**Determination of Selected Pollutants and Measurements of Physical Parameters for the Evaluation of Indoor Air Quality in School Buildings of Athens, Greece**

**K. E. BOUBA, A.P. STROUBOU, E.B.BAKEAS, P.A.SISKOS**

*Environmental Analysis Group-Laboratory of Analytical Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, Panepistimiopolis,15771 Zographos, Athens,Greece.*

## Abstract

The objectives of this work were to characterize the indoor air quality in 20 naturally ventilated classrooms at 10 different public schools in Athens, to compare the measured concentrations with the established standards and to propose measures to improve air quality. Carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen dioxide ($CO_2$), total volatile organic compounds (TVOC), and formaldehyde (HCHO) were determined simultaneously and temperature, relative humidity and noise were measured. Temperature and relative humidity were within "comfort ranges" in almost all classrooms. The noise level was too high both in classrooms (61 dBA) and outdoors (77 dBA). $CO_2$ concentrations exceeded 1,800 mg $m^{-3}$, suggesting inadequate ventilation in 75% of classrooms, CO and $NO_2$ were at levels that posed no health threats. TVOC concentrations were found to be < 1 mg $m^{-3}$, except in renovated buildings, and formaldehyde levels were > 0.1 mg $m^{-3}$ in 92% of classrooms.

## Introduction

Indoor air quality has caught attention of scientists and the public in recent years. [1] Apart from the home, school is the most important indoor environment for children aged 6-18 and there is a growing concern about the school environment and its impact on health. Several studies have been published showing that both human health and productivity can be affected by poor air quality, indications that poor air. Children spend a significant portion of their lives in school buildings. [2, 3]. Currently there are no regulated standards for indoor air quality but certain guidelines have been issued for pollutant exposures and ventilation rates by several governments and organisations [4,5].

Parameters of interest were temperature, relative humidity and noise. Pollutants of interest were carbon dioxide ($CO_2$) [6], carbon monoxide (CO), nitrogen dioxide ($NO_2$) and benzene ($C_6H_6$), total volatile compounds (TVOC) and formaldehyde ($H_2CO$) [7].

In the present work air pollutants and parameters that affect air quality were determined simultaneously and measured in twenty classrooms of ten schools in Athens. The objectives of this study were to characterise air pollution level at the selected classrooms, to compare the mean concentrations with the established standards, to suggest ways to reduce pollutant levels in classrooms and also to suggest clear and easily applied activities that can be used to help to improve air quality in schools.

**Materials and Methods**

In the city of Athens there are 200 primary and secondary public schools from which we selected ten for our study. They are located in the urban area with major traffic roads surrounding the schools. Three schools are primary, classrooms are fully decorated wall to wall with pictures, drawings, charts etc, and there are also open shelves, working tables, and fabrics. Seven schools are secondary, their classrooms have poor furnishings (desks chairs, blackboard) and minimal decoration. Two schools have been renovated in September 2000 School buildings were constructed with new materials after 1970. All classrooms are painted every year and sometimes twice with latex- plastic paints, and flooring is constructed from inlaid concrete. The schools varied in respect to factors such as age, construction and size. In each school two classrooms, were chosen for the study.

All classrooms are naturally ventilated. Passive systems of ventilation rely on operable windows, air leaks, and wind and stack effect. Air enters and escapes continually from all rooms through doors, window cracks and other openings

All measurements were performed in occupied classrooms, in the morning (8.15-14.15) lecturing hours. Sampling equipment were placed at 1.5 m above ground level at indoor locations in the middle of the classroom. Measurements of sound were carried out in the classrooms and outdoors. For the ambient air the measurements of the Hellenic Ministry of the Environment were used.

The determinations and measurements were performed in each classroom, two days per month on May 2000, December 2000 and January 2001.

A questionnaire was delivered before the measurements to 160 pupils, aged 15-18, and to 58 teachers. [8,9] , which consists of three parts: it contained six questions relating comfort in school environment, it requested information on present symptoms (irritations), and it asked for information whether or not the pupil were allergic.

For the determinations and the measurements the following equipment was used: a Sound Analyser CEL-593 (noise), a Babuck LSI monitor (temperature, relative humidity, $CO_2$, CO, and $NO_2$) a formaldehyde portable monitor kit (PPM Limited, Formaldemeter 3*)* ,a Photovac 2020 with PID detector (TVOC) and Gastec detectors and dosi tubes for a crude estimate of the above pollutants.(CO, $CO_2$, $NO_2$, formaldehyde and benzene).

Apparatus were calibrated according to manufacture specifications.

**Results**

The guidelines of CEC, ASHRAE and World Health Organization (WHO) were used for comparison. The guidelines and standards for pollutants relevant to this study are listed in Table 1.

Minimum, maximum and mean values of measured parameters and pollutants are listed in Table 2.

*Temperature* was in comfort values suggested by ASHRAE in approximately all classrooms. Central heating with oil burners is used in all buildings in winter.

*Relative humidity* varied in normal values, it also increases about 4 % during lecturing hours because of the bioeffluents of occupants. Barbat [11] in school near Lyon, found that relative humidity was never in agreement with indoor recommendation and could be responsible for people's discomfort (lethargy and breathing difficulties symptoms).

**Table 1.Guidelines and standards of parameters and pollutants.**

| | | |
|---|---|---|
| Temperature, $^0$C | 19-26 | ASHRAE 55-1992 |
| Relative humidity, % | 30-70 | ASHRAE 55-1992 |
| Noise dBA in classrooms | 45 dBA comfort value | CEC (recommended) |
| outdoor school | 65 dBA comfort value | |
| Carbon dioxide, mg/m$^3$ | 1800 | WHO 1995, ASHRAE 62-1989 |
| Carbon monoxide, mg/m$^3$ | 9.9 (8 h average) | WHO,1995 [4] |
| Nitrogen dioxide, μg/m$^3$ | 150( 24 h average)<br>40-50 (annual average) | NAAQS U.S, WHO,1995 |
| Total volatile compounds, μg/m$^3$ | 1000 | ECA (recommendation) [10] |
| Formaldehyde, mg/m$^3$ | 0,1 | WHO |
| Benzene, μg/m$^3$ | 16.2 ( annual average) | U.K EPA Q.S |

**Table 2. Mean concentrations of measured parameters and pollutants in twenty classrooms of ten schools on May 2000, December 2000 and January 2001.**

| | May | | | December | | | January | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameters and pollutants | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. | Mean |
| Temperature $^0$C | 23,45 | 31,06 | 24,36 | 14,93 | 21,96 | 19.18 | 16,80 | 22,27 | 19.99 |
| Relative Humidity % | 40,80 | 55,90 | 44,48 | 33,70 | 61,87 | 43,23 | 41,08 | 71,50 | 52,90 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Noise, dBA indoor<br>outdoor | 52<br>66 | 74<br>79 | 67<br>71 | 44<br>62 | 68<br>76 | 61<br>77 | | | |
| $CO_2$ , mg/m$^3$ | 604 | 5322 | 2263 | 882 | 4165 | 2434 | 984 | 4113 | 2537 |
| CO , mg/m3 | 0,19 | 7,98 | 6,22 | 0,21 | 3,30 | 1,98 | 0,16 | 3,48 | 1,89 |
| $NO_2$ , μg/m$^3$ | 10 | 80 | 56 | 10 | 80 | 49 | 10 | 70 | 41 |
| TVOC, μg/m$^3$ | 114 | 686 | 332 | 160 | 3429 | 668 | 169 | 3200 | 953 |
| $H_2CO$, mg/m$^3$ | 0.106 | 0.630 | 0.306 | 0.025 | 0.429 | 0.208 | 0.049 | 0.450 | 0.223 |
| $C_6H_6$ , mg/m$^3$ | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |

*Noise levels* were greater than the recommended values from the European Community in all classrooms as shown in Figure 1. The use of double glazed windows could eliminate the noise indoors. Teachers and pupils consider noise as the main problem in school, as it is referred in the answers of the questionnaire Table 3.
*The mean concentrations of $CO_2$* exceeded comfort value (1800 mg/m$^3$) in 75% of classrooms and in 11% of classrooms values exceeded the 3600 mg/m$^3$ Higher levels of $CO_2$ were observed in

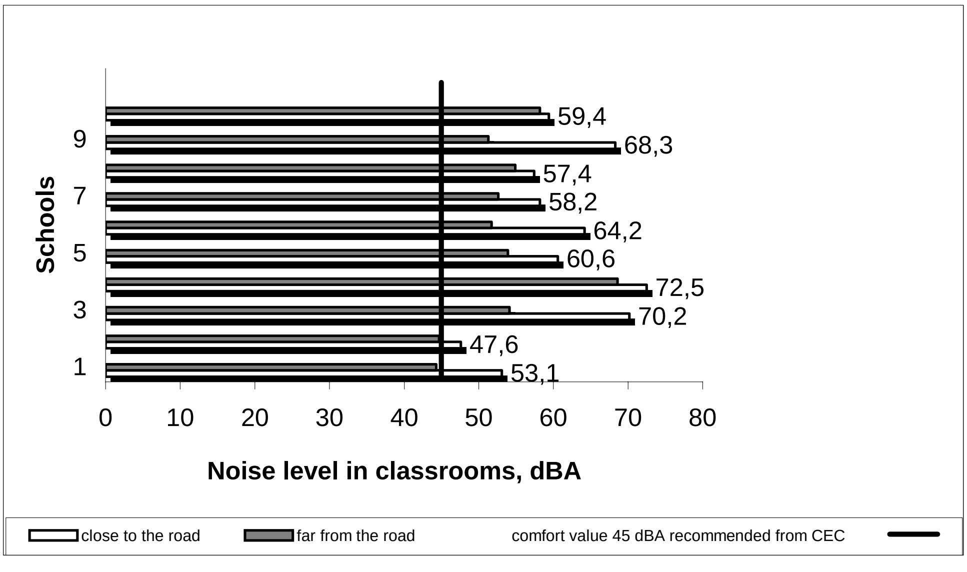


**Figure 1 .** Noise levels in two different classrooms for each school.

**Table 3.** Mean value of perceived air quality in classrooms measured in May 2000, December 2000 and January 2001.

| | May | December | January |
|---|---|---|---|
| Mean $CO_2$ in mg/m$^3$ | 2263 | 2434 | 2537 |
| % Dissatisfied | 20 | 21 | 22 |
| Air quality category | B | B | B |
| Decipol | 1.42 | 1.54 | 1.61 |

winter due to inadequate air exchange by closing windows and doors. Crowded classrooms could also be the reason for high $CO_2$ levels as shown in Figure 2.

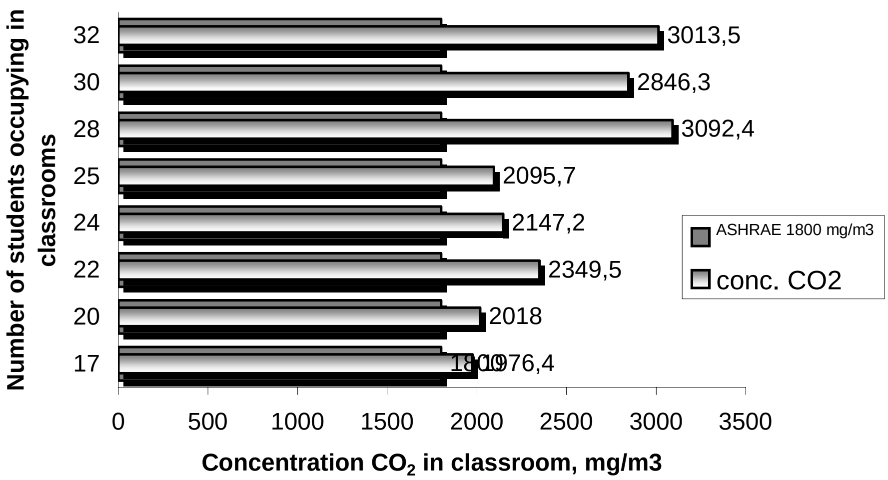


**Figure 2.** Number of students occupying classrooms and concentrations of $CO_2$.

A correlation of $CO_2$ with occupancy was observed. Carbon dioxide build up began when pupils started occupying classroom and reached a maximum until the break. As breaks are very short (5-10 min), $CO_2$ concentration reduces but not quite enough as shown in Figure 3. From the measured concentrations of $CO_2$ the percentage of dissatisfied persons entering the classroom was calculated (it ranged from 20-22%) and the human equivalent pollution in decipols (Fanger) [6]. Air quality can be classified into category B as shown in Table 3 .

Concentrations of CO were lower than outdoors (2.8-8.0 mg/m$^3$) and lower than the suggested standard of WHO. In teachers offices (smoking area) values varied from 3-12 mg/m$^3$. Values were higher in May due to specific climatic characteristics of the region and open windows. In addition, CO concentrations are strongly affected by vehicular exhaust emissions and the absence of ventilation systems results to high CO concentrations. Barbat found 0,85 mg/m$^3$, while in ambient air concentration of CO was found to be 0,72 mg/m$^3$.

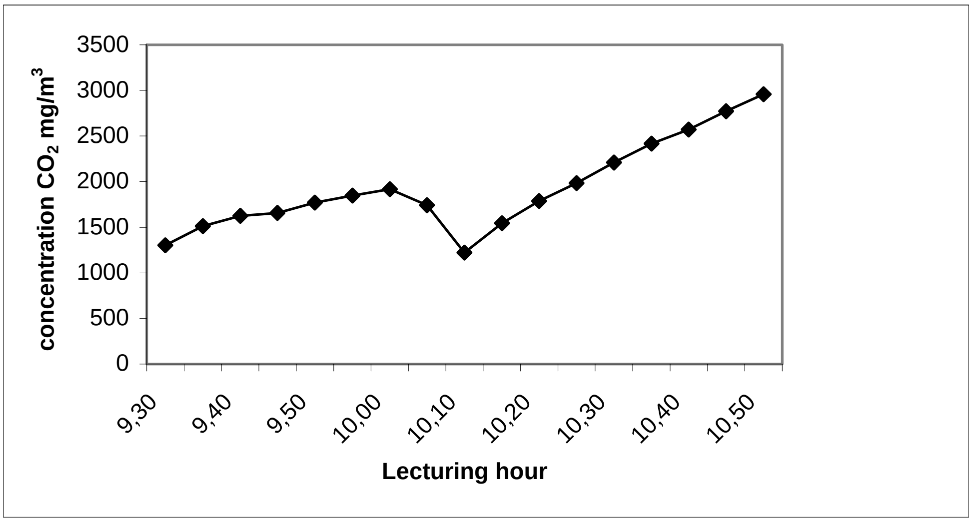


**Figure 3.** Concentration of $CO_2$ on lecturing hour.

*Mean concentrations of $NO_2$* were lower than outdoors and the established standard of WHO and ranged from 44-56 µg/m$^3$, outdoors mean concentrations varied from 51-64 µg/m$^3$. Roorda [12] measured concentrations of $NO_2$ in 12 schools in the same six city district in Holland. They found clear decline in $NO_2$ concentrations with distance from roadside which was more evident in periods with high exhaust exposures than in periods with low exhaust exposures. $NO_2$ concentrations were

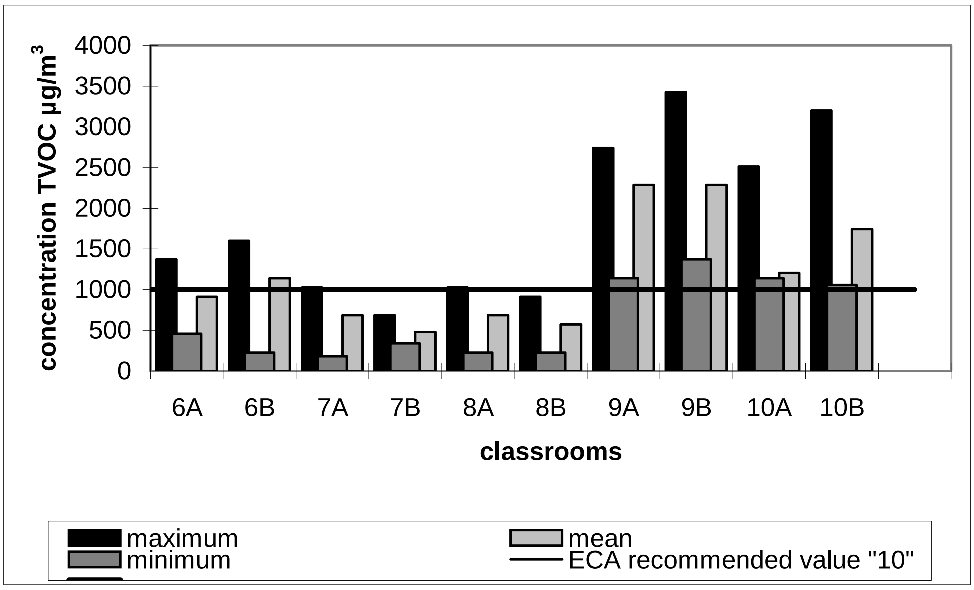


**Figure 4.** Maximum, minimum and mean concentrations of TVOC. Schools 9 and 10 were renovated in autumn.

significantly correlated with car and total traffic intensity, percentage of time downwind and distance of the school from the motorway. Barbat et al [9] found 52 µg/m$^3$ in a school.

*Mean TVOC concentrations* as recorded each month were lower than 1000 µg/m$^3$, value suggested by ECA as shown in Table 3. Concentrations recorded in winter were higher than those in May due to central heating, heavy traffic and poor concentrations of photooxidants. In renovated schools higher TVOC concentrations were observed as shown in Figure 4.

*Mean formaldehyde concentrations,* as shown in Table 2 were higher than WHO suggested standard in most classrooms. In May higher concentrations of formaldehyde were observed than winter. High concentrations of formaldehyde in summer may be due to the higher emission rate of formaldehyde from its indoor sources at relatively higher temperatures and relative humidity. It is supposed that the penetration of outdoor $O_3$ in indoor environment during summer seasons and its reaction with different indoor surfaces and building materials lead to an increase in the formation of indoor formaldehyde. The higher outdoor concentration of formaldehyde during the summer may be due to the higher prevalence of photochemical reactions and greater concentrations of $O_3$. Higher concentrations of formaldehyde were observed in primary schools (0.074-0.351 mg/m$^3$) due to furnishings (particle boards are used) and decoration material are the major sources of formaldehyde Fig 5.

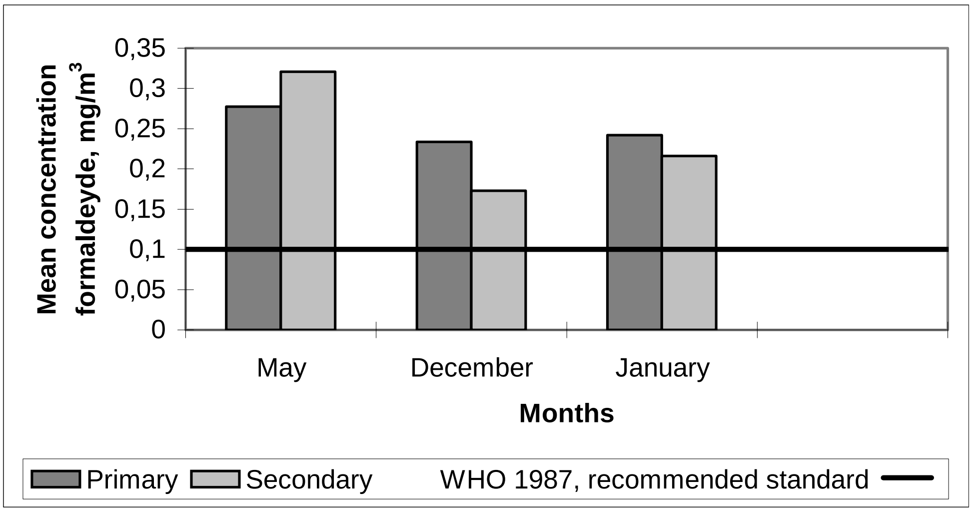


**Figure 5.** Mean values of formaldehyde in primary and secondary schools.

Higher concentrations of formaldehyde were also observed in small classrooms with inadequate ventilation (0.171-0.420).

The major problems concerning air quality in classrooms identified from this study are noise, high concentrations of $CO_2$ ,and formaldehyde and TVOC.

*Symptoms of pupils and teachers*

All occupants of schools were disturbed from noise, but teachers were more annoyed, as it is referred in the answers of the questionnaire. Table 4.

**Table 4.** Percentage of symptoms taking from the questionnaire.

| Symptoms | Teachers (N=56) | | Pupils (N=156) | |
|---|---|---|---|---|
| | Men | Women | Boys(N=8 | Girls |
| Too high room | 27 | 23 | 20 | 1 |
| Too low room temperature | 63 | 76 | 15 | 30 |
| Stuffy air | 14 | 21 | 34 | 27 |
| Dust | 72 | 76 | 20 | 46 |
| Unpleasant smells | 54 | 53 | 58 | 49 |
| Noise | 82 | 94 | 78 | 57 |
| Fatigue | 82 | 71 | 71 | 60 |
| Head ache | 73 | 76 | 34 | 43 |
| Dizziness | 9 | 35 | 20 | 35 |
| Difficulties in | 18 | 30 | 34 | 38 |
| Irritation, burning, itching | 45 | 77 | 22 | 14 |
| Irritated stuffy or runny | 82 | 41 | 25 | 5 |
| Cough | 36 | 35 | 32 | 22 |
| Hands dry itching red skin | 54 | 53 | 8 | 8 |
| Allergic diseases | 9 | 11 | 9 | 0 |

Double-glazed windows and probably air-conditioned classrooms are necessary occasionally, for helping in reducing noise.

Indoor $CO_2$ concentrations exceeded ASHRAE standard due to crowded classrooms and inadequate ventilation. The high concentrations of $CO_2$, TVOC, and formaldehyde clearly show that outdoor air flow rate required for dilution of emissions is inadequate in schools. Lowering the occupancy, improving the ventilation systems, and increasing breaks between lectures could alleviate high concentrations of pollutants. At least ceiling fans could be used in every classroom. Formaldehyde exceeded the WHO recommended standard value in most classrooms of the study. Renovations must be carried out in summer, when schools are closed.

Measurements of parameters can be performed with simple equipment in schools as U.S EPA suggests [2] and also for serving education as well. Parallel measurements were made with detector and dosi tubes. Results were compared with average concentrations measured. It was concluded that values from detector tubes correspond well only with the measured $CO_2$ and formaldehyde. Their use for measuring CO and $NO_2$ concentrations could lead to large errors. Benzene was not detected in all classrooms (Benzene concentrations <LOD = 225 $\mu g/m^3$).

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