean concentrations above the reference value of 1200 µg m^{-3} (600 µg m^{-3}+ 100% of MT); [g] A_{FO} – Classroom A in full occupation; [h] bdl – bellow detection limit; [i] na – not applicable; [j] A_{PO} – Classroom A in partial occupation; [k] LR_{FO} – Lunch Room in full occupation; [l] LR_{PO} – Lunch Room in partial occupation; [m] LR - Lunch Room

Table 6 – I/O ratios for NO_2 and O_3: median values observed in each studied site for weekdays and weekends and respective minimum (min) and maximum (max) ratio.

Nursery	Room	NO_2		O_3	
		Weekdays	Weekend	Weekdays	Weekend
RUR1	A_{FO} [a]	0.00 (min-max: 0.00-1.41)	0.06 (min-max: 0.00-0.92)	0.02 (min-max: 0.00-0.80)	-
	A_{PO} [b]	0.33 (min-max: 0.13-9.51)	-	0.00 (min-max: 0.00-0.52)	-
	B	1.08 (min-max: 0.62-18.22)	1.06 (min-max: 0.81-13.06)	0.02 (min-max: 0.00-0.63)	0.06 (min-max: 0.00-0.16)
	LR_{FO} [c]	0.17 (min-max: 0.00-0.41)	-	0.17 (min-max: 0.00-0.29)	-
	LR_{PO} [d]	0.26 (min-max: 0.16-4.29)	-	0.00 (min-max: 0.00-0.40)	-
RUR2	A	0.66 (min-max: 0.33-7.52)	0.53 (min-max: 0.33-7.22)	0.00 (min-max: 0.00-0.40)	-
	LR	0.04 (min-max: 0.00-2.90)	-	0.02 (min-max: 0.00-0.53)	.
RUR3	A	1.35 (min-max: 1.13-21.17)	1.19 (min-max: 0.91-17.29)	0.00 (min-max: 0.00-0.44)	0.00 (min-max: 0.00-0.01)
	B	1.21 (min-max: 0.90-14.37)	-	-	-
	LR [e]	0.06 (min-max: 0.00-2.34)	-	-	-
URB	A	5.14 (min-max: 1.11-38.67)	10.40 (min-max: 2.44-23.61)	0.00 (min-max: 0.00-0.06)	0.00 (min-max: 0.00-0.10)
	B	7.66 (min-max: 0.06-22.84)	-	0.00 (min-max: 0.00-0.05)	-
	C	3.27 (min-max: 1.00-9.08)	6.09 (min-max: 2.92-11.86)	0.00 (min-max: 0.00-0.09)	0.00 (min-max: 0.00-0.03)
	LR	0.62 (min-max: 0.05-2.66)	-	0.00 (min-max: 0.00-0.19)	-

[a] A_{FO} – Classroom A in full occupation; [b] A_{PO} – Classroom A in partial occupation; [c] LR_{FO} – Lunch Room in full occupation; [d] LR_{PO} – Lunch Room in partial occupation; [e] LR - Lunch Room



CO2 (mg m-3)
Hour
Room A FO - Week
Room A - Weekend
Room A PO
Room B - Week
Room B - Weekend
Lunch room FO
Lunch room PO
(a)
Hora
Room A - Week
Room A - Weekend
Lunch room
(b)
Room A - Week
Room A - Weekend
Room B - Week
Lunch room
(c)
Room A - Week
Room A - Weekend
Room B - Week
Room C - Week
Room C - Weekend
Lunch room
(d)

Figure 1.

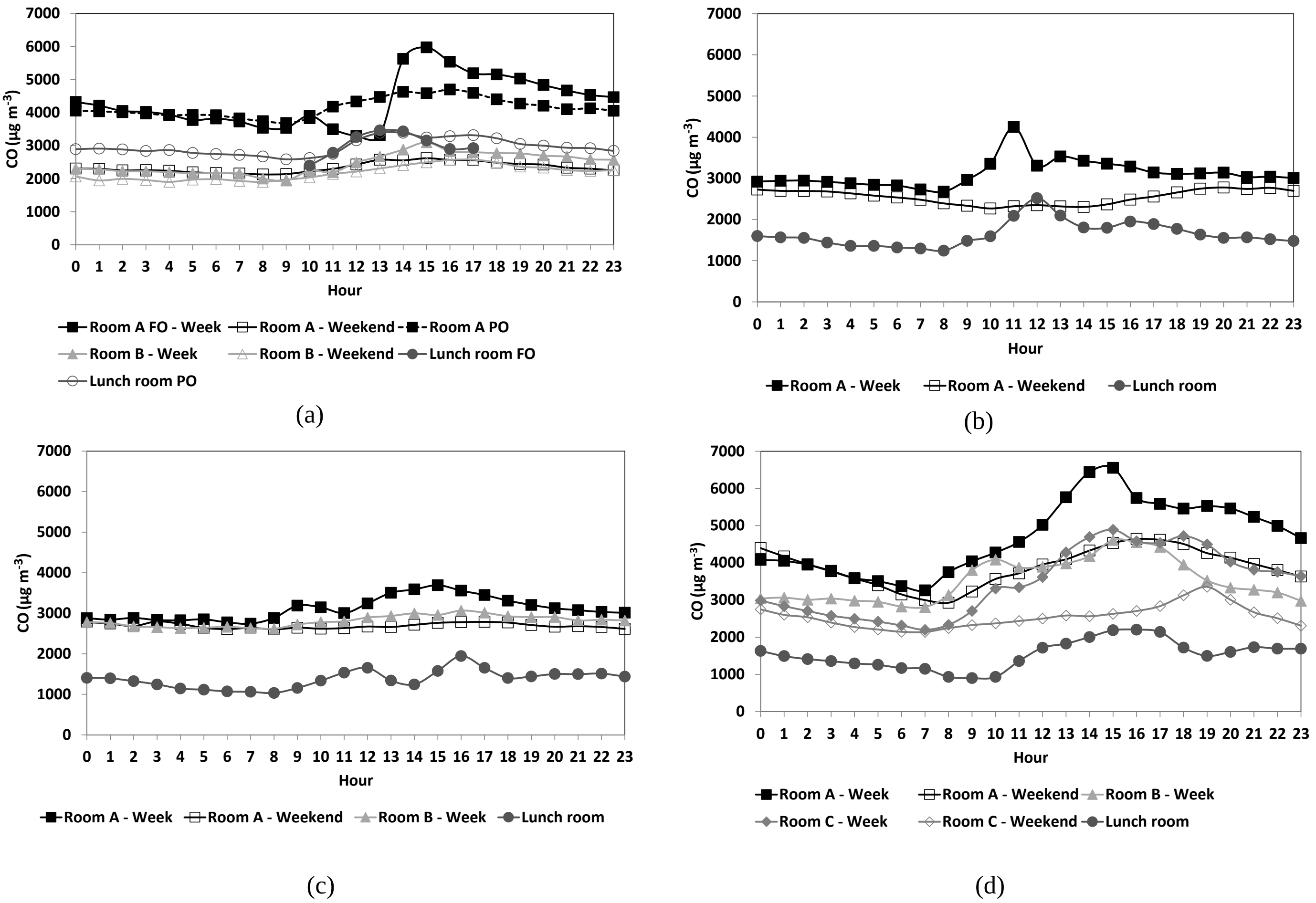

7000
6000
5000
4000
3000
2000
1000
0
CO (µg m-3)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
Room A FO - Week
Room A - Weekend
Room A PO
Room B - Week
Room B - Weekend
Lunch room FO
Lunch room PO
(a)
Room A - Week
Room A - Weekend
Lunch room
(b)
Room A - Week
Room A - Weekend
Room B - Week
Lunch room
(c)
Room A - Week
Room A - Weekend
Room B - Week
Room C - Week
Room C - Weekend
Lunch room
(d)

Figure 2.

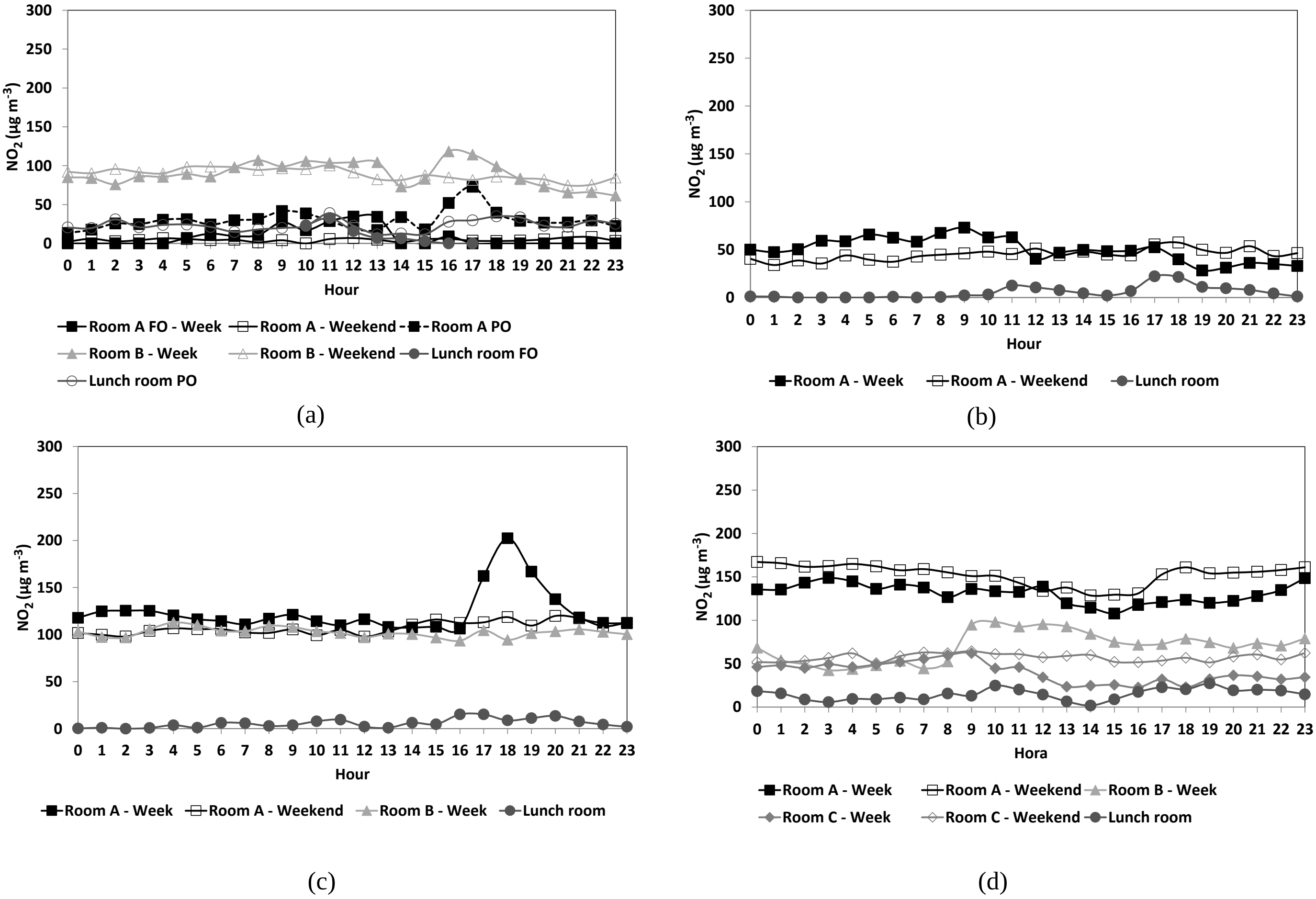
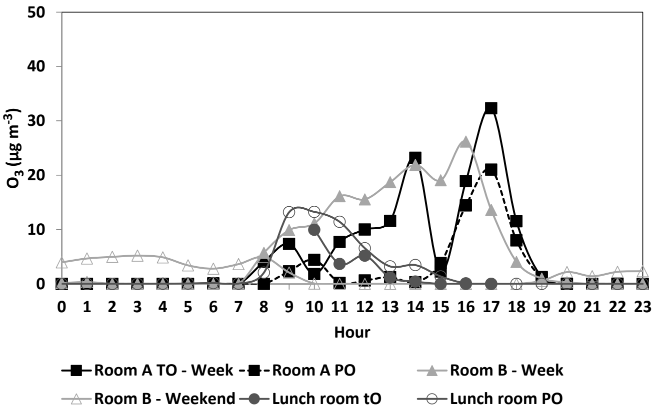
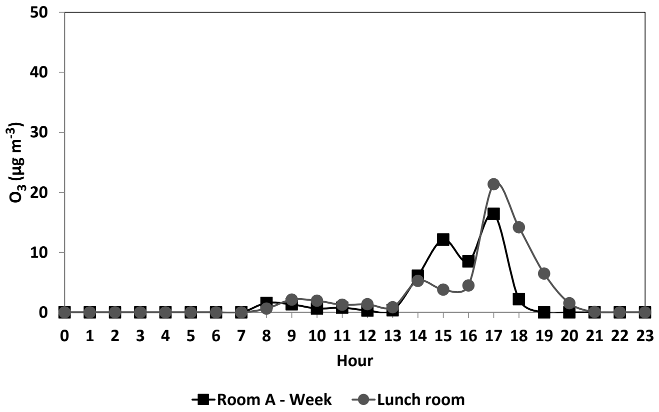

(a)
NO2 (µg m-3)
Hour
Room A FO - Week
Room A - Weekend
Room A PO
Room B - Week
Room B - Weekend
Lunch room FO
Lunch room PO
(b)
NO2 (µg m-3)
Hour
Room A - Week
Room A - Weekend
Lunch room
(c)
NO2 (µg m-3)
Hour
Room A - Week
Room A - Weekend
Room B - Week
Lunch room
(d)
NO2 (µg m-3)
Hora
Room A - Week
Room A - Weekend
Room B - Week
Room C - Week
Room C - Weekend
Lunch room

Figure 3.



(a)



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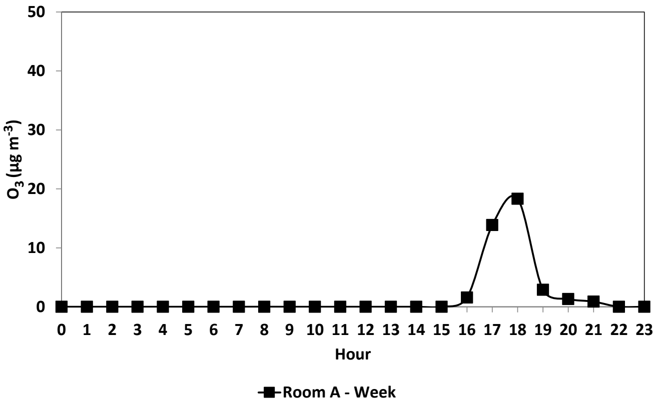

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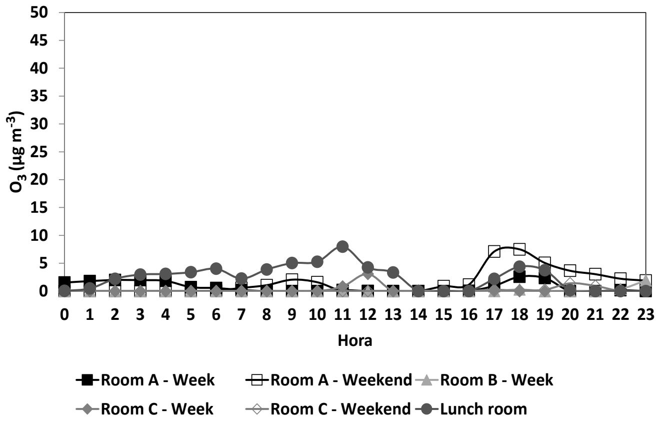


(d)

Figure 4.

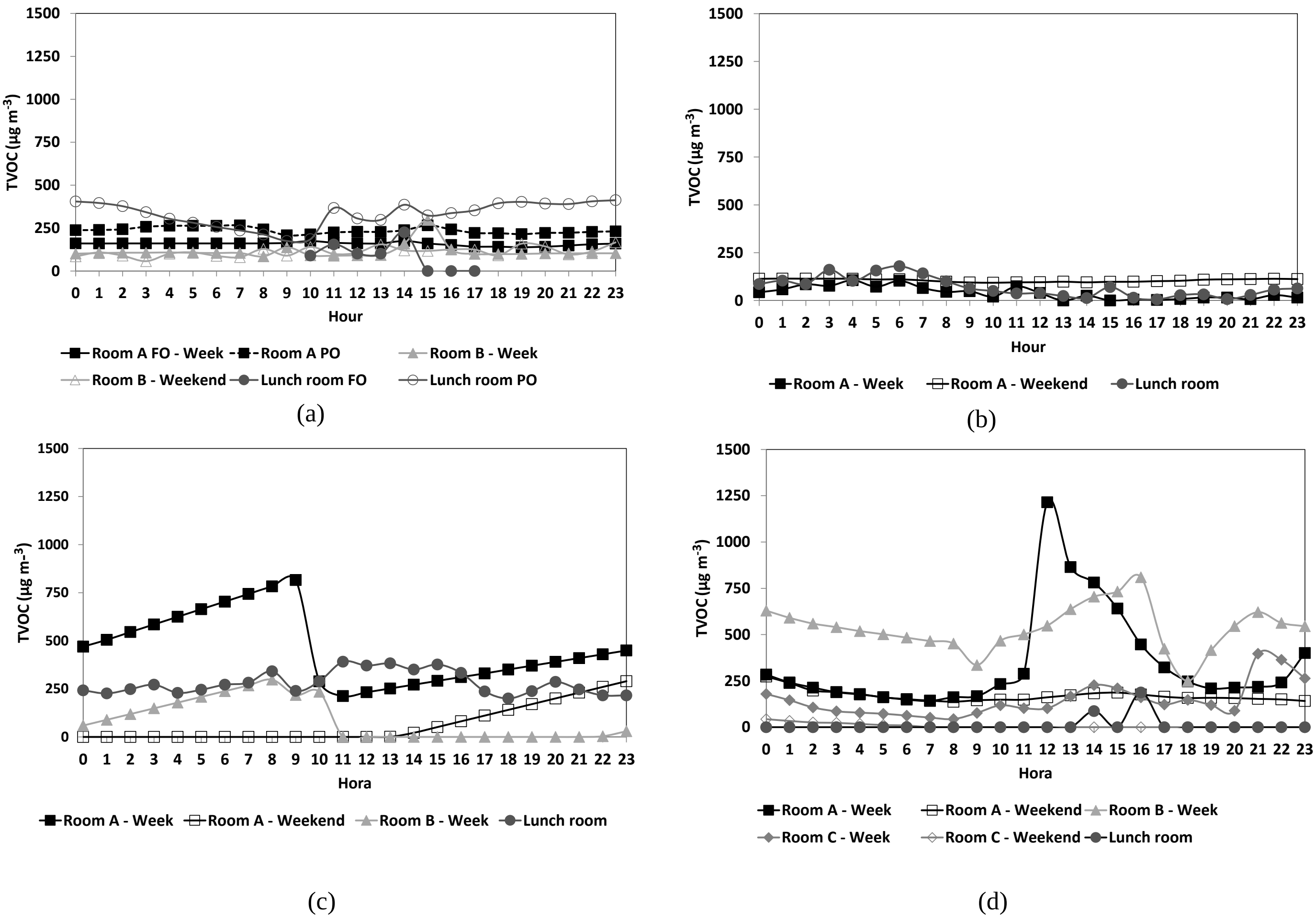
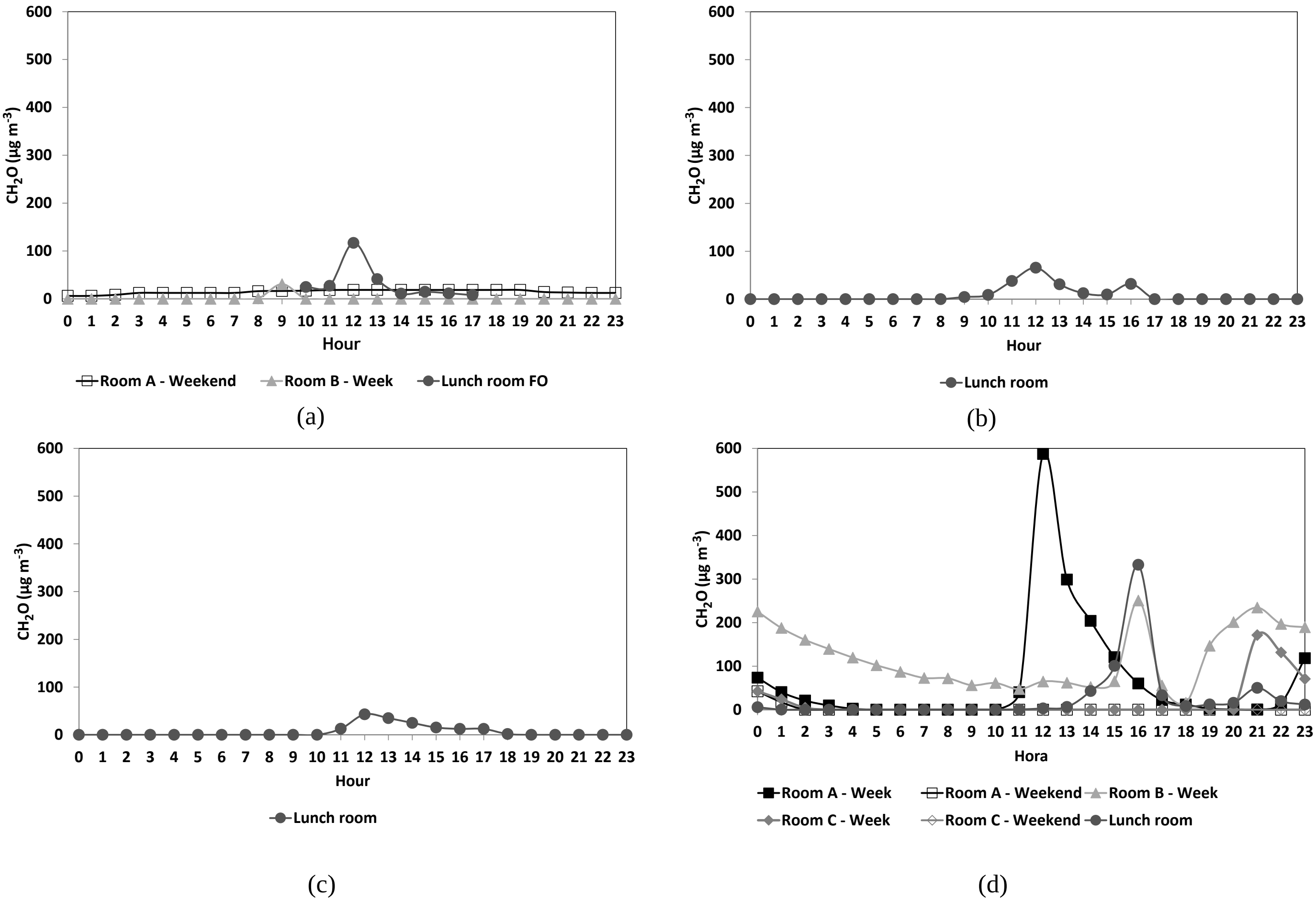

(a)
TVOC (μg m-3)
Hour
Room A FO - Week
Room A PO
Room B - Week
Room B - Weekend
Lunch room FO
Lunch room PO
(b)
TVOC (μg m-3)
Hour
Room A - Week
Room A - Weekend
Lunch room
(c)
TVOC (μg m-3)
Hora
Room A - Week
Room A - Weekend
Room B - Week
Lunch room
(d)
TVOC (μg m-3)
Hora
Room A - Week
Room A - Weekend
Room B - Week
Room C - Week
Room C - Weekend
Lunch room

Figure 5.



CH2O (µg m-3)
Hour
Room A - Weekend
Room B - Week
Lunch room FO
(a)
Lunch room
(b)
Lunch room
(c)
Hora
Room A - Week
Room A - Weekend
Room B - Week
Room C - Week
Room C - Weekend
Lunch room
(d)

Figure 6.