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Seasonal variation of total particulate matter and children respiratory diseases at Lisbon primary schools using passive methods

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Abstract

In this work, 14 primary schools of Lisbon city, Portugal, followed a questionnaire of the ISAAC - International Study of Asthma and Allergies in Childhood Program, in 2009/2010. The questionnaire contained questions to identify children with respiratory diseases (wheeze, asthma and rhinitis). Total particulate matter (TPM) was passively collected inside two classrooms of each of 14 primary schools. Two types of filter matrices were used to collect TPM: Millipore (Isopore™) polycarbonate and quartz. Three campaigns were selected for the measurement of TPM: Spring, Autumn and Winter. The highest difference between the two types of filters is that the mass of collected particles was higher in quartz filters than in polycarbonate filters, even if their correlation is excellent. The highest TPM depositions occurred between October 2009 and March 2010, when related with rhinitis proportion. Rhinitis was found to be related to TPM when the data were grouped seasonally and averaged for all the schools. For the data of 2006/2007, the seasonal variation was found to be related to outdoor particle deposition (below 10 µm).

Keywords: primary schools; indoor environments; particulate matter; passive samplers; total particulate matter; asthma; rhinitis

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1. Introduction

During the last two decades there was an increasing concern within the scientific community on the effects of indoor air quality upon health, mainly because people spend most of the time indoors [1, 2]. With airways not fully developed, children are a very sensitive group as the majorities of them spend most of their time at home or at school/preschool. Thus, the pollutant air concentrations at these sites are an important variable for the time-weighted exposure of children, as well as the outdoor contributions since they often play outside [3, 4].

Adverse effects of different pollutants on human health have been well documented in Europe and other parts of the world. The exposure to ambient air pollution has been pointed out as a cause of several diseases [3] and the prevalence of allergic rhinitis is increasing among children in many countries within the ISAAC Project [5]. There is accumulating evidence that both genetic and environmental factors play important roles in the etiology of allergic rhinitis, which was pointed out in recent findings suggesting a close relationship between exposure to indoor air pollutants and the increase of allergic rhinitis risk in children [6].

Most analyses of health effects of indoor air pollution exposure have relied on the data collected through surveys [7, 8]. In epidemiological settings, a questionnaire is usually designed to ask a large set of questions on the attributes of the subjects with the purpose of obtaining enough information for the subsequent exposure assessment [9]. However, sometimes the designed questions are not the direct indicators of true exposure variables. The latter may be difficult or impossible to define, or may not be directly measurable using this method [10, 11].

In the present study, a large dataset was constructed using a standardized questionnaire survey approach developed within the ISAAC project. A total of 14 primary schools located in Lisbon city, Portugal, were selected for sampling the total particulate matter (TPM) by passive deposition and to assess the indoor air quality. Thus, the aim of this study was to passively assess the children exposure to TPM inside the classrooms and to evaluate their respiratory symptoms and potential risk factors. Compared to automatic samplers, this passive sampling method represents an easier and cheaper way to assess several indoor air quality environments with no interference in the classroom activities [12]. The procedure was performed on three different campaigns: Spring 2009, Autumn 2009 and Winter 2010, making it possible to evaluate seasonal variations of the total particulate matter.

Due to its mode of operation, the passive method leads to a number of practical advantages, including cost / benefit little training required for handling devices and there is no need for an energy source for its operation [13]. Furthermore, the use of these samplers in indoor environments, most often passes unnoticed by the occupants because they have small dimensions and emit no noise and do not interfere in daily activities [14]. As disadvantages, the passive method does not provide instantaneous concentrations, does not allow changes in sampling rate and does not have adequate sensitivity when exposed for short periods of time [15].

2. Materials and methods

In 2006/2007, the questionnaire was administered to 37 primary schools (see Fig. 1 for school distribution in the city) and a total of 1175 viable questionnaires was obtained. In a second phase, during 2009/2010, the survey was again applied to 14 of the initial primary schools (Fig. 2), with a total of 343 viable questionnaires. The manually written answers, double checked, were transferred to a computer, codified and confirmed by two independent persons.

Filters of 47 mm diameter were passively exposed at two classrooms (a and b) of each of the 14 Lisbon primary schools. Two types of filter matrices to collect TPM were selected: Millipore (Isopore^{TM}) polycarbonate (M) and quartz (Q). Fig. 3 shows the positioning of the filters in the classrooms. There were three campaigns for the collection of TPM, the first campaign – Spring – lasted for 34 days (from May 19 to June 22, 2009), the second campaign – Autumn – lasted between 62 and 68 days (from October 15 to December 16 or December 22, 2009) and the third campaign – Winter – lasted between 76 and 78 days (from January 6 to March 24 or March 25 or March 26, 2010).

In the 1st, 2nd and 3rd campaigns, after the exposure time, the number of polycarbonate recovered filters was, respectively, 165 out of 168, 137 out of 140 and 100 out of 112 (4-6 replicates by classroom). No loss of quartz filters occurred, with 56 filters collected in the 1st campaign (two replicates by classroom) and 28 in each of the other two campaigns (one replicate for classroom). Filters were weighed before and after exposure in a clean classroom (class 10000) in a clean hood of class 100. The balance had a sensitivity of 0.1 μg.

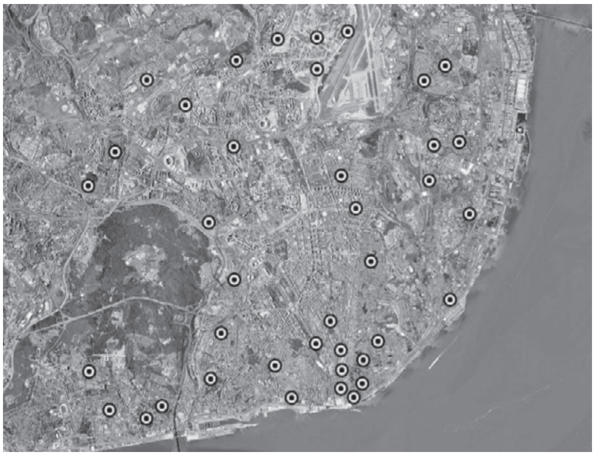

Fig. 1 Geographical distribution of the 37 primary schools, in Lisbon.

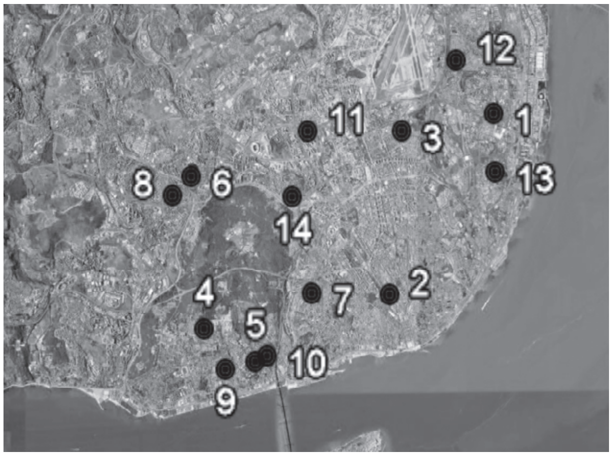

Fig. 2 Geographical distribution of the 14 primary schools, in Lisbon.

The areas of the classrooms vary between 37 and 65 m^2 and the height between 2 and 3.7 m. The occupancy varies between 17 and 24 children. All classrooms have natural ventilation except classrooms 4a and 4b; all of them use blackboard chalk except classrooms 1b and 12b, which use pen blackboards. The floor is typically brick (1, 2, 3, 6, 9b, 11, 13), wood (4, 5, 9a, 10), vinyl (7, 8, 12, 14b) and plastic (14a).

At three of the schools (schools 1, 2, 3), Gent samplers [16, 17] were used to collect PM2.5 and PM2.5-10 (particulate matter of aerodynamic diameter respectively below 2.5 µm and between 2.5 and 10 µm, respectively) in 47 mm Nucleopore polycarbonate filters. The experiment occurred in Spring (the three schools) and Autumn (Schools 1 and 2) two times with duration of 1 week each time (not continuously to avoid overloading of the filters). The air flux was kept at 16.7 L/min.

One Partisol – Plus Sequential Air Sampler – was placed to collect PM2.5 (particles with an aerodynamic diameter below 2.5 µm), in the centre of Lisbon (38º44' N – 9º8' W), from 1 January to 31 December 2007 [18, 19, 20]. The sampler used Teflon® filters of 47 mm diameter, which collected particles for periods of 24 h at 16.7 L/min. The mass of particles was gravimetrically determined as mentioned above for the passive filters.

The analysis of variance of results was performed by non-parametrics statistics for a significance level of 0.05, the Mann-Whitney U Test for binary independent groups and Kruskal-Wallis for multiple independent groups. All statistic tests were performing using Statistica®.

Fig. 3 Placement of the passive filters in the classrooms.

3. Results and Discussion

3.1 Questionnaires 2006/2007 and 2009/2010

Tables 1 and 2 summarise the results obtained by processing the questionnaires of 2006/2007 and 2009/2010. The non valid results were eliminated for each question, however all the questionnaires were reported independently of the non-zero % of answered questions.

The results obtained in 2006/2007 do not differ from the ones from 2006/2007 concerning asthma, rhinitis and its symptoms, as shown in Table 1. The results obtained for asthma and wheezing symptoms, in 2006/2007, were 27.0% and 12.0%, respectively, and for rhinitis and its symptoms were 28.0% and 25.6%, respectively. The results obtained in 2009/2010 for asthma and wheezing symptoms were 30.0% and 13.4%, respectively, and for rhinitis and its symptoms were 35.9% and 31.5%, respectively. Table 2 shows the children rhinitis complains by month.

Fig. 4 shows that 8.9% and 10.2% of the inquired children had asthma in 2006/2007 and 2009/2010, respectively. This is a relevant result for a chronic disease. In 2006/2007 and 2009/2010, the prevalence of asthma was in males (with 6.5% and 6.4%, respectively). However in 2009/2010 it is observed an increase of the prevalence of asthma in females of 1.4%, when comparing with 2006/2007.

Table 1. Results related to reported asthma and rhinitis symptoms

Asthma		**2006/2007**		**2009/2010**	
		N	**%[1]**	**N**	**%[1]**
Number of children inquired with wheezing symptoms	Female	124	10.6	56	16.3
	Male	184	15.7	47	13.7
	Total	317	27.0	103	30.0
Number of children with wheezing symptoms in the last 12 months	Female	52	4.4	26	7.6
	Male	87	7.4	20	5.8
	Total	141	12.0	46	13.4
Rhinitis		**2006/2007**		**2009/2010**	
		N	**%**	**N**	**%**
Number of children with sneezing, runny or nasal congestion not associated with common cold	Female	136	11.6	66	19.2
	Male	186	15.8	57	16.6
	Total	329	28.0	123	35.9
Number of children with sneezing, runny or nasal congestion not associated with common cold in the last 12 months	Female	130	11.1	59	17.2
	Male	166	14.1	49	14.3
	Total	301	25.6	108	31.5

[1]Percentage from the total of the questionnaires.

3.2 Total Particulate Matter

Tables 3 and 4 show the average TPM of each classroom and its standard deviation obtained in each campaign, for polycarbonate and quartz filters, respectively. All the values were normalized to 62 days of collection. Although the proximity of all replicates in the classroom, the collected masses are still different as shown by the values of the standard deviations. This shows the inhomegeneity of particle deposition in the classrooms.

Table 2. Rhinitis symptoms along the year

Rhinitis symptoms along the year	**2006/2007**		**2009/2010**	
	N	**%**	**N**	**%**
January	95	10.4	23	6.9
February	75	8.2	27	8.1
March	134	14.7	37	11.1
April	122	13.4	32	9.6
May	105	11.5	29	8.7
June	51	5.6	15	4.5
July	20	2.2	7	2.1
August	26	2.8	13	3.9
September	82	9.0	33	9.9
October	87	9.5	55	16.6
November	59	6.5	37	11.1
December	57	6.2	24	7.2

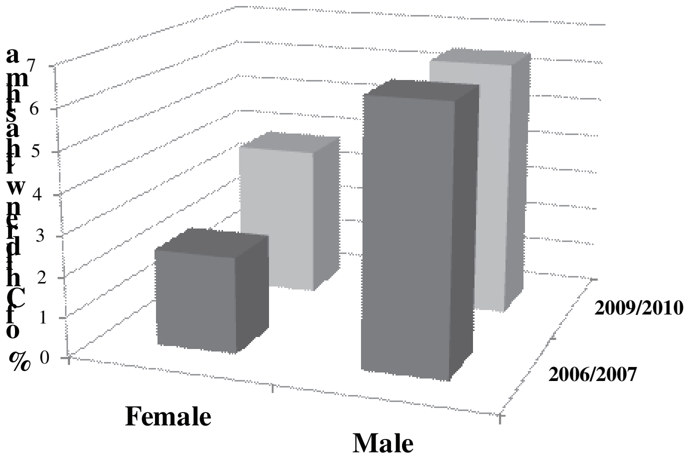

Fig. 4 Proportion of children with asthma by sex.

The efficiency of collection of the quartz filters was higher than the one of the polycarbonate filters since the masses collected in the latter were lower. The lower mass deposed in polycarbonate filters may be explained by the electrostatic effect which may induce loss of particles during the handling of the filters. However, the correlation between the masses collected in both filters is excellent, as shown in Figs. 5a and 5b, which means that the reduction of mass was not selective. The correlation coefficients were 0.96, 0.92 and 0.93 respectively for Spring 2009, Autumn 2009 and Winter 2010.

Table 3. TPM masses (in mg) obtained in the Polycarbonate filters for Spring, Autumn and Winter campaigns. Numbers refer to the schools and "a or b" refers to the classrooms of each school. SD is Standard Deviation. The results were normalized for 62 days. nd: Not determined.

Campaign	**Spring**	SD Normalized Results	**Autumn**	SD Normalized Results	**Winter**	SD Normalized Results
Days of exposure:	34		62;68		76-78	
Schools			**Mass (mg)**			
1_a	1.73	0.01	2.08	0.13	1.85	0.24
1_b	0.90	0.07	0.79	0.06	1.11	0.11
2_a	1.55	0.32	2.01	0.01	1.91	0.02
2_b	2.02	0.42	2.82	0.21	3.01	0.87
3_a	1.82	0.10	1.01	0.11	1.10	0.10
3_b	1.38	0.34	1.14	0.13	1.55	0.10
4_a	0.53	0.01	0.86	0.07	1.14	0.12
4_b	0.58	0.11	1.43	0.10	0.75	0.19
5_a	1.64	0.25	1.61	0.33	1.47	0.60
5_b	1.27	0.32	1.11	0.04	1.17	0.07
6_a	0.41	0.06	1.09	0.03	0.88	0.05
6_b	0.92	0.13	1.08	0.27	1.09	0.49
7_a	1.10	0.13	1.70	0.09	0.84	0.16
7_b	1.16	0.50	0.89	0.12	2.33	0.22
8_a	0.90	0.20	3.44	0.31	2.56	0.57
8_b	1.03	0.31	3.22	0.40	2.95	0.72
9_a	0.99	0.08	1.38	0.80	2.00	1.50
9_b	0.90	0.15	0.76	0.07	0.86	0.13
10_a	0.82	0.16	1.62	nd	1.49	0.35
10_b	1.25	0.31	1.32	0.03	1.78	0.05
11_a	1.65	0.37	1.00	0.03	1.29	0.06
11_b	0.90	0.24	1.30	nd	0.90	0.28
12_a	1.49	0.53	2.03	0.11	2.13	0.18
12_b	1.45	0.16	1.59	0.14	1.39	0.23
13_a	1.47	0.15	3.70	1.20	1.83	0.15
13_b	1.42	0.13	2.26	0.23	2.04	0.42
14_a	0.90	0.10	1.72	0.42	1.58	0.77
14_b	0.54	0.05	1.43	0.13	1.77	0.24
Min	0.41	0.01	0.76	0.01	0.75	0.02
Max	2.02	-	3.70	-	3.01	-
Mean	1.17	-	1.66	-	1.60	-
SD	0.42	-	0.79	-	0.62	-

Table 4. TPM masses (in mg) obtained in the quartz filters, for Spring, Autumn and Winter campaigns. Numbers refer to the schools and "a or b" refers to the classrooms of each school. SD is the standard deviation. The results were normalized for 62 days. nd: Not determined.

Campaign	**Spring**	**SD Normalized Results**	**Autumn**	**SD Normalized Results**	**Winter**	**SD Normalized Results**
Days exposure:	34		62;68		76-78	
Schools			**Mass (mg)**			
1_a	1.7	0.09	2.35	0.24	2.03	0.21
1_b	0.86	0.00	0.97	0.098	1.25	0.13
2_a	1.58	0.38	2.71	0.28	2.23	0.23
2_b	2.23	0.17	3.55	0.36	3.34	0.34
3_a	2.21	0.09	1.16	0.12	1.24	0.13
3_b	1.45	0.13	1.36	0.14	1.60	0.16
4_a	0.58	0.02	1.03	0.11	0.81	0.08
4_b	0.60	0.03	1.95	0.20	1.33	0.13
5_a	1.65	0.34	2.34	0.24	1.84	0.19
5_b	1.17	0.16	1.31	0.13	1.30	0.13
6_a	0.27	0.17	1.30	0.13	0.98	0.10
6_b	0.75	0.20	1.43	0.15	1.25	0.13
7_a	1.16	0.08	2.34	0.24	0.88	0.09
7_b	1.12	0.35	1.11	0.11	2.81	0.29
8_a	0.55	0.05	3.49	0.35	4.25	0.43
8_b	1.00	0.44	4.55	0.46	4.42	0.45
9_a	1.04	0.60	2.93	0.30	2.08	0.21
9_b	1.13	0.03	1.09	0.11	0.96	0.10
10_a	1.00	0.11	1.94	0.20	1.64	0.17
10_b	1.45	0.18	1.49	0.15	2.16	0.22
11_a	1.58	0.23	1.16	0.12	1.58	0.16
11_b	0.79	0.10	nd	nd	0.91	0.09
12_a	1.63	0.21	2.62	0.27	2.30	0.23
12_b	1.44	0.14	1.86	0.19	1.53	0.16
13_a	1.41	0.15	3.46	0.35	1.92	0.19
13_b	1.27	0.26	2.81	0.29	2.49	0.25
14_a	0.70	0.16	2.04	0.21	1.57	0.16
14_b	0.37	0.34	1.58	0.28	2.42	0.28
Min	0.27	-	0.97	-	0.81	-
Max	2.23	-	4.55	-	4.42	-
Mean	1.17	-	2.07	-	1.90	-
SD	0.50	-	0.93	-	0.93	-

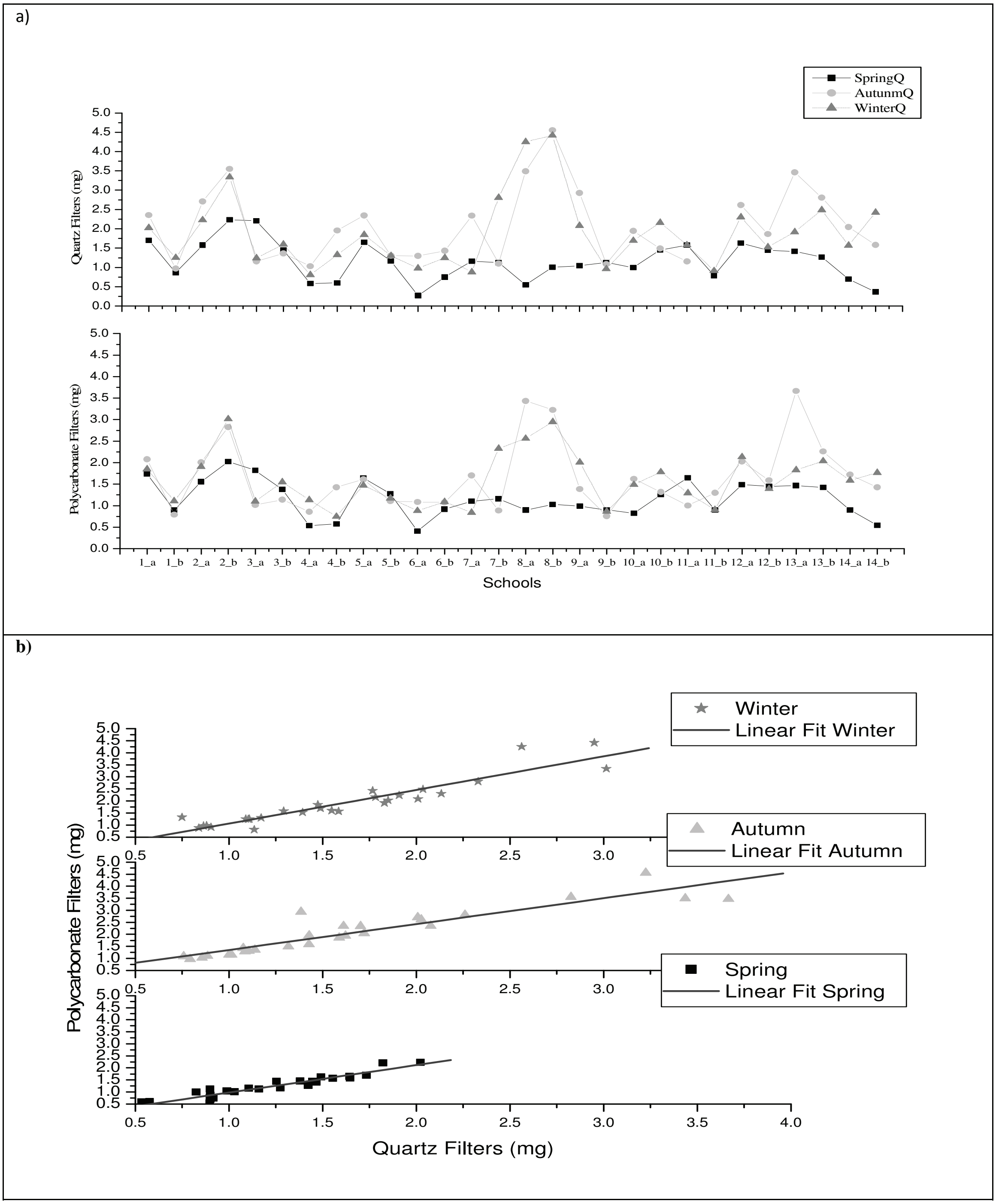

Fig. 5. (a) Total particulate Matter (TPM) in polycarbonate and quartz filters collected in the 14 primary schools, in Lisbon, at the three campaigns. (b) Correlation between TPM mass collected with both filter types.

The 62 days normalized TPM values of the polycarbonate and quartz filters of all campaigns were averaged and each value was then divided by the obtained average. These ratios are shown in Fig. 6. It is observed that it is mostly in Autumn and Winter campaigns that the values of TPM are higher than the whole average. This is verified for both types of matrices. It is also observed that some classrooms present values below the average in all campaigns. Both classrooms of schools 4 and 6 are in this situation and one of the classrooms of schools 1, 5 and 11.

The analysis of variance of results was performed by non-parametrics statistics for a significance level of 0.05, the Mann-Whitney U Test for binary independent groups and Kruskal-Wallis for multiple independent groups. The first points out for an excellent correlation between autumn and winter (p=0.946 for polycarbonate filters and p=0.310 for quartz filters) and no correlation between spring and autumn and spring and winter (p-values of polycarbonate filters 0.02 and 0.02, respectively, and p-values of quartz filters 0.0002 and 0.001, respectively); the second showed that the seasonal averages are significantly different either using polycarbonate filters (p-value=0.188) or quartz filters (p=0.285).

The TPM values of schools 1-3, normalized to 2 weeks, were compared to the results of PM2.5, PM2.5-10 and PM10 (obtained by summing the previous ones). The Gent values were averaged for 2 weeks, for Spring and Autumn. Fig. 7 shows that the results are independent, either because the size of particles is different (one with total sizes, the other with finer particles), or because the TPM does not reflect much the finer particles which are in Brownian movement [21] inside the room and have difficulty in deposing without a sticky surface. In fact, whatever the TPM mass in Spring the PM10 values stay constant. Also, the tendency is reversed for PM10 and PM2.5-10 in Spring, because higher values of TPM correspond to lower values of the latter. In Autumn, there are only two points and nothing can be concluded on the tendency. In conclusion, active and passive methods could not be compared.

3.3 Particulate deposition, rhinitis and asthma

Fig. 8 compares the % of children with rhinitis and asthma symptoms in 2009/2010 and the TPM results of quartz and polycarbonate filters, in the studied schools. Higher results of TPM in all schools occurred in Autumn and Winter. This may be related to the accumulation of particles because the natural ventilation is not applied [22], except for classrooms 4a and 4b. These classrooms present low TPM values in all campaigns; however, also other classrooms have low TPM with natural ventilation. Furthermore, the children bring indoor dirtier shoes in Autumn and Winter than in Spring, easing resuspension of soil particles. According to Janssen et al. [23], indoor mass particulate is higher than outdoor indicating indoor sources rather than outdoor ones. Schools 2, 8 and 13 present the highest TPM values. No association was found in general between the classrooms characteristics and TPM deposition values.

Fig. 8 also shows, in %, the children with asthma and rhinitis of each school relative to the number of studied children with these diseases (questionnaires of 2009/2010). The classrooms 2a, 3b, and 14a present the highest % of children with rhinitis and asthma. Furthermore, classrooms 10a and 11b have high incidence of rhinitis, and classrooms 10b and 14a have high incidence of asthma. No apparent association exists between TPM and the % of children with asthma and/or rhinitis, except for school 2. This is situated downtown where outdoor PM10 frequently exceeds the Portuguese legislation [24].

Fig. 9 attempts to extract conclusions on seasonal associations of indoor TPM, outdoor PM2.5 and % of children with rhinitis complains. The TPM values were obtained by averaging the normalized data to 62 days for all schools, either for polycarbonate or quartz. The daily outdoor PM2.5 values given by Partisol were joined for periods equal to the ones of the 62 days of the 3 campaigns [25] and the values were averaged by campaign. The number of children with rhinitis complains in January, February and March were grouped for Spring, in October, November and December for Autumn and January, February and March for Winter, and the percentages relative to the total number of children with rhinitis complains were calculated. An apparent correlation between TPM and the rhinitis complains in 2009/2010 appears. It should be noted that the children who answered about rhinitis in 2009/2010 are the ones who also were in the classrooms where TPM were collected. This is not the case for the children who answered the 2006/2007 questionnaire, and this may be the most probable reason why the association occurs with the data of 2009/2010 and not with the ones of 2006/2007. Therefore, maybe a seasonal association is found when the data are considered as a whole and not found when the data are processed individually. Concerning the outdoor PM2.5 collected in 2007, an association appears with the results of 2006/2007 questionnaires. Therefore, the 2006/2007 reported cases relate to outdoor measurements.

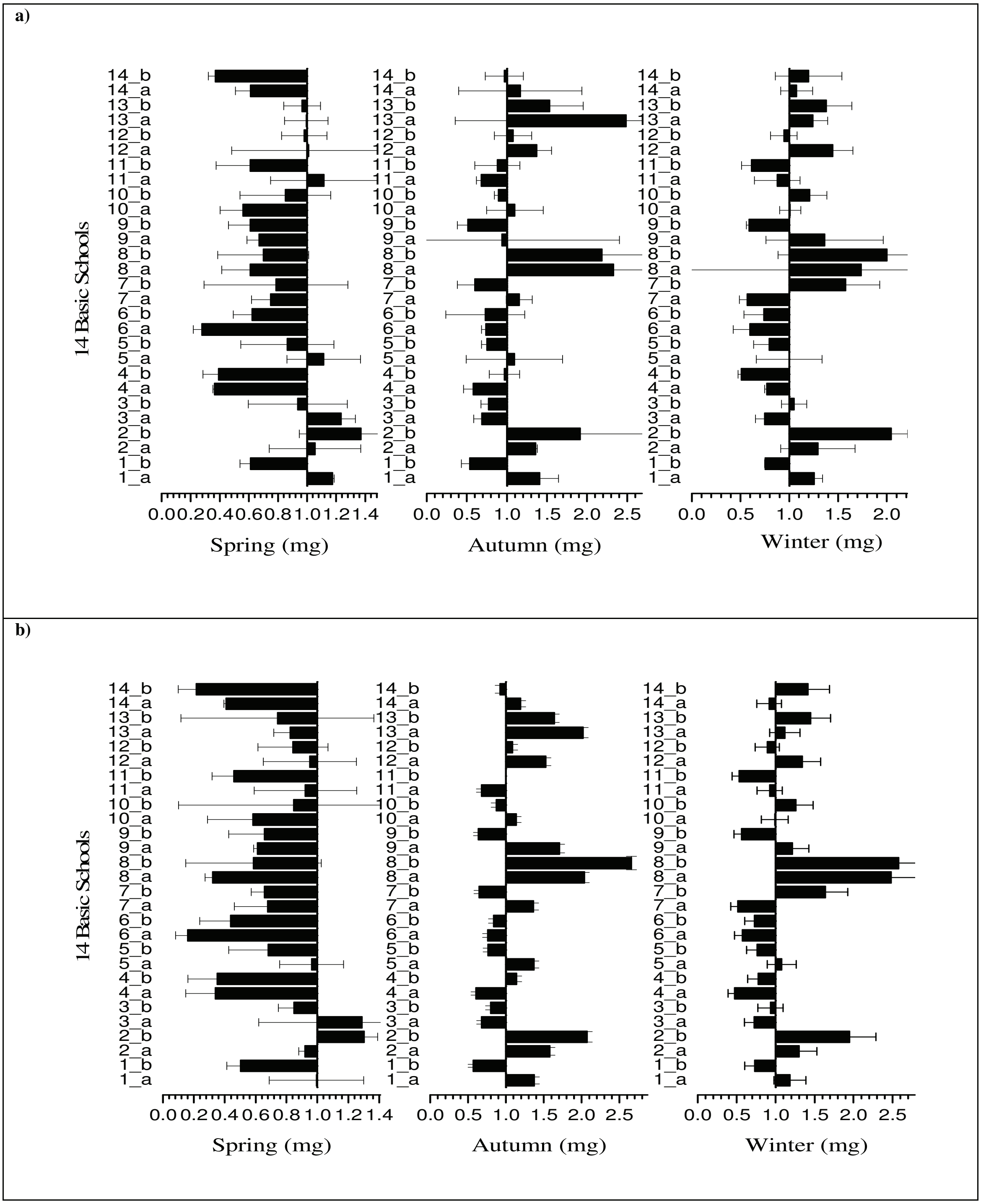

Fig. 6 (a) Ratio of each TPM value and the average of all TPM values of the three campaigns, for polycarbonate filters, shown by campaign. (b) Ratio of each TPM value and the average of all TPM values of the three campaigns, for quartz filters, shown by campaign.

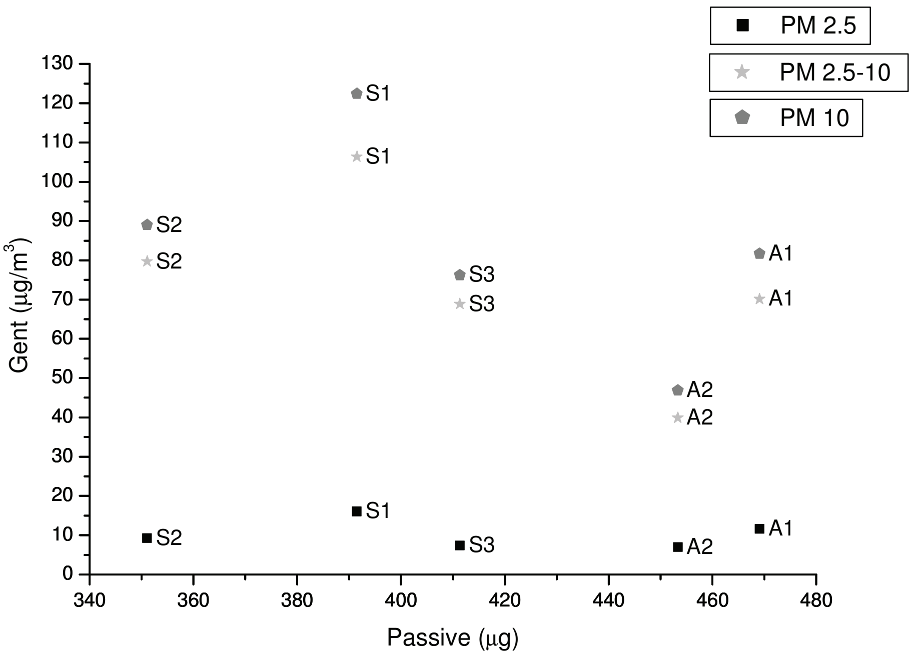

Fig. 7 Relation between TPM obtained in the passive filters with results of the particles below 10 µm, collected by the Gent sampler in Spring and Autumn campaigns. 1,2,3 refer the schools, A and S refer Autumn and Spring respectively.

The % of children with rhinitis symptoms in each school was normalized with the average in all schools and separated by campaigns (Fig. 10). Most of the schools present rhinitis percentages lower than the average. However, schools 2 (2a), 10 (10a), 11 (11b), 12 (both classrooms) present higher values than average in all seasons.

4. Conclusion

Total particulate matter in the indoor air of a total of 14 primary schools was determined passively in three campaigns: Spring, Autumn and Winter. It was obtained higher TPM values in Autumn and Winter than in Spring and only was correlation between Autumn and Winter. This suggests a significant difference between Spring and both other seasons. This may be due to the fact that there is insufficient ventilation, especially in winter. The campaigns which showed higher percentages of rhinitis were also Autumn and Winter. No association with the characteristics of the classrooms was found. The mass of collected particles in indoor was higher in quartz than in polycarbonate filters. However, an excellent correlation was found for both types of matrices in the three campaigns. An apparent association appeared between TPM averaged by campaign and the reported rhinitis by campaign, in 2009/2010. An apparent association appeared between the outdoor PM2.5 data averaged by campaign and the reported rhinitis by campaign, in 2006/2007.

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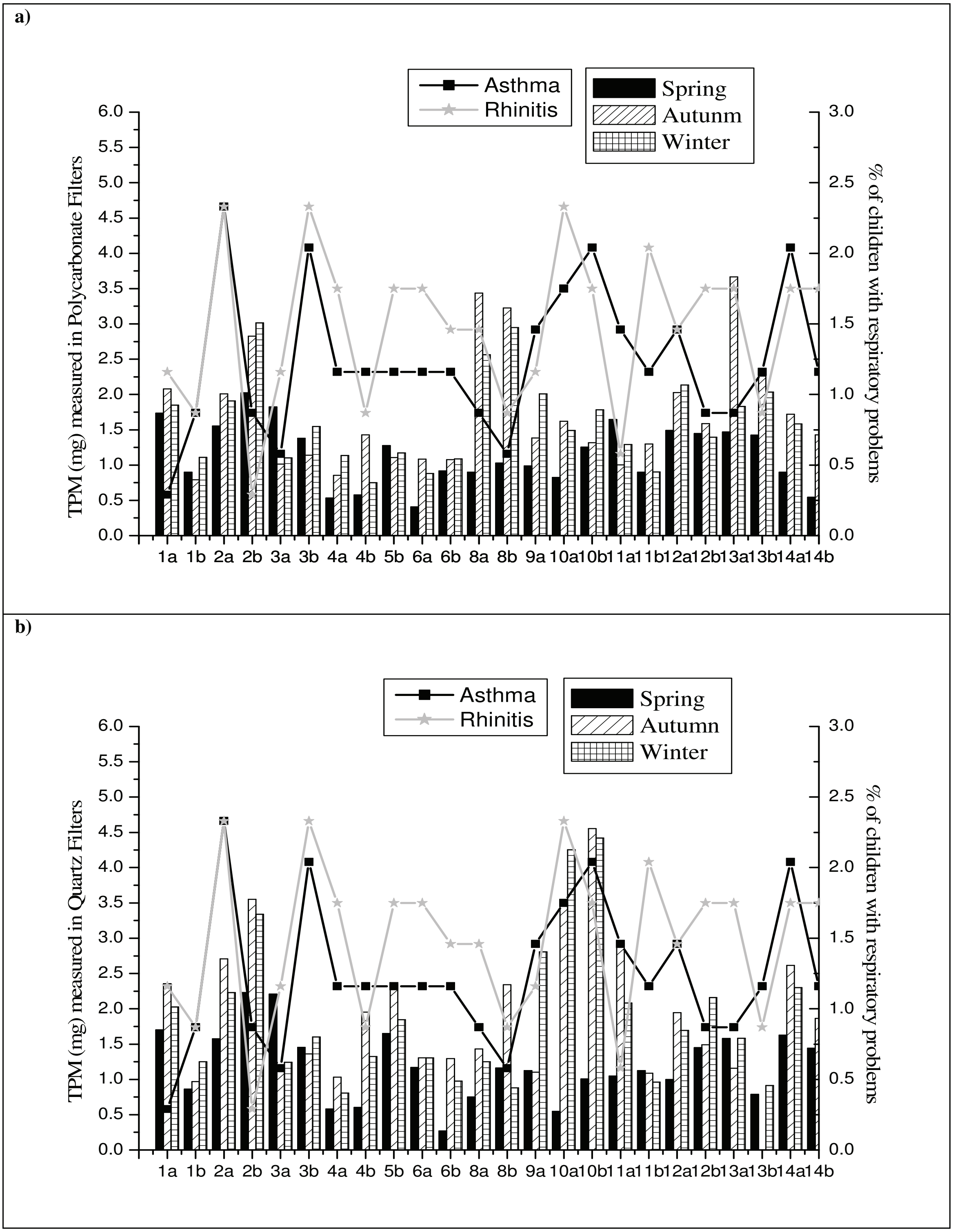

Fig. 8 (a) Comparison between the percentage of children with respiratory problems and seasonal TPM in the studied schools of Lisbon, with polycarbonate filters. (b) Comparison between the percentage of children with respiratory problems and seasonal TPM in the studied schools of Lisbon, with quartz filters.

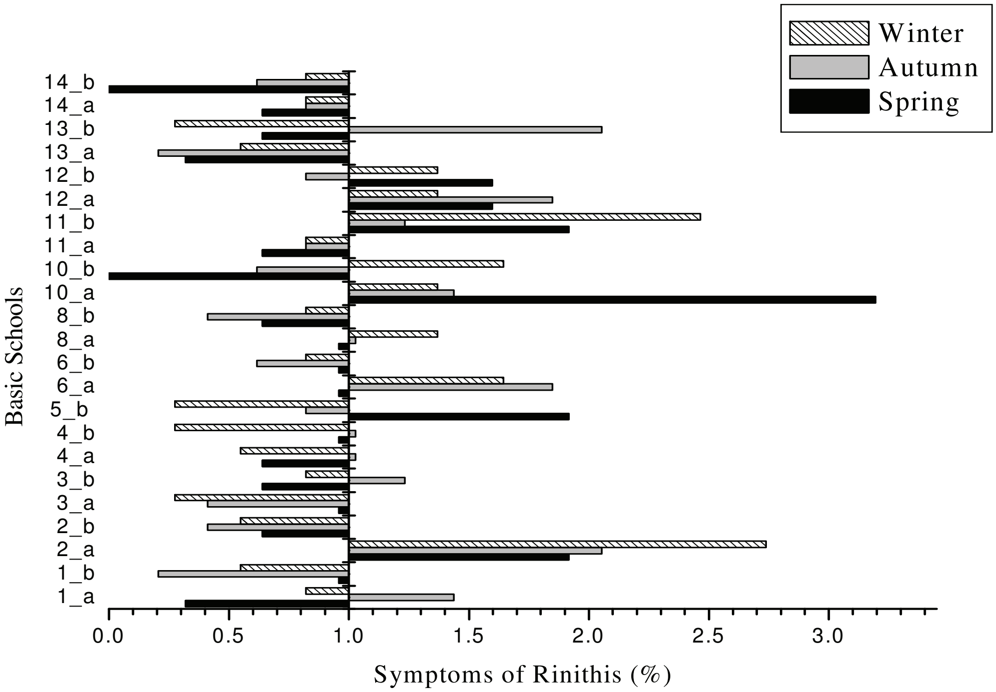

Fig. 9 Ratio of the number of children reporting rhinitis in each school and the average of all children reporting rhinitis in all schools, shown by campaign.

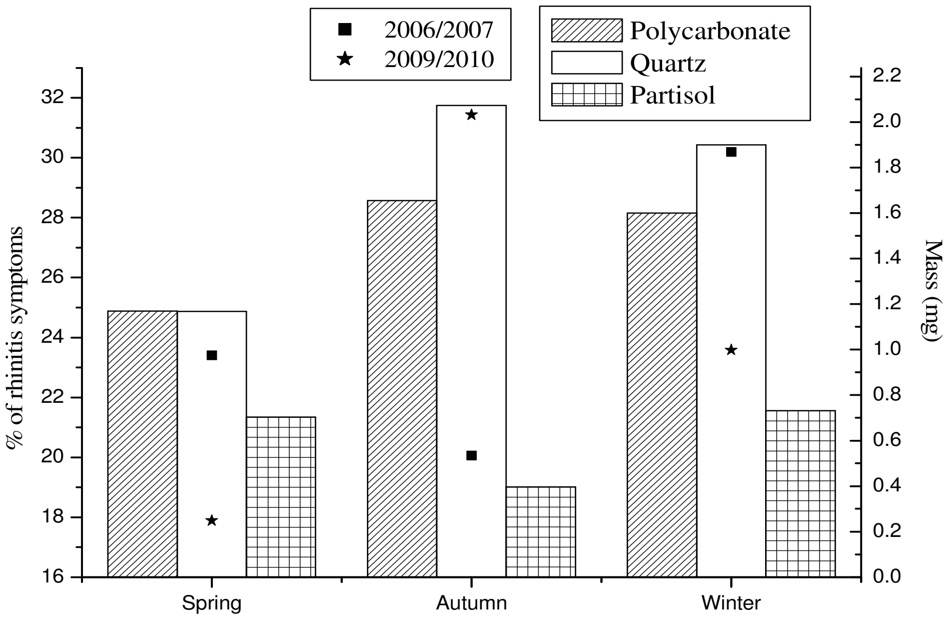

Fig. 10 Comparison between the seasonal variation of indoor TPM in polycarbonate and quartz, the seasonal variation of outdoor PM2.5 (measured by Partisol air sampler) and the % of children with rhinitis symptoms as reported in 2006/2007 and 2009/2010.

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