Rev Saúde Pública 2013;47(6):1-9

DOI:10.1590/S0034-8910.2013047004810

Ana Maria Conceição Ferreira[I]

Salvador Massano Cardoso[II]

Exploratory study of air quality in elementary schools, Coimbra, Portugal

ABSTRACT

OBJECTIVE: To analyze the air quality in elementary schools and their structural and functional conditions.

METHODS: Air quality in 51 elementary schools (81 classrooms) in the city of Coimbra, Portugal, both inside and outside of the rooms was evaluated during the four seasons, from 2010 to 2011. Temperature (T°), relative humidity (Hr), concentrations of carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), compounds were evaluated, as were volatile organics (VOC), formaldehyde and particulate matter (PM_{10}), from November 2010 to February 2011 (autumn/winter) and March 2011 to June 2011 (spring/summer). A grid characterizing the structural and functional conditions of the schools was created. The statistical Student t test for paired samples and the Wilcoxon t test were applied.

RESULTS: In 47 schools, the average CO_2 concentrations were above the maximum reference concentration (984 ppm) mentioned in Portuguese legislation. The maximum concentration values found inside the rooms were critical, especially in the fall/winter (5,320 ppm). In some schools the average concentrations of VOC and PM_{10} within the maximum concentration exceeded the reference legislated. The values (risk) of CO, formaldehyde, NO_2, SO_2 and O_3 detected were not relevant.

CONCLUSIONS: There was a higher concentration of pollutants inside the rooms compared with outside. Inadequate ventilation is associated with high CO_2 concentration in the classroom.

DESCRIPTORS: Schools. Education, Primary and Secondary. Air Pollution, Indoor. Air Pollution, adverse effects. Air Pollutants, analysis. Air Quality.

[I] Departamento de Saúde Ambiental. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra, Portugal

[II] Instituto de Higiene e Medicina Social. Faculdade de Medicina. Universidade de Coimbra. Coimbra, Portugal

Correspondence:
Ana Maria da Conceição Ferreira
Rua 5 de Outubro, São Martinho do Bispo
3000 Coimbra, Portugal
E-mail: anaferreira@estescoimbra.pt

Received: 3/4/2013
Approved: 3/28/2013

Article available from: www.scielo.br/rsp

INTRODUCTION

The current and growing pattern of consumption has consequences for the environment which are, inevitably, reflected in human health. Air quality has implication for our well-being, it influences our future and can affect it. Interior air quality (IAQ) is one of the main environmental risks for public health and is especially significant for vulnerable groups, such as children.[a]

The level of pollution in the air inside buildings is often much worse than that outside and may reach figures from two to five times, and occasionally up to one hundred times, higher than the levels of pollution in the exterior. Levels of contamination of interior air become more relevant when we consider that individuals generally spend around 80.0% to 90.0% of their time inside of buildings. Due to the complex and diverse functions carried out within schools, air quality becomes of great importance because of the adverse effects it can have on the occupants' health, concentration and performance.[8,9,13]

The effects of air pollution on children has been increasing[b] due to their entering school at ever earlier ages and spending more and more time there. One of the consequences of this is the increase in respiratory problems, namely the increase in prevalence of allergic rhinitis, bronchitis and asthma.[6] Air quality in schools is of great importance, as the children spend at least 1/3 of their time inside these buildings, i.e., around seven hours or more a day at school.[2,11,c] Poor IAQ can affect performance, effort, comfort and productivity.[3,5] The conditions inside the school buildings may affect the incidence of respiratory symptoms.[7,9,15] There are various studies on the quality of air quality inside schools.[2,4,11,12,a] However, there are few studies involving this area in Portugal.

The aim of this study was to analyze air quality in elementary schools and their structural and functional conditions.

METHODS

This was an exploratory study of IAQ, measuring temperature, relative air humidity and concentrations of carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), volatile organic compounds (VOC), formaldehyde and articulate matter with a diameter between 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10}), in autumn/winter and spring/summer, in 51 elementary schools and 81 classrooms, Coimbra, Portugal, 2011. Coimbra is a municipality with around 143,052 inhabitants, subdivided into 31 prefectures, of which 15 are predominantly urban areas (PUA), 14 are moderately urban area (MUA) and two areas are predominantly rural (PRA).[d] Coimbra was selected as it is one of the largest cities in central region and one of the most important in Portugal, due to its infrastructure, organization and companies, its historical importance and privileged geographical position in the center of the country. This is the first study evaluating IAQ in schools in Coimbra. Elementary schools within the 31 prefectures of Concelho de Coimbra were assessed.

In total, 45 public and six private schools were analyzed, covering 81 classrooms (with a mean of 18 pupils), totaling 1019 children. These schools were selected based on comparative analysis of the 81 public and private schools (230 classrooms) in *Concelho de Coimbra*.

It was decided to use a non-probabilistic convenience sample. The inclusion criteria were: one school per prefecture and, for the others, the above mentioned comparison criteria were used in the schools whose governors gave permission to participate in the study. If the parents/guardians did not give consent, this was an exclusion criteria.

It was not possible to evaluate biological parameters (due to lack of resources). Chemical and physical parameters inside and outside of 51 schools were evaluated. These evaluations were conducted in the autumn/winter (November 2010 to February 2011) and in spring/summer (March to June 2011).

A preliminary visit was made to educational establishments to assess overall conditions of facilities, type of activities taking place there, type of ventilation system and number of occupants and to identify potential sources of interior and exterior pollution. The sampling stations in the classrooms were decided, considering their layout, the location of doors and windows and the existence of sources of interior and exterior pollution. Quantifying the environmental parameters was based on recommendations described in the NT-SCE-02[e] and

[a] Borrego C, Neuparth N, Carvalho AC, Carvalho A, Miranda AI, Costa AM, et al. A saúde e o ar que respiramos - um caso de estudo em Portugal. Lisboa: Fundação Calouste Gulbenkian; 2008.
[b] Khan I, Freitas MC, Dionisio I, Pacheco AMG. 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, Helsinki; 2007.
[c] Unites States Environmental Protection Agency (US). Managing Asthma in the School Environment – Indoor air quality tools for schools. Washington (DC); 2010 [cited 2012 Jul 20]. Available from: http://www.epa.gov/iaq/schools
[d] Portugal. Deliberação nº 2717/2009 de 6 de agosto. 8ª Deliberação da Secção Permanente de Coordenação Estatística. Revisão da tipologia de áreas urbanas. *Diario Republica*. 28 set 2009.
[e] Agência Portuguesa do Ambiente. Sistema Nacional de Certificação Energética da Qualidade do Ar Interior nos Edifícios. Direção Geral de Energia e Geologia, Ministério das Obras Públicas, Transportes e Comunicações, Lisboa; 2006.

in the Portuguese Environmental Agency technical guide to air quality in interior spaces.[f]

The reference maximum concentrations (RMC) established in annex VII of Ordinance no. 79/2006, 4th April,[g] on IAQ and in ordinance no. 80/2006, 4th April,[h] on parameters of air temperature and relative humidity and international recommendations on Indoor Air Quality Association (IAQA)[i] and the American Society of Heating, Refrigeration and Air – Conditioning Engineers, 2001 Standard 62.1.[j]

The Portuguese legislation does not set a limit for as $PM_{2.5}$, SO_2 or NO_2 inside buildings. There are standards setting limits for exposure to NO_2 in the workplace. The average values recorded in the analytical measurements of outdoor air were taken as a reference point.

IAQ was measured during school hours, two hours after lessons started. The equipment was located at around pupils' head height when seated. The sample was taken at a height of 1 m, at least 3 m from the walls, in representative measuring areas, so as to guarantee there was appropriate distance from the pupils themselves, to ensure there was no interference in reading the instruments.

The measurements were taken according to the method established in the Technical Note NT-SCE-02, of the National Certification System, Portugal, 2009, between 10:30 a.m. and 5:30 p.m., over a 30 minute period, sampling each particulate every 30 seconds, volatile organic compounds[a] every 15 seconds and the others every minute, for one week.[k] The measurements of environmental air quality took place during break time, at the same height at which the IAQ measurements were taken, but at least 1m from the school's exterior walls.[k]

Specific portable equipment (Table 1), calibrated before each sampling period, was used to obtain real time readings, using the reset function whenever necessary, with a comparative base of results found in cases of measurements with exchanged sensors. Variations in temperature and air pressure were considered when converting the readings.

The data were analyzed using SPSS (Statistical Package for the Social Sciences), version 19.0. The data were subject to descriptive and inferential analysis. The mean, standard deviation and range of variation were calculated, with the minimum and maximum values in order to discover the quantitative variables. In some situations, after checking for normality (Kolmogorov-Smirnov and Shapiro-Wilk tests), parametric tests to evaluate differences between mean values were used. When the evaluation of asymmetry was not called into question, parametric measurements were applied. When they were very asymmetrical (> or < 1.96), non-parametric statistical models were applied.

The Student's-t test for paired samples and the Wilcoxon t test were used.

Statistical interpretation was conducted based on a 0.05 level of significance, with 95% confidence interval.

This study was approved by the Science Committee of the Faculty of Medicine, *Universidade de Coimbra* (approved December 2010). All of those responsible in the schools signed consent forms.

RESULTS

The majority of the schools had central heating (86.3%), but not had air conditioning. None of the schools had any sort of ventilation system, and ventilation was achieved by opening doors and windows. Most of the classrooms (88.3%) were equipped with a blackboard and chalk and had a wooden floor (80.4%). The mean volume of the classrooms was 150 m^3.

The environmental parameter with the most significant results and high potential risk was that of CO_2. Mean concentrations of CO_2 inside the classrooms were above RMC (984 ppm), reaching 1,942 ppm. The maximum values found inside the classrooms placed the children's health at risk, reaching 5,320 ppm in one school. CO_2 concentrations inside the classrooms in autumn/winter were higher than the values in spring/summer.

In two schools, the mean concentration of VOC exceeded RMC in both seasons. The RMC for particulates with a diameter of 10 μm (PM_{10}) was exceeded in classrooms in four schools.

The mean concentration of formaldehyde was above the RMC (0.08 ppm) in spring/summer in one classroom.

[f] Agência Portuguesa do Ambiente. Qualidade do ar em espaços interiores – um guia técnico. Lisboa; 2010 [cited 2010 Sep 27]. Available from: http://www.apambiente.pt/serviços/LaboratórioReferenvia/Documents/Manual%20QAI%20APA%20Maio%202010.

[g] Portugal. Decreto-Lei nº 79/2006 de 4 de Abril. Estabelece o Regulamento dos Sistemas Energéticos de Climatização em edifícios/RSECE. *Diario Republic*a. 4 abr 2006:2416-68.

[h] Portugal. Decreto-Lei nº 80/2006 de 4 de Abril. Estabelece a Norma Técnica NTSCE02-Metodologia para Auditorias periódicas de qualidade do ar interior em edifícios existentes no âmbito do RSECE. *Diario Republica*. 4 abr 2006.

[i] Indoor Air Quality Association. Quick Reference Guide to IAQA 01-2000. Recommended Guidelines for Indoor Environments. Washington (DC); 2000 [cited 2010 Sep 28]. Available from: http://americanhomeinspect.net/reference.html

[j] American National Standards Institute. American Society of Heating, Refrigerating and Air Conditioning Engineers. Standard 62.1 Ventilation for Acceptable Indoor Air Quality. Atlanta; 2004.

[k] Carvalho R, Coelho D, Ferreira C, Nunes T. A monitorização da Qualidade do Ar Interior (QAI) em Portugal - estudo comparativo de metodologias de amostragem e medição de QAI. Aveiro: Universidade de Aveiro; 2009.

Table 1. Parameters evaluated, equipment and monitoring methods used,[a] Coimbra, Portugal, 2011.

Environmental parameter	Equipment	Monitoring method I.M.[b]	Method/Reference principle[c]	Method/Equivalent principle[d]
Evaluation of air velocity	DELTA OHM - HD32.1			
Evaluation of relative humidity	TSI 9555-P	Electrochemical sensor		
Evaluation of the air temperature	TSI 9555-P	Electrochemical sensor		
Evaluation of CO_2 concentrations	TSI 9555-P	NDIR sensor	NDIR	Electrochemical method; Infra Red
Evaluation of CO concentrations	TSI 9555-P	NDIR sensor	NDIR	Electrochemical method; Infra Red
Evaluation of O_3 concentrations	AEROQUAL 500 series	Electrochemical sensor	Ultra Violet Absorption	Electrochemical method
Evaluation of VOC concentrations	PHOTOVAC 220ppb Pro	Photoionization detector	Collection and analysis by ISO 16000 – 2007 chromatography	PID Photo-Ionization Detector; PAS-Sensor photo Acoustic
Evaluation of NO_2 and SO_2	QRAE Plus PGM-2000/2020			
Evaluation of the concentration of airborne particles	TSI DUSTTRACK	Laser particle quantifier	Gravimetric method with selective PM10 sampling head	Optical dispersion (UV, Laser); Beta Radiation Absorption
Evaluation of formaldehyde	PPM formaldmeter	Electrochemical sensor	Collection and analysis by ISO 16000-2:2006 chromatography	Electrochemical method; Photometry method

NDIR: Non dispersive infra red

[a] This table took into consideration annex III of NT_SCE_02 consisting of monitoring methods

[b] Internal Method according to NT_SCE_02 (Principle Reference principle or equivalent principle).

[c] Method/Reference Principle. Method established by national, EU or international legislation (e.g., ISO) for measuring a specific pollutant of ambient air. The CEN (EN-ISO) methods are considered reference methods.

[d] Methods/Principles equivalents. The equivalent method is a method of measuring establishing an appropriate response for the intended purpose in relation to the reference method, in the equivalent method, the results do not differ from the reference method within a certain range of statistical uncertainty.

O_3 concentrations were below RMC values. Those for CO were significantly below the RMC (10.7 ppm). No relevant values were found for NO_2 or SO_2.

Mean air temperature in autumn/winter were below the reference value (20ºC). The majority of schools had insufficient heating, due to the age and size of the buildings and the conditions of their insulation. The values for air temperature inside the schools, in spring/summer, were above the reference value (25ºC) due to the external temperature and the classrooms not having any air conditioning system. The values for relative humidity were within the upper and lower limits in spring/summer and in autumn/winter (30.0% and 70.0%), except in seven schools, which had relative humidity above 70.0% in autumn/winter.

The atmospheric pollutants CO, CO_2, O_3 and formaldehyde underwent marked changes between the two seasons assessed. Significant alterations were also noted between the seasons for certain atmospheric pollutants and particulates in classrooms of pupils in the fourth year. Significant variations were also noted between the two seasons when the classrooms used by pupils in the first and fourth years together (all in the same classroom) (Table 2).

CO, CO_2, $PM_{2,5}$, PM_{10} and formaldehyde were those which underwent significant changes in the mean in the exterior areas of the different schools.

A pattern of correlation was observed between the mean relative humidity in autumn/winter and CO, CO_2, VOC and formaldehyde (Table 3), as well as patterns of variation between relative humidity and PM_{10}, VOC and formaldehyde in spring/summer.

When the Kruskal Wallis test was used to compare distribution of environmental parameters by geographical area, it was noted that there were statistically significant differences ($p < 0.05$) in concentrations of CO inside the classrooms in autumn/winter. On average, schools located in predominantly rural areas had higher values than those in moderately or predominantly urban areas. PM_{10} showed higher mean values in schools located in moderately urban areas ($p < 0.05$). Although

Table 2. Distribution of values of mean concentrations of pollutants according to location evaluated. Coimbra, Portugal, 2011.

Environmental parameter	Location							
	Classrooms						Outside	
	1st grade (n = 35)		4th grade (n = 34)		1st and 4th grade together (n = 12)		(n = 51)	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd
CO (ppm) - autumn/winter	0.44[b]	0.627	0.39[b]	0.445	0.45[a]	0.433	0.33[a]	0.329
CO (ppm) - spring/summer	0.15	0.107	0.15	0.159	0.12	0.075	0.21	0.194
CO_2 (ppm) - autumn/winter	1,575.17[b]	791.251	1,632.64[a]	707.493	1,414.64[b]	422.946	425.16[c]	33.779
CO_2 (ppm) - spring/summer	1,080.94	642.457	1,282.23	602.939	976.18	281.810	402.71	27.091
$PM_{2,5}$ (mg/m^3) - autumn/winter	0.09	0.039	0.08[a]	0.031	0.08	0.034	0.07[b]	0.028
$PM_{2,5}$ (mg/m^3) - spring/summer	0.09	0.026	0.10	0.025	0.07	0.023	0.09	0.028
PM_{10} (mg/m^3) - autumn/winter	0.13	0.054	0.11	0.040	0.11	0.035	0.08[c]	0.033
PM_{10} (mg/m^3) - spring/summer	0.11	0.026	0.11	0.025	0.10	0.024	0.12	0.059
O_3 (ppm) - autumn/winter	0.00[a]	0.005	0.00	0.008	0.00	0.000	1.29	8.956
O_3 (ppm) - spring/summer	0.00	0.001	0.00	0.007	0.00	0.004	0.03	0.024
VOC (ppb) - autumn/winter	97.85	74.382	96.41	73.818	102.23	78.143	31.28	73.567
VOC (ppb) - spring/summer	89.44	68.258	92.46	65.567	87.82	63.043	45.27	50.046
SO_2 (ppm) - autumn/winter	0.01	0.022	0.00	0.014	0.00	0.000	0.00	0.010
SO_2 (ppm) - spring/summer	0.01	0.037	0.00	0.000	0.00	0.000	0.00	0.014
Formaldehyde (ppm) - autumn/winter	0.01[a]	0.016	0.01[a]	0.009	0.01[a]	0.008	0.00[c]	0.003
Formaldehyde (ppm) - spring/summer	0.02	0.019	0.02	0.014	0.02	0.014	0.01	0.008

O_3: Ozone; T°: Temperature; Rh: Relative humidity; NO_2: Nitrogen dioxide; SO_2: Sulfur dioxide; VOC: Volatile organic compounds; PM_{10}: particulates with diameter < 10 ug; $PM_{2.5}$: particulates with diameter < 2.5 ug;
The NO_2 parameter was not shown as there was no significant quantity in any of the locations evaluated
Student t-test for paired samples; Wilcoxon t test[a] $p < 0.05$
[a] $p < 0.05$
[b] $p < 0.001$
[c] $p < 0.0001$

the differences are not statistically significant, schools located in predominantly rural areas had higher CO_2 and VOC values. Concentrations of $PM_{2.5}$ and formaldehyde were similar, and higher, in schools located in predominantly rural or moderately urban areas. The highest O_3 values were in schools located in predominantly urban areas, and those for SO_2 in moderately urban areas (Table 4).

There were statistically significant differences in the mean concentrations of $PM_{2.5}$, PM_{10} and VOC I spring/summer. Concentrations of VOC and PM_{10} were higher in schools located in predominantly rural areas. Mean concentrations of $PM_{2.5}$ were similar, and high, in schools located in predominantly rural and predominantly urban areas. O_3 values were highest in schools located in predominantly urban areas, as were SO_2 values. Formaldehyde and CO_2 had higher mean concentrations in schools located in predominantly rural areas. Schools in moderately urban areas had the highest mean values for CO.

DISCUSSION

The most significant results of this study are those referring to CO_2 concentrations, which were above the legislated maximum in most of the schools (92.0%). As the only source of this contamination in the classrooms was the occupants' metabolism, the level was used as an indicator of the degree of vitiation in the indoor environment, providing an indication of IAQ.

The results found for autumn/winter show higher levels of CO_2 than in spring/summer. The classrooms in which doors and windows are habitually open during lessons had better values and had lower number of students (< 10). CO_2 is the main indicator of air renewal inside classrooms which exceed the reference value (984 ppm). The volume of the classrooms, associated with the number of occupants, means that it is not possible for the airing during break times to lower CO_2 levels to an acceptable value. Some classrooms have the windows open during the lessons. However, this practice is not always possible, given noise levels outside, or when weather conditions, e.g., cold or rain,

Table 3. Variation of air pollutants as a function of temperature and relative humidity in autumn/winter and spring/summer. Coimbra, Portugal, 2011.

		Autumn/Winter							
Temperature/Humidity		CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	O_3 (ppm)	VOC (ppb)	SO_2 (ppm)	Formaldehyde (ppm)
Mean/Temperature	r	-0.152	0.063	-0.077	0.130	-0.090	0.098	0.070	-0.124
	p	0.174	0.573	0.490	0.243	0.421	0.379	0.530	0.266
	N	81	81	81	81	81	81	81	81
Minimum/Temperature	r	-0.157	0.069	-0.082	0.090	-0.121	0.064	0.139	-0.061
	p	0.158	0.535	0.465	0.422	0.280	0.565	0.212	0.586
	N	81	81	81	81	81	81	81	81
Maximum/Temperature	r	-0.133	0.050	-0.067	0.153	-0.056	0.118	0.006	-0.168
	p	0.233	0.653	0.552	0.169	0.616	0.290	0.955	0.131
	N	81	81	81	81	81	81	81	81
Mean/Relative humidity	r	0.425	0.433	0.184	0.065	-0.210	0.284	0.074	0.370
	p	0.000	0.000	0.099	0.559	0.059	0.010	0.511	0.001
	N	81	81	81	81	81	81	81	82
Minimum/Relative humidity	r	0.393	0.373	0.169	0.035	-0.189	0.207	0.114	0.377
	p	0.000	0.001	0.129	0.755	0.090	0.062	0.309	0.000
	N	81	81	81	81	81	81	81	82
Maximum/Relative humidity	r	0.432	0.466	0.187	0.091	-0.218	0.342	0.031	0.343
	p	0.000	0.000	0.092	0.416	0.049	0.002	0.783	0.002
	N	81	81	81	81	81	81	81	82
		Spring/Summer							
		CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	O_3 (ppm)	VOC (ppb)	SO2 (ppm)	Formaldehyde (ppm)
Mean/Temperature	r	0.085	0.047	-0.115	-0.022	-0.038	0.093	-0.038	0.201
	p	0.448	0.674	0.305	0.846	0.737	0.406	0.732	0.071
	N	81	81	81	81	81	81	81	81
Minimum/Temperature	r	0.038	0.033	-0.113	-0.066	-0.035	0.137	-0.007	0.185
	p	0.735	0.770	0.313	0.557	0.754	0.220	0.949	0.095
	N	81	81	81	81	81	81	81	81
Maximum/Temperature	r	0.132	0.052	-0.079	0.004	-0.052	0.072	-0.062	0.130
	p	0.237	0.645	0.481	0.972	0.645	0.519	0.579	0.245
	N	81	81	81	81	81	81	81	81
Mean/Relative humidity	r	0.054	-0.011	0.141	0.223	-0.051	0.313	0.073	0.466
	p	0.631	0.923	0.208	0.044	0.651	0.004	0.514	0.000
	N	81	81	81	81	81	81	81	81
Minimum/Relative humidity	r	0.017	-0.025	0.126	0.209	-0.019	0.270	0.086	0.471
	p	0.879	0.825	0.258	0.060	0.868	0.014	0.443	0.000
	N	81	81	81	81	81	81	81	81
Maximum/Relative humidity	r	0.069	-0.014	0.147	0.231	-0.062	0.299	0.059	0.454
	p	0.541	0.902	0.187	0.037	0.583	0.006	0.599	0.000
	N	81	81	81	81	81	81	81	81

r: Pearson's coefficient of linear correlation; p: p-value; N: Sample; O_3: Ozone; Tº: Temperature; Rh: Relative humidity; NO_2: Nitrogen dioxide; SO_2: Sulfur Dioxide; VOC: Volatile organic compounds; PM_{10}: particulates with diameter < 10 ug; $PM_{2.5}$: particulates with diameter < 2.5 ug

make it impossible. Airing during the night would be good practice (except in cold periods), but the schools reported that this was not possible for motives of security. Recent studies, including some in Portugal,[3,13] have indicated the existence of high levels of CO_2 in schools, due to high density of occupation and insufficient ventilation.[1,10] High levels of CO_2 were associated with high levels of other pollutants.[12]

Table 4. Variation of air pollutants as a function of temperature and relative humidity in autumn/winter and spring/summer. Coimbra, Portugal, 2011.

		Autumn/Winter	
Pollutants/Location	Mean	Standard deviation	p
Mean CO (ppm) - Predominantly urban area	0.28	0.38	0.003[a]
Mean CO (ppm) - Moderately urban area	0.69	0.69	
Mean CO - Predominantly rural area	0.95	0.21	
Mean CO_2 (ppm) - Predominantly urban area	1,550.84	750.62	0.437
Mean CO_2 (ppm) - Moderately urban area	1,611.65	636.82	
Mean CO_2 (ppm) - Predominantly rural area	1,941.50	685.19	
Mean $PM_{2,5}$ (mg/m^3) - Predominantly urban area	0.08	0.03	0.063
Mean $PM_{2,5}$ (mg/m^3) - Moderately urban area	0.10	0.04	
Mean $PM_{2,5}$ (mg/m^3) - Predominantly rural area	0.10	0.04	
Mean PM_{10} (mg/m^3) - Predominantly urban area	0.11	0.05	0.024[a]
Mean PM_{10} (mg/m^3) - Moderately urban area	0.14	0.04	
Mean PM_{10} (mg/m^3) - Predominantly rural area	0.11	0.06	
Mean O_3 (ppm) - Predominantly urban area	0.002	0.007	0.580
Mean O_3 (ppm) - Moderately urban area	0.001	0.003	
Mean O_3 (ppm) - Predominantly rural area	0.000	0.000	
Mean VOC (ppb) - Predominantly urban area	99.12	76.46	0.234
Mean VOC (ppb) - Moderately urban area	89.60	68.91	
Mean VOC (ppb) - Predominantly rural area	160.00	7.07	
Mean SO_2 (ppm) - Predominantly urban area	0.005	0.02	0.806
Mean SO_2 (ppm) - Moderately urban area	0.006	0.01	
Mean SO_2 (ppm) - Predominantly rural area	0.000	0.000	
Mean formaldehyde (ppm) - Predominantly urban area	0.006	0.01	0.345
Mean formaldehyde (ppm) - Moderately urban area	0.01	0.01	
Mean formaldehyde (ppm) - Predominantly rural area	0.01	0.01	
		Spring/Summer	
Mean CO (ppm) - Predominantly urban area	0.14	0.14	0.675
Mean CO (ppm) - Moderately urban area	0.15	0.10	
Mean CO - Predominantly rural area	0.10	0.00	
Mean CO_2 (ppm) - Predominantly urban area	1,115.50	632.62	0.203
Mean CO_2 (ppm) - Moderately urban area	1,222.66	528.32	
Mean CO_2 (ppm) - Predominantly rural area	1,359.00	66.47	
Mean $PM_{2,5}$ (mg/m^3) - Predominantly urban area	0.10	0.03	0.003[a]
Mean $PM_{2,5}$ (mg/m^3) - Moderately urban area	0.08	0.02	
Mean $PM_{2,5}$ (mg/m^3) - Predominantly rural area	0.10	0.04	
Mean PM_{10} (mg/m^3) - Predominantly urban area	0.12	0.02	0.003[a]
Mean PM_{10} (mg/m^3) - Moderately urban area	0.09	0.03	
Mean PM_{10} (mg/m^3) - Predominantly rural area	0.14	0.02	
Mean O_3 (ppm) - Predominantly urban area	0.0009	0.005	0.852
Mean O_3 (ppm) - Moderately urban area	0.0007	0.002	
Mean O_3 (ppm) - Predominantly rural area	0.000	0.000	
Mean VOC (ppb) - Predominantly urban area	82.66	68.42	0.055[a]
Mean VOC (ppb) - Moderately urban area	102.62	56.59	
Mean VOC (ppb) - Predominantly rural area	165.00	7.07	
Mean SO_2 (ppm) - Predominantly urban area	0.005	0.03	0.958
Mean SO_2 (ppm) - Moderately urban area	0.002	0.01	
Mean SO_2 (ppm) - Predominantly rural area	0.000	0.000	
Mean formaldehyde (ppm) - Predominantly urban area	0.02	0.02	0.220
Mean formaldehyde (ppm) - Moderately urban area	0.01	0.01	
Mean formaldehyde (ppm) - Predominantly rural area	0.03	0.01	

O_3: Ozone; T°: Temperature; Rh: Relative humidity; NO_2: Nitrogen dioxide; SO_2: Sulfur Dioxide; VOC: Volatile organic compounds; PM_{10}: particulates with diameter < 10 ug; $PM_{2.5}$: particulates with diameter < 2.5 ug
Test: Kruskal Wallis
[a] $p < 0.05$

In this study, the values found were below the reference value, with the exception of CO_2, however, the values for some of the environmental parameters analyzed, such as CO and PM_{10} were significant.

Levels of particulate matter above the legislated values were found. The majority of classrooms were equipped with blackboards and chalk and had shelves or cupboards containing large quantities of stored paper, which accumulated dust. Countless activities take place inside the classrooms, often requiring mats, glue, paint, clay and other materials and, according to the results found by Almeida et al[3] (2011) and Pegas et al[13] (2012), children's activities themselves contribute to increasing the particles in the atmosphere.

The VOC values found, although significant, were below the RMC. There are many possible sources, from glue and paints and all sorts of organic based compounds present in the classrooms.

The CO values found were below the RMC, in both autumn/winter and spring/summer. On average, schools located in predominantly rural areas had higher values of CO compared with those located in areas that were moderately or predominantly urban. The highest value found in autumn/winter was in a school in which there was a noticeable smell of smoke from a stove without a chimney, indicating a problem with extracting smoke from the classrooms.

O_3 and formaldehyde levels were below the RMC. Some classrooms had higher levels, although no sources of contamination were perceptible (Table 2). Two classrooms had significant values, although below the RMC, for formaldehyde in autumn/winter. In these classrooms, the pupils had been working with glue in the previous lesson, demonstrating a lack of airing and ventilation in the classroom during this type of activity. One school had significant values for formaldehyde in spring/summer, without any handicraft activities having taken place previously.

Values for NO_2 and SO_2 mean air temperature in autumn/winter was above the reference limit established in Ordinance no. 80/2006 (20ºC). This is probably because all of the classrooms had heating systems and the doors and windows remained closed. Air temperature values were below the reference value in spring/summer, except for two schools where temperatures higher than the reference (25ºC) were found. Seven schools had values for relative humidity of > 70.0% in the autumn/winter. Diverse sources of contaminants were found inside the buildings. They may originate in the occupants, their activities, construction and decoration materials or from air outside entering the building. Thermo-hygrometric conditions are important in guaranteeing a healthy environment. As well as affecting comfort, temperature and humidity affect the emission of chemical pollutants from existing sources of contamination.[1]

Poor IAQ over short periods (hours) may lead to discomfort, decreased attention and diminished learning capacity. However, prolonged exposure (days and weeks) to interior air pollutants may lead to serious health problems, such as respiratory disease or allergies.

The majority of schools studied were old buildings that had not been restored in a long time. Their constructive aspects were cared for, there was a lack of air conditioning systems and a lack of mechanical or mixed ventilation, this generally being achieved by opening doors and windows. Especially high levels of CO_2 were measured in the interior environment, showing the deficiencies in IAQ due to insufficient ventilation.

Concentrations of pollutants in the air inside the classrooms were higher than those observed outside, indicating the significance of interior sources of emission.

It is essential that the schools continually monitor this situation so as to avoid exposing the pupils to risk. It is also important to improve airing systems, to make them more effective and efficient. The behavior and attitudes of the buildings' occupants also needs to be modified, e.g., developing the simple habit of opening the windows frequently.

Currently, there is debate on restructuring within schools, above all, increasing the numbers of pupils per class. Considering that CO_2 is essentially the result of the metabolism of living beings, decision makers concerned in this policy should perceive that, if the classrooms become fuller, levels of CO_2 and, consequently, health problems, will increase.

Efforts to develop methodologies of the determining and conditioning factors of air pollutants that affect human health need to be intensified, creating effective tools in the public health area and contributing to drawing up policies aimed at improving air quality. Similarly, control and prevention programs concerning the consequences for the health of the occupants of these environments need to be established.

Developing other studies to evaluate the impact of air pollutants on the population's health should be encouraged so as to contribute to adequate measuring of environmental health within buildings.

[1]Viegas J, Papoila Al, Martins P, Aelenei D, Cano M, Proença C, et al. Ventilação, qualidade do ar e saúde em creches e infantários resultados preliminares do Projeto ENVIRH. Seção reabilitação, ambiente interior, conforto e energia. 4º Congresso Nacional, Coimbra, Portugal, dez 2012.

REFERENCES

1. Al-Rashidi K, Loveday D, Al-Mutawa N. Impact of ventilation modes on carbon dioxide concentration levels in Kuwait classrooms. *Energy Build*. 2012; 47:540-9. DOI:10.1016/j.enbuild.2011.12.030
2. Almeida SM, Canha N, Silva A, Freitas MC, Pegas P, Alves C, et al. Children exposure to air particulate matter in indoor of Lisbon primary schools. *Atmos Environ*. 2010;45:7594-9. DOI:10.1016/j.atmosenv.2010.11.052
3. Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air*. 2003;13 (1):53-64. DOI:10.1034/j.1600-0668.2003.00153.
4. Freitas MC, Canha N, Martinho M, Silva M, Almeida S, Pegas P, et al. Indoor Air quality in primary schools. In: Modoveanu A, editor. Advanced topics in environmental and air pollution case studies. Rijeka: InTech Europe; 2011. p. 361-84.
5. Godoi RHM, Avigo DJ, Campos VP, Tavares TM, Marchi MRR, Grieken R, et al. Indoor air quality assessment of elementary schools in Curitiba, Brazil. *Water Air Soil Pollut Focus*. 2009;9(3-4):171-7. DOI:10.1007/s11267-009-9220-3
6. International Study of Asthma and Allergies in Childhood. Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. The International Study of Asthma and Allergies in Childhood (ISAAC) Steering Committee. *Lancet*. 1998;351(9111):1225-32. DOI:10.1016/S0140-6736(97)07302-9
7. Kim JL, Elfman L, Mi Y, Johansson M, Smedje G, Norback D. Current asthma and respiratory symptoms among pupils in relation to dietary factors and allergens in the school environment. *Indoor Air*. 2005;15(3):170-82. DOI:10.1111/j.1600-0668.2005.00334.x
8. Kotzias D, Geiss O, Tirendi S, Barrero-Moreno J, Reina V, Gotti A. Exposure to multiple air contaminants in public buildings, schools and kindergartens - The European Indoor Air Monitoring and Exposure Assessment Study (AIRMEX). *Fresenius Environ Bull*. 2009;18(5):670-81.
9. Mendell M, Heath G. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*. 2005;15(1):27-52. DOI:10.1111/j.1600-0668.2004.00320.x
10. Mumovic D, Palmer J, Davies M, Orme M, Ridley I, Oreszczyn T, et al. Winter indoor air quality, termal confort and acoustic performance of newly built schools in England. *Build Environ*. 2009;44(7):1466-77. DOI: 10.1016/j.buildenv.2008.06.014
11. Pegas PN, Evtyugina MG, Alves CA, Nunes T, Cerqueira M, Franchi M, et al. Outdoor/ Indoor air quality in primary schools in Lisbon: a preliminary study. *Quim Nova*. 2010;33(5):1145-9. DOI:10.1590/S0100-40422010000500027
12. Pegas PN, Alves CA, Evtyugina MG, Nunes T, Cerqueira M, Franchi M, et al. Seasonal evaluation of outdoor/indoor air quality in primary schools in Lisbon. *J EnvironMonit*. 2011;13(3):657-67. DOI:10.1039/c0em00472c
13. Pegas PN, Nunes T, Alves CA, Silva JR, Vieira SLA, Caseiro A, et al. Indoor and outdoor characterisation of organic and inorganic compounds in city centre and suburban elementar schools of Aveiro, Portugal. *Atmos Environ*. 2012;55:80-9. DOI:10.1016/j.atmosenv.2012.03.059
14. Shusterman D, Murphy MA. Nasal hyperreactivity in allergic and non-allergic rhinitis: a potential risk factor for non-specific building-related illness. *Indoor Air*. 2007;17(4):328-33. DOI:10.1111/j.1600-0668.2007.00482.x
15. Sundell J. On the history of indoor air quality and health. *Indoor Air*. 2004. 14 Suppl7:51-8. DOI:10.1111/j.1600-0668.2004.00273.x

The authors declare that there are no conflitcs of interest.