Topic 3. Indoor and outdoor air quality, thermal comfort and health impact related to built environment

Indoor Air Quality in Portuguese Children Day Care Centers – ENVIRH Project

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SUMMARY

This paper describes field measurements of indoor air quality (IAQ) parameters, performed in 19 Portuguese Children Day Care Centers (CDCC) during the springtime of 2011 and aims to characterize the indoor environment.

The results demonstrate an association between carbon dioxide and bacterial concentrations, which in turn are affected by the number of children present in each classroom. Indoor PM_{10} concentrations were higher than outdoor levels (I/O ratio>1) and was also found statistically significant association between PM_{10} concentrations and the type of floor covering materials.

These results provide evidence that IAQ is inadequate and, as a consequence, human source contaminants such as bacteria and carbon dioxide accumulate indoors. This study suggests that it is necessary to improve ventilation in order to achieve a healthier indoor environment.

INTRODUCTION

The negative impact of a poor indoor air quality in children's health is well recognized and the development of a relation between air quality, ventilation and children's health is considered crucial from this point of view. Children attending day care centers have been reported to be more susceptible to infectious diseases when compared with those cared for at home and are exposed to conditions that may increase the risk of allergies and asthma (Zuraimi et al., 2007, Hagerhed – Engman 2006).

Several studies revealed poor ventilation conditions associated with high levels of carbon dioxide to be common in schools (Van Dijken et al. 2006, Mumovic et al. 2009, Borodinecs and Budjko 2009) and are often related with the raise of many other indoor pollutants accumulated as a consequence (Norback et al. 2011, Freitas et al. 2011). Indoor air quality depends not exclusively on ventilation rates, but also on indoor pollutant sources, occupant's behavior and outdoor air pollution (Jantunen 2006). Poor ventilation may increase indoor generated contaminants and elicit symptoms among occupants, however good ventilation is generally related with poor thermal comfort (Mumovic et al. 2009).

According to Sundell et al. (2011) there is a need for studies exploring the relationship between ventilation rates, pollutant sources and health in buildings such as day care centers in regions of the world different from North America and northern Europe.

Portugal is the westernmost country of Europe, is bordered by the Atlantic Ocean to the West and South and by Spain to the North and East and has a temperate continental climate with dry and mild summer.

This paper describes field measurements of chemical (carbon dioxide, carbon monoxide, formaldehyde, total volatile organic compounds and PM10) and microbiological (bacteria and fungi) indoor contaminants, as well as thermal comfort parameters, performed in order to investigate indoor environmental quality in 19 children day care centres (CDCC), located in two different urban centres of Portugal, Lisboa and Porto.

The present study is part of a larger project ENVIRH (Environment and Health in children day care centres) that intends to correlate IAQ, building characteristics and ventilation patterns with children's health.

METHODS

The monitoring tasks were carried out in 125 classrooms of 19 CDCC located in the urban areas of Lisboa and Porto. The studied CDCC were selected from a universe of 45 using a cluster analysis (Ward's method) considering indoor carbon dioxide concentrations, relative humidity and temperature measurements.

Monitoring surveys were carried out in the cities of Lisboa and Porto, during a two-month period (March-April) corresponding to spring conditions. Lisboa maximum air temperatures ranged from 15°C to 27.5°C and minimum air temperatures from 10° C to 17°C. The city of Porto registered maximum air temperatures in the range of 16-28°C and minimum air temperatures from 4 to 13.5°C.

In each CDCC were evaluated from 5 to 9 classrooms, being monitored at least one classroom per age group (3 month up to 5-6 years), and all measurements being conducted during routine school activities (from 10 AM to 5 PM). The following parameters were determined: air temperature, relative humidity and velocity, mean radiant temperature, PM_{10}, carbon dioxide, carbon monoxide, total volatile organic compounds (TVOCs), formaldehyde, bacteria and fungi. Outdoor measurements of chemical and biological parameters were also conducted. Formaldehyde was collected by active sampling on impingers, using personal pumps GilAir 5 operating at 1L/min airflow and analyzed according to NIOSH 3500 method using visible spectrometry. PM_{10} were collected by active sampling on pre-weighted PTFE filters mounted on PM_{10} collectors (PEM, SKC), using GilAir 5 personal pumps operating at 2L/min, followed by gravimetric analysis for particle mass. Total volatile organic compounds (TVOC) were actively collected on TENAX Tubes using SKC personal pumps calibrated to 0.5L/min and analyzed after thermal desorption using gas chromatography according to ISO 16000-part 6. Carbon monoxide and carbon dioxide were monitored using a Photoacoustic Multi-gas Monitor Type 1312, INNOVA, Air Tech Instruments. Samples of viable airborne bacteria and fungi were collected using the Microbiological Air Sampler MAS-100 (Merck) with Malt Extract Agar (MEA) plates supplemented with chloranphenicol and Trypticase Soy Agar (TSA) as collecting media for fungi and total bacteria respectively.

Thermal parameters (air temperature, air velocity, relative humidity and mean radiant temperature) were monitored using an INNOVA 1221 Thermal Comfort Data Logger. Thermal comfort was evaluated according to the ISO 7730 International Standard (2005). The metabolic rate was estimated in 1.4 met and the thermal insulation of clothing was estimated in 0.7 clo.

The equipment for environmental quality assessment was placed at the breathing zone of children (0.5-0.7m) for chemical and microbiological parameters and at children abdomen level for thermal parameters.

Statistical analysis

An exploratory analysis was carried out for carbon dioxide, carbon monoxide, formaldehyde, PM_{10}, TVOC, viable airborne bacteria and fungi, thermal parameters (air temperature, air velocity, relative humidity and mean radiant temperature). Categorical data were presented as frequencies and percentages, and continuous variables as mean or median, standard deviation (SD) or inter-quartile range (25th percentile-75th percentile). Nonparametric tests (Chi-squared test or Fisher's Exact test as required, Mann-Whitney U and Kruskall-Wallis) were used due to the existence of outliers, high variability and skewed distributions. Scatter plots showed that there was no linear association between the natural logarithm of CO_2 levels and bacterial concentrations, bacteria and number of children, therefore, Generalized Additive Models (GAMs) for Gaussian response were used. The level of significance was $\alpha = 0.05$. Data analysis was performed using the software SPSS 15.0 (Statistical Package for Social Sciences, Chicago, Illinois, USA) and R software, version 2.14.2 (R Development Core Team 2008).

RESULTS

Most of the studied CDCC are located in old buildings adapted to the current use, with a mean age up to 60 years. The classrooms mean net floor area is $35m^2$ ($102\ m^3$) and the number of children range from 5 to 29 per room (mean 17). Seventeen of the studied CDCC are naturally ventilated and two are mechanically ventilated, however it was observed *in situ* that the ventilation system was off and the windows open, so all the CDCC were considered naturally ventilated. The floor covering materials were wood, tile/stone or PVC, according to the CDCC.

Descriptive statistics regarding chemical and microbiological contaminants, Indoor/Outdoor ratios (I/O) and comparison with reference values (Decreto-Lei 79/2006) are shown in tables 1 and 2.

Table 1 - Descriptive statistics of the studied chemical parameters CDCC classrooms (n=125)

Chemical contaminants	Median[1] (mg/m^3)	Minimum (mg/m^3)	Maximum (mg/m^3)	Reference (mg/m^3)	≥ Ref. (%)	I/O
LISBOA (n=73)						
Carbon Dioxide	1850	827	5630	1800	53	2,20
Carbon Monoxide	0,630	0,275	7,5	12,5	0	1,23
PM_{10}	0,143	<0.007*	9,01	0,15	49	1,13
TVOCs	0,153	0,038	6,44	0,600	18	2,36
Formaldehyde	<0,02*	<0,02*	0,09	0,100	0	-
PORTO (n=52)						
Carbon Dioxide	2541	642	5647	1800	73	-
Carbon Monoxide	0,339	0,036	0,920	12,5	0	-
PM_{10}	0,116	0,040	0,420	0,15	35	1,49
TVOCs	0,114	0,036	0,920	0,600	4	3,65
Formaldehyde	<0,02*	<0,02*	0,362	0,100	0	-

[1] - non-normal distribution |*LOD –Limit of detection

The median CO_2 concentrations obtained during routine activities were above the recommended limit (1800 mg/m^3) in more than 50% of the studied rooms. There are statistically significant differences (p=0.005) between carbon dioxide median concentrations in Lisboa (1850; P_{25}:1365; P_{75}:2625) and Porto (2541; P_{25}:1761; P_{75}:3566).

The concentrations of TVOC and formaldehyde found in most of the rooms were acceptable and the median concentrations of formaldehyde were under the limit of detection (LOD). Indoor PM_{10} concentrations were higher than outdoor levels (I/O ratio>1) in 43% of the CDCC, being generally also above recommended limits.

The obtained bacterial concentrations, shown on table 2, were above the reference concentration defined by the Portuguese regulation in more than 95% of the schools and the I/O ratio>10. Although in some rooms were observed water infiltrations there was no visible mould growth and the I/O ratio, close to 1, obtained to fungi suggests the outdoor air is the probable contamination source. In 37% of the classrooms fungal concentrations were above the Portuguese regulation recommended limits.

Table 2 - Descriptive statistics of microorganisms in the studied CDCC classrooms (n=125)

Microbiological contaminants	Median[1] (UFC/m^3)	Minimum (UFC/m^3)	Maximum (UFC/m^3)	Reference (UFC/m^3)	≥ Ref. (%)	I/O
LISBOA (n=73)						
Total Bacteria	3115	260	26280	500	97	13,1
Fungi	498	4*	10512	500	49	1,0
PORTO (n=52)						
Total Bacteria	4432	510	18770	500	98	48,8
Fungi	300	15	1555	500	19	1,2

[1] - non-normal distribution |*LOD –Limit of detection

Figure 1 illustrates the increase of bacterial concentration with the increase of the number of children present in the classroom. The observed decrease of bacterial concentrations for children's number higher than 20 may be due to the small number of classrooms in those circumstances (leading to a wide confidence interval).

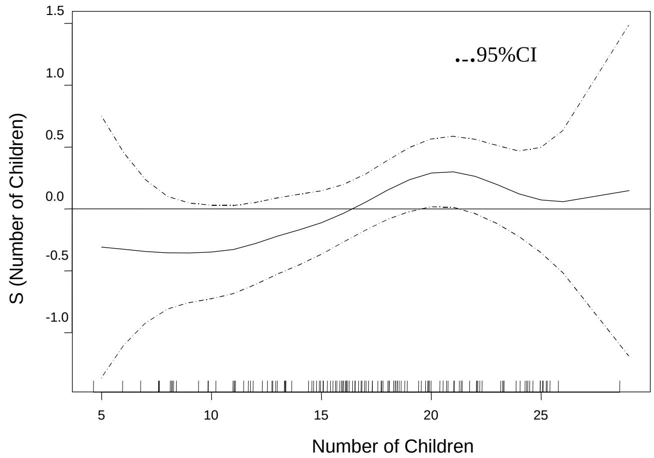

Figure 1. Functional form of number of children influence on bacterial concentration (_) and corresponding 95% confidence interval (...) (zero line means no influence).

Figure 2 illustrates the increase of carbon dioxide concentration natural logarithm with the increase of bacterial concentrations. The decrease that can be observed for bacterial concentration higher than approximately 7000 UFC/m^3 may be due to the small number of classrooms with such higher concentration (leading to a wide confidence interval).

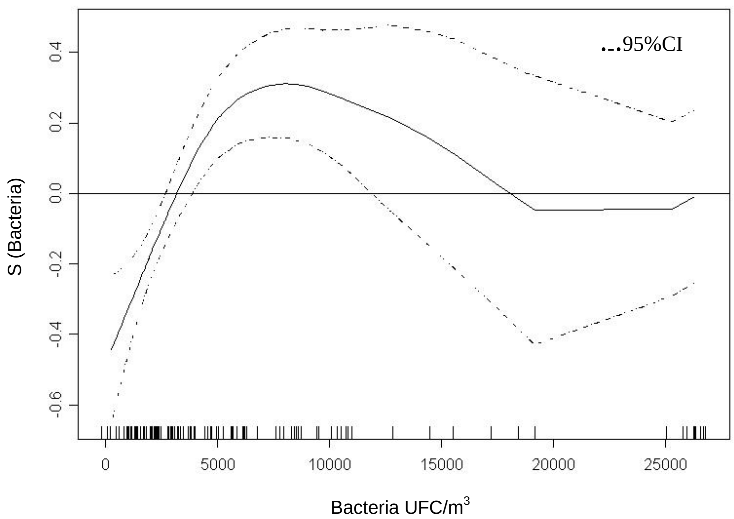

Figure 2. Functional form of bacterial concentration influence on carbon dioxide natural logarithm (_) and corresponding 95% confidence interval (...) (zero line means no influence).

The box plots, in Figure 3, illustrate the difference between indoor and outdoor carbon dioxide concentrations according to window type of moving leaf, showing a greater difference in casement windows, followed by sliding windows, being the smallest difference obtained for tilting windows.

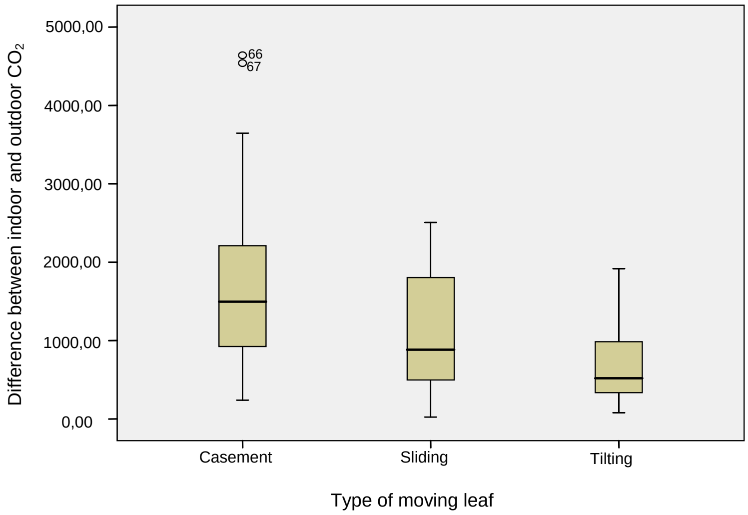

Figure 3. Difference between indoor and outdoor carbon dioxide concentrations according to window type of moving leaf

In table 3, PM_{10} median concentrations and the 25 and 75 percentiles (P_{25}, P_{75}) are presented, according to the type of floor covering materials in CDCC located in Lisboa. It was observed a statistically significant association (overall p=0.011) between PM_{10} concentrations and the type of floor covering material, wood/cork *versus* tile (p=0.015), wood/cork *versus* PVC (p=0.005) and tile *versus* PVC (p=0.778), this onewithout statistical significance.

Table 3. Association between PM_{10} and floor covering materials in CDCC classrooms located in Lisboa (n=73)

Floor covering materials	P_{25}	Median[1]	P_{75}
Wood and Cork	0,20	0,97	3,56
Tile	0,05	0,12	0,67
PVC	0,08	0,12	0,82

[1] - non-normal distribution

The median indoor air temperature is higher in Lisboa than in Porto reflecting outdoor air temperatures. There were no reported complaints about local thermal discomfort and none of the CDCC had warm or cold floors, thus, thermal parameters required to calculate the local discomfort indices were not measured. In 26 of the studied classrooms (n=125) the obtained PPD was under 6%, in 65 classrooms the PPD was under 10% and 92 rooms registered PPD under 15%. In 33 of the studied classrooms the PPD was above or equal to 15%, most of them due to a cool sensation.

The results indicate that in some of the studied rooms there could be some discomfort for the body as a whole among children due to the thermal environment.

DISCUSSION

In Portugal, a significant number of CDCC are naturally ventilated and when outdoor temperature is comfortable the windows are left open and room thermal environment reflects outdoor meteorological conditions. The thermal environmental conditions determined are not comfortable in 33 out of 125 studied classrooms.

The differences between indoor and outdoor carbon dioxide are influenced by the type of window moving leaf, which influences the ventilation habits, with higher differences obtained in classrooms with casement windows (kept closed), followed by sliding windows and tilting windows that are kept habitually open. The highest CO_2 concentrations found in CDCC located in Porto are probably due to the cooler outdoor temperature that induces occupants to maintain windows closed.

Most of the particulate matter found in schools has its origin outdoors and the high concentrations of PM_{10} are probably related with children's activity that induces deposited particulate matter to become airborne (Freitas et al. 2011, Janssen et al. 1999). One of the determinants of indoor PM_{10} concentrations is the floor covering material, being observed that wooden floor is more likely to constitute a PM_{10} indoor source, probably due to the larger junctions that make cleaning difficult.

The ratios between indoor and outdoor concentrations of contaminants are indicators of the extent to which those found indoors are dominated by indoor sources (Jantunen 2006, Zuraimi et al. 2003). The high I/O ratios (>10) obtained to bacteria indicate that indoor sources are probably at the origin of the contamination (Zhao 2009).

The high levels of human related contaminants such as carbon dioxide and bacteria, having the latter an association with children number per classroom, allied to the fact that in classrooms children are positioned close to each other, have been identified by several author as risk factors to the spread of bacterial and viral infections (Olmedo et al. 2012, Gupta et al. 2010 and Zuraimi et al. 2007).

This study suggests that it is necessary to improve ventilation and comfort in order to achieve a healthier indoor environment. In countries such as Portugal with temperate continental climate, efforts should be made to ventilate classrooms through short airing during school breaks (windows opening) without energy consumption as described in published papers (Heiselberg and Perino 2010).

CONCLUSIONS

As mentioned before, this study corresponds to the spring IAQ evaluation and is part of a large project currently under development. Despite of the obtained preliminary data suggesting that it is necessary to improve ventilation, it is expected that the results from the winter campaign (under development) will provide further input for a better understanding of the conditions under research.

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