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INDOOR AIR QUALITY IN PRIMARY SCHOOLS

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Abstract: Nowadays, Indoor Air Quality (IAQ) is a subject of high importance due the several studies that were conducted in the past years and which revealed the impact of poor IAQ upon on schools, such as students' absence and acute health symptoms that decrease students' performance. The IAQ in classrooms is expected to play a key role in the assessment of the effects of the children's personal exposure to air pollution since they spend on average 7-11h per weekday at school. A statistical treatment was conducted over a database of indoor air parameters and the primary schools where these parameters were sampled (urban area of Lisbon, Portugal). The aim of this study was to assess the associations between indoor air parameters (measured inside classrooms of primary schools) with the schools building characteristics, through the use of statistical methods. Several associations were found. Overall, the conclusions of this study point to the following recommendations: 1) classrooms should face streets rather than patios and should not be located in basements, 2) the density of students can affect the indoor environment and should be limited, 3) wooden materials appear to have advantages as building materials due to a lower input of contaminants. Other factors, like ventilation, cleanings and use chalk versus whiteboard pens, can reduce or increase specific contaminants inside the classrooms.

Key words: Indoor air quality, primary schools, statistical treatment, building materials, indoor air pollutants

INTRODUCTION
Clean air is a basic requirement of life (WHO, 2010). The Indoor Air Quality (IAQ) has been the object of several studies due to an increasing concern within the scientific community on the effects of indoor air quality upon health, especially as people tend to spend more time indoors than outdoors (Canha et al., 2010; Freitas et al., 2011; Fraga et al., 2008; Lee et al., 2002). The quality of air inside homes, offices, schools or other private and public buildings is an essential determinant of healthy life and people's well-being (WHO, 2010).

People can be exposed to contaminants by inhalation, ingestion and dermal contact. In the past, scientists have paid much attention to the study of exposure to outdoor air contaminants, because they have realised the seriousness of outdoor air pollution problems. However, each indoor microenvironment has unique characteristics, determined by the local outdoor air, specific building characteristics and indoor activities (Pegas et al, 2010). Indeed, hazardous substances are emitted from buildings, construction materials and indoor equipment or due to human activities indoors (Carrer et al., 2002).

Reports about buildings with air-related problems have received increasing attention since the 1970s (Spengler, J.D. and K. Sexton, 1983). In an indoor environment, dust on floors and other surfaces contains minerals, metals, fibres from textiles, paper, and insulation material, particles from tobacco smoke, including polycyclic aromatic compounds (PAH's). For this reason, the indoor environment is cleaned to maintain an acceptable level of perceived cleanliness, to prevent surface degradation, to control potential risk of infection from microorganisms, and to control dust exposure in general. All of these pollutants could cause significant damage to health globally (WHO, 2010).

The IAQ in school buildings is expected to be a key role player in the assessment of the effects of the children personal exposure to air pollution as children spend at least a third of their time inside school buildings, that is, approximately seven or more hours a day in school (Almeida et al., 2010; Pegas et al., 2010). Poor IAQ can affect scholarly performance and attendance (Mendell, M. and G. Heath, 2005). Environmental asthma triggers commonly found in school buildings include respiratory viruses; cockroaches and other pests; mold resulting from excess moisture in the building; dander from animals in the classroom; and dander brought on the clothing from animals at home. Second-hand smoke and dust mites are other known environmental asthma triggers found in schools. Children with asthma may be affected by other pollutants from sources inside schools, such as unvented stoves or heaters and common products including chemicals, cleaning agents, perfumes, pesticides and sprays.

Indoor Air Quality problems in schools may be even more serious than in other categories of buildings, due to higher occupant density and insufficient outside air supply, aggravated by frequent poor construction and/or maintenance of school buildings (Pegas et al., 2010). Schools are seen as particularly likely to have environmental deficiencies because chronic shortages of funding contribute to inadequate operation and maintenance of facilities. Previous studies showed the poor indoor environmental quality at schools may be explained by: (1) insufficient ventilation in schools, especially in winter, (2) infrequently and not thoroughly cleaned indoor surfaces, and (3) a large number of students in relation to room area and volume, with constant re-suspension of particles from room surfaces (Janssen et al., 1999).

Children constitute a sensitive group with higher risk than adults because children are particularly vulnerable to pollutants due to their undeveloped airways (Stranger et al., 2007). Moreover, children have greater susceptibility to some environmental pollutants than adults, because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing (Mendell, M. and G. Heath, 2005). The effects of air pollution on children have been growing (Khan et al., 2007) and one of the consequences is the increase of the prevalence of allergic rhinitis (ISAAC, 1998).

The aim of this study was to assess the associations between indoor air parameters (measured inside classrooms of primary schools) with the schools building characteristics, through the use of statistical methods. Improving the understanding of the sources of the indoor air pollutants in schools, this study will contribute to identify what sort of additional actions should be taken to enforce an effective improvement of IAQ in schools.

EXPERIMENTAL

Sampling Site And Schools Description

This study was carried out in Lisbon, which is the largest city of Portugal. Lisbon has a population of about half a million inhabitants in 84.8 km^2 while the metropolitan area of 2870 km^2 has around 2.8 million inhabitants. Data on the characteristics of classrooms and indoor air were collected in 14 primary schools in Lisbon. Figure 1 shows the location of these 14 primary schools. For each school, data were collected in two classrooms, named for reference purposes as classroom “a” and classroom “b”. The information concerning the classrooms characteristics is already presented and described (Freitas et al., 2011). All schools have natural ventilation and there is no forced ventilation or air conditioning system in use (ventilation is done by opening doors and windows). The data studied here is part of a larger study, which has been described and analysed in previous research (Almeida et al., 2011; Canha et al., 2010, 2011; Pegas et al., 2010, 2011).

Figure 1. Spatial distribution of the 14 primary schools in Lisbon, Portugal, studied in this work.

Sampling And Chemical Analysis

Three campaigns for total particulate matter sampling were conducted: spring (May-June 2009, total of 34 days), autumn (October-December 2009, total of 62/68 days) and winter (January-March 2010, total of 76/78 days). Sampling of VOCs and carbonyls was performed in the same periods but only for 14 consecutive days within the studied season. Although there are results for all the campaigns and measured parameters, only the campaigns and measured parameters which have results for the two classrooms of all 14 schools were considered in this study. The sampling and analysis methods used for the studied parameters were already fully described elsewhere (Freitas et al., 2011). All the values of the parameters were normalized to the day. The indoor analysed parameters were: VOCs, Carbonyls and Total Particulate Matter (TPM, by passive deposition) and its composition in terms of chemical elements and water-soluble ions.

Statistical Analysis

Wilcoxon signed rank tests (Hollander, M. and D.A. Wolfe, 1973) were used to test differences between seasonal concentrations of the studied parameters. To investigate the association between independent variables (classroom characteristics) and dependent variables (measured parameters), for each dependent variable a linear model was first applied using all the ten independent variables characterizing the classrooms. The independent variables considered are: 1) level of classroom, 2) number of student per m^3, 3) number of windows and doors opened, 4) type of board, 5) floor material, 6) ceiling material, 7) presence of heating device, 8) dusty surfaces, 9) number of cleanings per day, 10) view from classroom. The thirty-one dependent variables analysed are part of one of the following groups: 1) total particle mass, 2) chemical element mass, 3) mass of water soluble ions, 4) VOCs, 5) carbonyls.

Then, the independent variables were taken out from the model, one by one, in order to select the best model. The best model selected was the one that minimized the AIC (Akaike, H., 1974; Hollander, M and D.A. Wolfe, 1973) and had all terms significant. This analysis was conducted in the statistics package R. All selected models have all terms significant at 5%. The multiple R-squared refers to the fraction of variance explained by the model and was calculated for all selected models.

RESULTS

Seasonal Variability

The seasonal variation of total particulate matter is resumed in Figure 2. The results of the Wilcoxon signed rank tests indicated that the concentration of total particles in the air is lower in the spring than in the autumn ($p=0.001$) and in the winter ($p<0.001$). On the other hand, the tests showed no evidence to suggest a difference in the concentration of total particles in the air between the autumn and the winter ($p=0.76$).

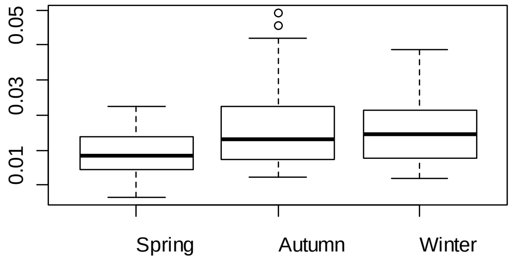

Figure 2. Boxplot of TPM mass, in mg/day, in three seasons in 28 classrooms of 14 primary schools.

Concerning to Cr, K, Sb, Sc and Zn concentrations in autumn and winter in 28 classrooms of the 14 schools, an evidence was found which suggest that the air concentration is smaller in the winter than in the autumn for Cr ($p<0.001$), K ($p=0.03$) and Sb ($p=0.016$). On the contrary, there is no evidence supporting a difference between autumn and winter in the concentrations of Sc ($p=0.11$) and Zn ($p=0.22$).

About VOCs and carbonyls, the statistical tests suggested that the air concentrations are larger in the winter than in the autumn for pentane ($p<0.001$), isooctane ($p<0.001$) and acetone ($p<0.001$). The test results supported that the concentration of benzene in the air is lower in the spring than in the autumn ($p<0.001$). There is also evidence that the concentration is smaller in the autumn than in the winter ($p<0.001$). The results indicated no difference in the concentration of toluene between the spring and the autumn ($p=0.20$), but suggested that the concentration is smaller in the spring than in winter ($p<0.001$) and also smaller in the autumn than in the winter ($p<0.001$).

Analysis of the Association of the Classroom/School Characteristics and the Particle Mass, Water Soluble Ions, Air Concentration of Certain Elements VOCs

The results obtained are summarized and fully described in a work already published (Freitas et al., 2011). The effects (i.e. regression coefficients) are shown for variables with significant effects. Figure 3 illustrates the relation of some of these variables in boxplot charts.

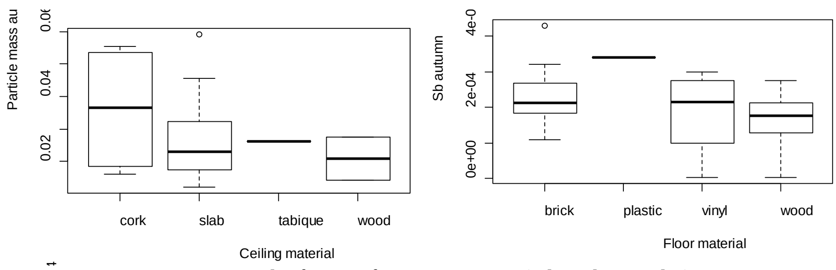

Figure 3. Boxplot for significant parameters (selected examples).

Mass of total particulate matter: In autumn and winter, 73% and 67% respectively of the variability across classrooms of the particle mass indoor is explained by classroom characteristics. There are negative significant associations with the number of windows opened ($p<0.01$ in autumn; $p<0.05$ in winter) and the existence of heating device ($p<0.001$ in autumn; and $p<0.05$ in winter). Classroom facing the street – as opposed to an inner patio – are associated with lower concentrations of particle mass indoor in both autumn and winter ($p<0.001$ in autumn and $p<0.01$ in winter). The ceiling material ($p<0.001$ in autumn and $p<0.01$ in winter) has also a significant effect, with the results suggesting that wood may be associated with lower levels of particle mass indoor and false ceilings with higher levels of particle mass indoor. Regarding the particle mass in spring, none of the variables is significant at 5%.

Chemical elements in particulate mass: Available measurements for the chemical elements refer all to the autumn season. The classroom characteristics considered in this study explained 57% of the variability of Cr. Significant effects were found for: (i) the ceiling material ($p<0.05$), with a positive association with wood ceilings, and (ii) the existence of a heating device ($p<0.05$) with lower Cr when devices are present. According to the value of the multiple R^2, the floor and ceiling materials explain together 52% of the variation of the Sb in particle mass indoor. The significant effects of floor material ($p<0.05$) and the ceiling material ($p<0.01$) suggest lower Sb amount in classrooms with vinyl floors and slab ceilings. For Sc in particle mass, 57% of its variation is explained by: (i) the number of windows/doors opened ($p<0.05$), which is negatively associated to Sc, (ii) the use of whiteboard with pen ($p<0.01$), which is associated to higher Sc amount, (iii) the ceiling material ($p<0.05$), with slab associated to lower levels of Sc in the classroom, and (iv) the classroom facing the streets as opposed to an inner patio, the former being negatively associated to the Sc amount in the classroom ($p<0.05$). With 55% of the variability explained, the Zn in particle mass displays significant effects for (i) the number of students per m^3 (positive relation, $p<0.01$), (ii) the existence of a heating device in the classroom (negative relation, $p<0.05$), (iii) the dust present in the classroom (negative relation, $p<0.01$) and (iv) the number of cleanings per day (negative relation, $p<0.001$).

Water-soluble ions in particulate mass: All data on ions were collected in the winter season. The classroom characteristics appear to explain a large part of the variability across classrooms of Cl^-, Mg^{2+} and Na^+ ions (multiple R^2 equals 0.81, 0.77 and 0.68, respectively). On the contrary, few variation has been explained for the SO_4^{2-} and Ca^{2+} ions, as the multiple R^2 are relatively low (0.18 and 0.25, respectively). This suggests that other factors, not included in this study, may have responsibility for the variability of these ions. For example, the sodium and chloride ions present significant associations with almost the same group of variables. Namely, both ions present significant associations with the floor level of the classroom ($p<0.05$) suggesting lower concentrations in the ground and 1st floors. The floor and the ceiling materials also have significant effects on these two ions with wooden floors and ceilings presenting the lowest coefficient and thus associated with lower concentrations. In addition, the number of cleanings per day also has a significant negative effect (Na^+: $p<0.05$; Cl^-: $p<0.001$). The results indicate that the use of whiteboard with pen – as opposed to blackboard with chalk - is associated with higher levels of the soluble ion Cl^- indoor ($p<0.01$) and the number of windows/doors opened is associated with lower levels of Na^+ indoors. Results for the water soluble ions K^+, F^-, NO_3^- and PO_4^{3-} are described elsewhere (Freitas et al., 2011).

VOCs and Carbonyles: For example, toluene and isooctane, both collected in autumn, present significant effects for the same variables: floor level ($p<0.001$ and $p<0.01$, respectively), ceiling material ($p<0.001$), heating device ($p<0.001$) and classroom facing street/inner patio ($p<0.01$). These variables explain 92% and 80% of variability of these pollutants, respectively. For both VOCs, higher concentrations are associated with classrooms in the basement, facing inner patios or without heating devices. Classrooms with wooden ceilings are associated with higher levels of toluene while classrooms with cork ceilings are associated with higher levels. Lower concentrations of both are associated with classrooms on the ground floor, with heating devices, facing the street. Classrooms with slab ceilings are associated with lower levels of toluene and those with wooden ceilings are associated with lower levels of isooctane. Benzene was measured in spring, autumn and winter, but only the autumn and winter measurements show significant effects with variables considered in this study, which explained 82% and 53%, respectively, of the variation of those measurements. For the autumn measurement, significant effects were found for floor level ($p<0.01$), floor material ($p<0.05$), presence of heating device ($p<0.001$), dust in surfaces ($p<0.01$) and classroom facing the street/inner patio ($p<0.001$). The concentration of benzene in winter was shown to be significantly larger from that in the autumn and the set of variables with significant effects is also different: type of board ($p<0.01$), the ceiling material ($p<0.05$), dust ($p<0.05$) and the number of cleanings per day ($p<0.05$). Results for m+p xylene, n-hexane, acetone, 2-methylpentane, cychlohexane, ethanol and isopropanol, which variation is between 78% to 50% and it is explained by a one or more schools characteristics, are described elsewhere (Freitas et al., 2011). For all other VOCs and carbonyls, the multiple R^2 is less than 50% and the selected models contain at most two variables with significant effects.

DISCUSSION OF THE RESULTS

In this study, models were applied to several components of the air to investigate associations with classrooms characteristics. Some patterns emerged across these analyses:

1. Classrooms facing a street seem to have lower air concentrations of several components than those facing an inner patio. This could be linked to ventilation issues as inner patios may generate less air movement and consequent accumulation of some components. Classrooms facing the inner patios are associated with higher concentration of Au, Sc, PO43-, F-, isooctane (autumn), acetone, benzene (autumn) and toluene, as well as TPM mass with less particle mass in the autumn and winter.
2. Classrooms with higher number of windows/doors opened were associated with less particle mass, K, Sc, acetone and Na^+ in the air, possibly due to increased ventilation. However, a larger number of opened windows/doors was also associated with more o-xylene and ethanol, which suggest outdoor sources for these two components.
3. Crowded classrooms (high density of students per m^3) seem to lead to increased concentrations of several components, such as, Zn, 2-methylpentane, methanol, isooctane (winter) and benzene - (autumn).
4. Classrooms located in basements seem to suffer from accumulation of several components, perhaps due to lack of ventilation. The results indicated that the air of the classrooms in the basement tended to have more particle mass, cyclohexane, ethanol, isooctane, acetone, benzene, toluene, Na^+ and Cl^-.
5. Cleanings appear to contribute to a decrease in several air components, but to an increase of others. It is possible that some components of the cleaning products pass into the air. Classrooms with higher number of cleanings a day were associated with higher concentrations of acetaldehyde but reduced concentrations of Zn, several ions (Na^+, Cl^-, K^+, NO_3^-, F^-, Mg^{2+}), 2-methylpentane, methanol and benzene (winter).
6. Chalk and whiteboard pens are expected to liberate distinct substances. The use of whiteboard pens was associated with higher concentrations of Sc, benzene (winter), Cl^-, PO_4^{3-}, NO_3^- and F^-.
7. Different construction materials appear to impact on specific elements. Overall, wood seems to lead to a reduced concentration of several elements. Wooden ceilings in particular were associated with lower concentrations of particle mass, K, Sc, cyclohexane, isooctane (autumn) and acetone; wooden ceilings and floors were associated with lower concentrations of Na^+, Cl^-, Mg^{2+} and K^+. Plastic floors on the contrary were associated with higher concentrations of several components, including Sb; VOCs such as n-hexane, n-heptane, ethylbenzene, m+p xylene and o-xylene; several ions, like Cl^-, Mg^{2+} and NO_3^-. These results support evidence on the emissions of hazardous substances from buildings and construction materials (WHO, 2010; Carrer et al., 2002), but must be interpreted with caution as there is only one classroom with plastic floor and one school (two classrooms) with wooden ceilings. The significant effects observed could be associated with other factors presented in that particular classroom/school.

Few components in this study were measured for more than one season. The seasonal analysis, albeit limited, suggested higher concentrations in winter as compared to spring of particle mass and of two VOCs, benzene and toluene. Spring being the season when windows tend to be open due to higher temperatures, these results suggest that these components get trapped in classrooms for lack of ventilation. The concentrations of isooctane, acetone, benzene and toluene seem to be higher in winter than in autumn. For some elements, namely Cr, K and Sb, the concentrations seem, on the contrary, to be higher in autumn than in winter.

CONCLUSIONS

This study shows the importance of considering cleaning and ventilation practices as well the construction materials when studying the indoor air quality in schools. It is known for example than benzene has adverse health effects. The results obtained here suggest that lower concentrations of benzene may be obtained with less crowded and better ventilated classrooms, frequent cleanings and by avoiding the use of whiteboard pens.

Overall, the conclusions of this study point to the following recommendations: 1) classrooms should face streets rather than patios and should not be located in basements, 2) the density of students can affect the indoor environment and should be limited, 3) wooden materials appear to have advantages as building materials due to a lower input of contaminants. In particular, in this work, wood did not contribute to an increase of the VOCs, as reported in previous research (Norback et al., 1995). Other factors, like ventilation, cleanings and use chalk versus whiteboard pens, can reduce or increase specific contaminants inside the classrooms. Therefore, caution is suggested when deciding on building materials for schools and on school practices, such as cleaning and boards, as these may affect the indoor air which children will breathe for long periods of the day.

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REFERENCES

Almeida, S.M., Canha, N., Silva, A., Freitas, M.C., Pegas, P,; Alves, C., M. Evtyugina and A.C. Pio, 2010: Children exposure to air particulate matter in indoor of Lisbon primary schools. *Atmos. Environ.* (in press; doi:10.1016/j.atmosenv.2010.11.052).

Akaike, H., 1974: A new look at statistical model idemtification. IEEE Transactions on Automatic Control, AU-19, 716-722.

Canha, N., Freitas, M.C., Almeida, S.M., Almeida, M., Ribeiro, M., C. Galinha and H.Th. Wolterbeek, 2010: Indoor school environment: easy and low cost to assess inorganic pollutants. *J. Radioanal. Nucl. Chem.*, 286 (2): 495-500.

Canha, N., Almeida, M., Freitas, M.C., S.M. Almeida and H.Th. Wolterbeek, 2011: Seasonal variation of total particulate matter and children respiratory diseases at Lisbon primary schools using passive methods. *Procedia Environ. Sci.*, 4, 170-183.

Carrer, P., Kotzias, D., Rameckers, E., Seppanen, O., J. Bronswijk and G. Viegi, 2002: THADE project - Towards healthy air in dwellings in Europe. European Federation of Allergy and Airways Disease Patients and Associations.

Fraga, S., Ramos, E., Martins, A., Samúdio, M. J., Silva, G., Guedes, J., E.O. Fernandes and H. Barros, 2008: Indoor air quality and respiratory symptoms in Porto schools. *Revista Portuguesa de Pneumologia*, 14 (4), 487-507.

Freitas, M.C., Canha, N., Martinho, M., Almeida-Silva, M., Almeida, S.M., Pegas, P., Alves, C., Pio, C., Trancoso, M., Sousa, R., F Mouro and T. Contreiras, 2011: Chapter 20 - Indoor Air Quality in Primary, Advanced Topics in Environmental Health and Air Pollution Case Studies, InTech Press, Croatia, 361- 384.

Hollander, M. and D.A. Wolfe, 1973: Nonparametric statistical methods. John Wiley & Sons.

ISAAC, 1998: Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. *The Lancet*, 351 (9111), 1225-1232.

Janssen, N. A., Hoek, G., B. Brunekreef and H. Harssema, 1999: Mass concentration and elemental composition of PM10 in classrooms. *Occupational Environmental Medicine*, 52 (7), 482-487.

Khan, I., Freitas, M. C., I. Dionísio and A.M.G. Pacheco, 2007: Indoor habits of children aged 5 to years learning at the public basic schools of Lisbon city, Portugal. Proceedings of the Ninth REHVA World Congress Clima - Well Being Indoors.

Lee, S.C., Guo, H., W.M. Li and L.Y. Chan, 2002: Inter comparison of air pollutant concentrations in different indoor environment in Hong Kong. *Atmos. Envir.*, 36 (12), 1929–1940.

Mendell, M. and G. Heath, 2005: Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*, 15 (1), 27-52.

Norback, D., Bjornsson, E., C. Janson and G. Boman, 1995: Asthmatic symptoms and volatile organic compounds, formaldehyde and carbon dioxide in dwellings. *Occupational and Environmental Medicine*, 52 (6), 388-395.

Pegas, P.N., Evtyugina, M.G., Alves, C.A., Nunes, T., Cerqueira, M., M. Franchi and C.A. Pio, 2010: Outdoor/Indoor air quality in primary schools in Lisbon: a preliminary study. *Química Nova*, 33 (5), 1145-1149.

Pegas, P.N., Alves, C.A., Evtyugina, M.G., Nunes, T., Cerqueira, M., Franchi, M., Pio, C.A., Almeida, S.M., S. Cabo Verde and M.C. Freitas, 2011: Seasonal evaluation of outdoor/indoor air quality in primary schools in Lisbon. *Journal of Environmental Monitoring*, 13, 657-667.

Spengler, J.D. and K. Sexton, 1983: Indoor air pollution: A public health perspective. Science, 221 (4605), 9–17.

Stranger, M., S. Potgieter-Vermaak and R. Grieken, 2007: Comparative overview of indoor air quality in Antwerp, Belgium. *Environment International*, 33 (6), 789–797.

WHO - World Health Organization, 2010: Guidelines for indoor air quality – selected pollutants. Denmark.