AIR QUALITY AND VENTILATION RATES IN SCHOOLS IN POLAND - REQUIREMENTS, REALITY AND POSSIBLE IMPROVEMENTS

J Sowa*

Institute of Heating and Ventilation, Warsaw University of Technology, Warsaw, Poland

ABSTRACT
The goal of the paper is to compare real state of indoor air quality in classrooms in Poland with national and international requirements and standards. The evaluation of existing situation is based on indoor environment measurements in 28 classrooms in Warsaw. Both temperature and carbon dioxide concentration were measured with 1 minute interval during the workweek. Measurements of formaldehyde and total volatile organic compounds (TVOC) were used to characterize level of air pollution caused by building materials and furnishing. Special questionnaire helped to collect all-important information about localization, construction and furnishing. The investigation indicated that Polish regulations on indoor air quality not only seem to drop behind similar regulations in developed countries as far as their rigidity is concerned, but also, generally, are not observed.

INDEX TERMS
Schools, Ventilation rate, Carbon dioxide, TVOCs, Formaldehyde

INTRODUCTION
In many countries school buildings receive special care on the part of legislative and executive authorities as well as local governments. This is based on the assumption that children at school acquire not only systematized knowledge but also some solutions and behavior patterns. Modern schools, where these solutions are applied, started to appear also in Poland. Majority of them, however, are housed in the buildings dating from the 1960s and 1970s which have been recently renovated. The purpose of such renovation works is often to conserve energy by means of thermal insulation of walls, replacing windows, modernizing central heating systems and boilers. Since some of these improvement works are believed to have negative effect on indoor air quality, it has been decided to check the actual indoor air quality and ventilation rates in the Polish schools and compare the results with requirements and tendencies in this respect.

POLISH REQUIREMENTS FOR THE INDOOR AIR QUALITY IN SCHOOLS
The Polish building law often stipulates requirements based on "wishful thinking". For instance, there is a provision, set out in § 309 of the Regulation on technical conditions for buildings and their location, which requires that "*materials and products used for the construction of buildings as well as construction methods should not be hazardous for hygiene and health of their occupants or neighbors...*" (MGPiB, 1999). Unfortunately, as it is usually the case of similar regulations there are no sufficiently detailed rules for implementation of these requirements.

* Contact author email: Jerzy.Sowa@is.pw.edu.pl

Permissible values of concentration and intensity of factors hazardous to health, emitted in all living areas by building materials, equipment and furnishing, are set out in a Regulation of the Minister of Health and Social Care (MHSC, 1996). This Regulation sets two categories of rooms, i.e. A and B. Classrooms belong to category A. The Regulation also specifies permissible concentration values (average 24 hrs) for 35 chemicals. Moreover, in the case of 17 substances and their mixtures this Regulation sets limits (in many cases their application is generally forbidden) as for their content in building materials. It should be noted that smoking outside clearly marked smoking areas in schools and educational institutions is also legally forbidden in Poland.

Standards of air quality may also be indirectly established, for instance, by defining required ventilation rate. In Poland minimum flow of outdoor air in apartment houses, residential buildings and public buildings, which include schools, is specified in the Polish Standard PN-83 B-03430 (PKN, 2000). This Standard requires at least 20 m^3/h of outdoor air for each occupant in rooms permanently or temporarily occupied by people. The Standard does not specify the type of ventilation in school buildings leaving this decision to the architect. Practically almost all classrooms are ventilated in a natural way. It should be noted that, in exceptional cases, it is permissible to supply schools and kindergartens with up to 3 changes per hour of outdoor air under negative pressure, whereas in all buildings natural outdoor air supply may not exceed 2 air changes per hour.

TESTS OF INDOOR AIR QUALITY IN POLISH SCHOOLS

The concept of indoor air quality is quite broad. Therefore, complex quality tests of indoor environment may include numerous elements such as: surveys carried out among occupants, medical examination of occupants, psychological tests identifying potentially independent sources of their dissatisfaction, specification of the kind and values of concentration of gas, dust and microbiological contamination, examination of indoor microclimate, measuring of ventilation efficiency, measuring physical hazard (noise, quality of visual environment, ionizing and non-ionizing electromagnetic radiation). Such a broad scope of tests is very expensive and technically difficult even in the case of one room. Moreover complex measurement procedure may influence test results. In majority of tests only some selected values are analyzed. In order to assess quality of indoor air in current study, a special measurement method was developed (Table 1). This method prefers automatic measurement, which limits work of research teams to periods in which classrooms are not used. Additional information about location of the classroom, its volume, ventilation system, furnishing, type of window, number of seats and many, many others has been collected in special questionnaire filled out by the measurement team.

In February and March 2000, 28 rooms in 24 school buildings in Warsaw were tested. Schools were random chosen from the lists provided by local district authorities. In each school building typical rooms (in respect of size, furnishing, wear and tear, etc) were selected. Chemistry laboratories were excluded from the tests, which were performed in 16 classrooms in elementary schools, 4 classrooms in grammar schools and 8 classrooms in secondary schools. The area of these rooms varied from 43 m^2 to about 74 m^2, whereas the height ranged from 2.7 m to 4 m. In fully occupied classrooms density ranged from 1.22 to 2.5 m^2 per person. The lowest number of seats in the classroom was 24 and the highest 44.

Figure 1 presents an example of variable CO_2 concentration and air temperature in the classroom. It can be noticed that practically throughout the whole period in which the classroom was used, CO_2 concentration exceeded 1000 ppm.

Histogram showing maximum CO_2 concentration (Figure 2) indicates that in all tested classrooms CO_2 concentration exceeded 1000 ppm at times.

Table 1. Simplified measurement procedure developed for the study.

Type of measurement	Measurement procedure	Utilization of measurement
Variability of air temperature	Automatic measurement with 1 min interval (Monday morning -Friday afternoon)	Indicator of both thermal comfort and effectiveness of heating system
Variability of carbon dioxide concentration	Automatic measurement with 1 min interval (Monday morning -Friday afternoon)	Indicator of both indoor air pollution caused by occupants and air change rate
Formaldehyde concentration	Approx. 12 hour long measurement in empty classroom	Indicator of pollution caused by furnishing
TVOC concentration	Approx. 12 hour long measurement carried out parallel to formaldehyde measurement, sampling medium - activated carbon, number of samples - 2, identification of main components and TVOC concentration using gas chromatography with FID detector	Indicator of caused by all sources

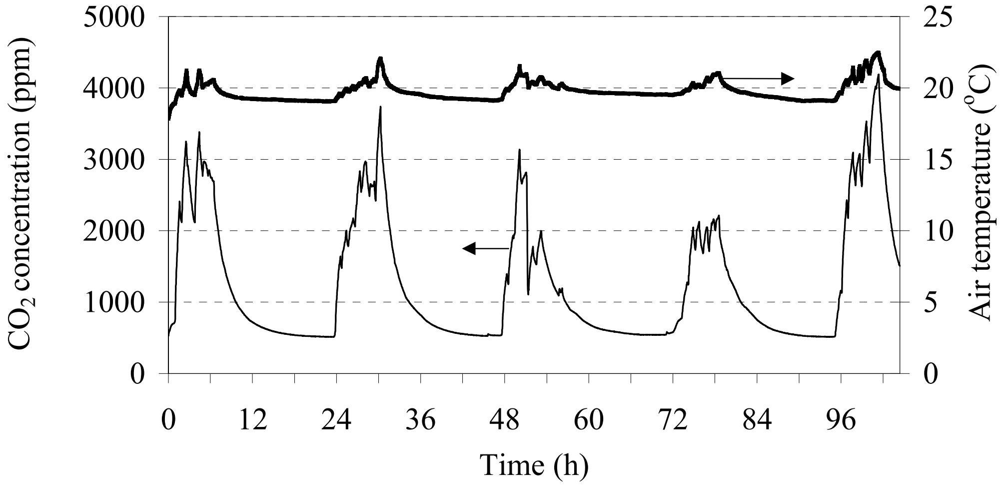

Figure 1. Variability of carbon dioxide concentration and air temperature, in one of examined classrooms.

Figure 3 presents the results of measurement of formaldehyde concentration. It exceeds the permissible value for category A rooms (50 $\mu g/m^3$) in 5 out of 27 tested classrooms.
Figure 4 illustrates the frequency of occurrence of the assumed ranges of TVOC in tested schools. The compounds most often identified from among 4-5 main air-polluting substances were: toluene (in 21 classrooms), xylenes (in 17 classrooms), decane (in 15 classrooms), undecane (in 11 classrooms), pentane (in 8 classrooms) as well as acetone, hexane, heptane and isopropyl benzene (in 6 classes). At the same time the research team often noticed stale air or strong chemical odor in the classrooms. Relevant remarks were made in the reports concerning the tested classrooms.

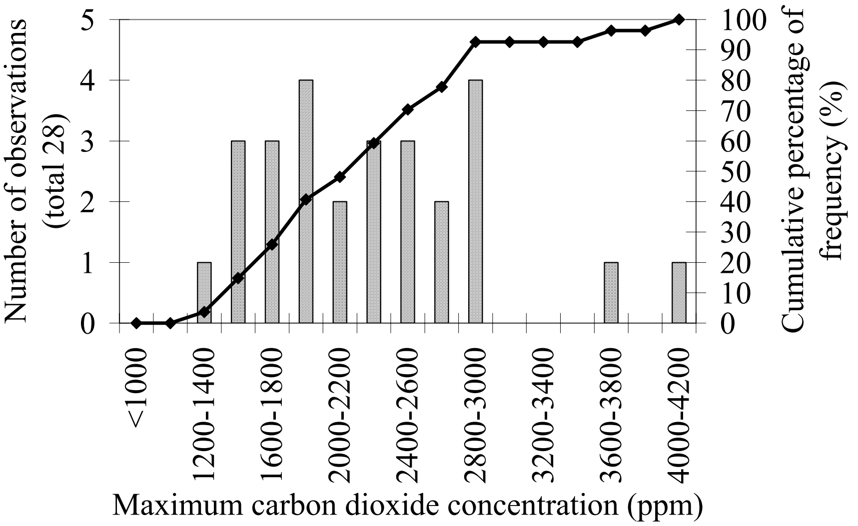

Figure 2. Maximum CO_2 concentration histogram.

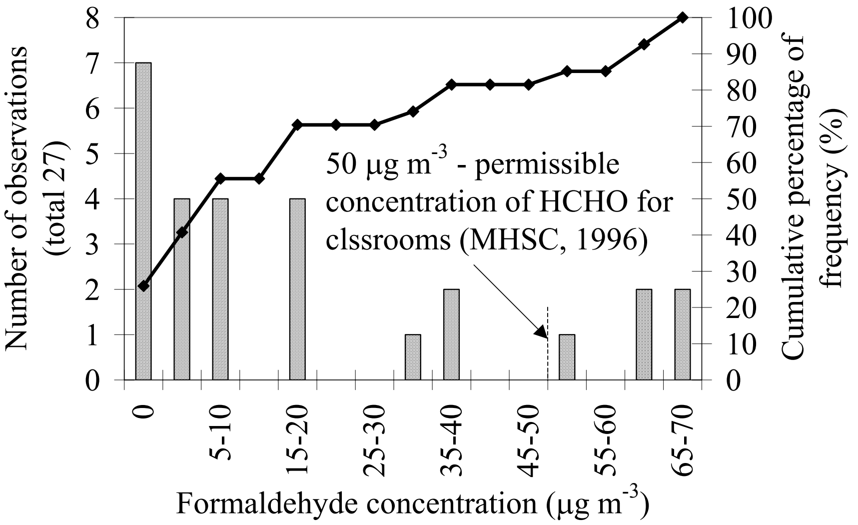

Figure 3. Formaldehyde concentration histogram.

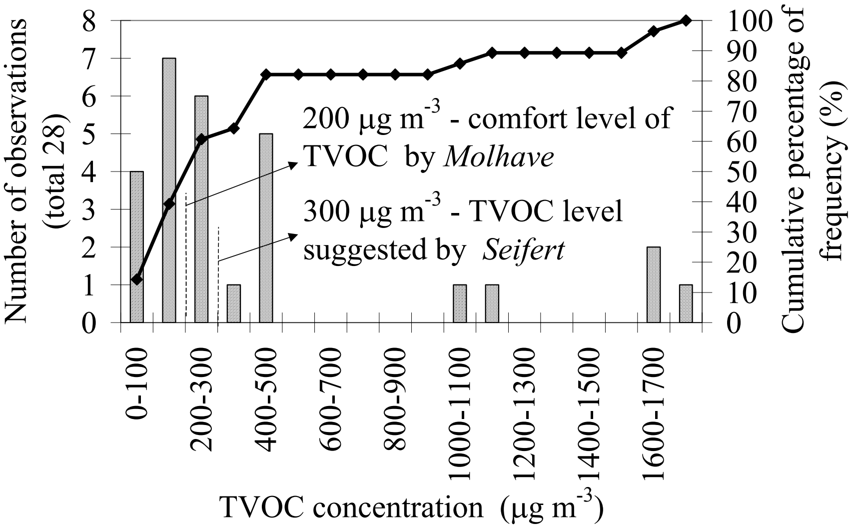

Figure 4. TVOC concentration histogram.

A method of interpretation of variable CO_2 concentration (Sowa, 1999) (test of tracer gas concentration decay) was applied to assess air change rate in the classrooms. Average air change rate after the pupils left the classroom is shown in Figure 5. This is usually determined on the basis of 4 CO_2 decay schemes. Absolute majority of classrooms had air change rate below 1 h^{-1} (range from 0.325 h^{-1} to 3.18 h^{-1}).

Assuming that classrooms were full (all seats were occupied), in test conditions the airflow rate per person would range from 1.2 to 9.6 m^3/(h person), and only in one exceptional case clearly deviating from the other ones it would be 21.5 m^3/(h person), Figure 6.

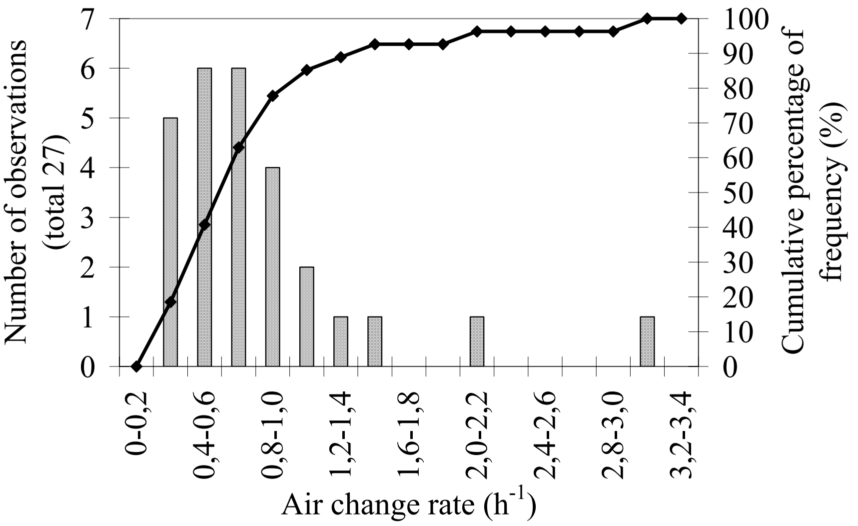

Figure 5. Air change rate histogram.

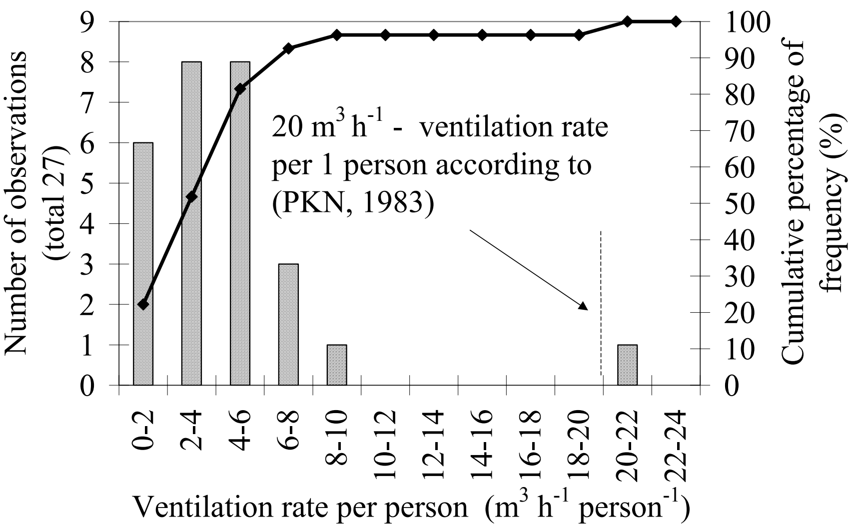

Figure 6. Ventilation rate per person histogram.

CONCLUSIONS

The tests performed in schools have shown that natural ventilation systems applied in all schools were not able to ensure proper ventilation rate. If we take into consideration airflow estimated per 1 person (assuming that all seats are occupied), only one school would meet the requirements. Inefficient ventilation systems result in very high CO_2 concentration in the classrooms throughout most of the time in which classes are held.

In the tested ventilation systems the only practical possibility to increase ventilation rate is to open the windows. Unfortunately in many schools situated in busy town areas it is impossible to open windows during the classes due to traffic and street noise. Moreover, in cooler seasons, open windows could cause discomfort for pupils sitting near the windows. Airing classrooms during breaks is a certain solution. Analyses of variable CO_2 concentration have shown that classrooms were periodically aired during the tests.

In view of the above comments on ventilation rate, the problem of polluting classrooms with chemicals emitted by building materials or furnishing is a secondary one. If ventilation rate was intensified to reach the required conditions (2-10 times), formaldehyde and TVOC concentration would come down to the permissible level. This suggests that school furniture manufactured nowadays does not emit excessive formaldehyde whereas emission from old furniture has lowered to the permissible level with time. We should be more careful when interpreting measurement results of TVOC concentration. *Mølhave,* the author of TVOC index proposed comfort level of 200 $\mu g/m^3$. However, due to different toxicity of individual chemicals *Seifert* proposed permissible concentration values for separate groups of chemicals, where the total level should not exceed 300 $\mu g/m^3$. In the tests discussed in this paper 11 out of 28 classrooms had TVOC concentration lower than 200 $\mu g/m^3$, and 17 classrooms - lower than 300 $\mu g/m^3$. Without separate detailed measurement we can never exclude that air has very low concentration of very toxic compounds.

The tests performed in schools have shown that classrooms are generally overheated. Central heating control systems do not compensate heat gains coming from persons, electric lighting or solar radiation. This causes excessive energy consumption and possible thermal discomfort and creates conditions increasing possible negative symptoms resulting from air quality.

To sum up, all Polish regulations on indoor air quality not only drop behind similar regulations in developed countries as far as their rigidity is concerned, but also, generally, are not observed. The increase of ventilation rate (number of air changes) may have the key role in improving indoor air quality in schools. It seems that the only solution to this problem, while keeping to energy conservation and air quality requirements, is general application of more sophisticated ventilation systems (easy to use) with heat recovery and effective filtration.

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