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NATURAL VENTILATION AND INDOOR AIR QUALITY IN EDUCATION BUILDINGS

BY

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Abstract. Research on indoor air quality and natural ventilation ascertained the causality between poor air quality inside the classroom and poor school performance and even the high incidence of respiratory diseases at children. Therefore possibilities to improve indoor air quality in these areas are more and more searched for. In the present case study it is emphasized a rate of unorganized ventilation in the classroom, far below the present standard. In consequence, there are necessary measures to increase the frequency of air exchange through windows on the first stage, so that in next stage, there are provided ventilation channels and holes with automatically opening, which is scheduled according to the required ventilation rate in those areas.

Key words: indoor air quality; ventilation rate; schools.

1. Introductions

The reduction of energy consumption for building operation, caused by the perspective of energy resource depletion, especially that of climate change, is an important concern of involved politicians in most countries. At the same time it is not ignored that the role of a building is to provide to the occupants an

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environment not only comfortable but also healthy, according to specific activity.

Indoor environmental quality is not a simple concept, easily to be defined, because it is determined by a complex of factors that interact and are constantly changing. A healthy environment is provided by air quality, respectively by the oxygen content, but it is also negatively influenced by pollutants such as carbon dioxide, water vapour, volatile organic compounds, dust, mold spores, etc.

All the buildings for education enjoy special attention from this point of view, because they have certain specific features namely

a) The number of people occupying a space in a classroom is relatively large, larger than in an office, for example.

b) In schools, multiple activities take place and produce a variety of pollutants.

c) The sensitivity of pupils and students is higher than that of adults.

Ventilation has an important role in ensuring the optimum air composition through: the dilution of contaminants, increasing the quantity of outside air or at least filtered air and also by improving the air flow distribution.

2. Concerns for Improving the Quality of Indoor Environment in School Buildings

Problems of indoor air pollution can be subtle and do not produce a recognizable impact on health.

A. According to the U.S. Government Accountability Office Report, 50% of teaching spaces have indoor air quality problems.

B. In Canadian schools studied by Bartlett, Kennedy and Brauer (1998) 71% of the classes do not meet the ASHRAE ventilation standards, and 45% of classes have concentrations of CO_2 above the 1,000 ppm ASHRAE.

C. In the UK study was conducted in eight schools for a week. The findings were made in “Ventilation and Indoor Air Quality in Schools – Guidance Report 202825/2006”. These include the following conclusions:

a) Ventilation rate is less than the minimum required by the School Premises Regulation 1999, namely 3 m/s.

b) 88% of classes had CO_2 concentrations of 2,100 ppm.

c) Indoor temperature was 17…25°C.

d) Relative humidity was 30…75%.

e) VOC limit of 300 mg/m^3 was exceeded in four schools.

The final conclusion was that any school should establish a preventive program to minimize exposure to indoor pollutants.

D. In USA, IAQ Management Plan for Schools helps officials to develop and implement health policies to protect students and teachers and improve the learning environment of the occupants. This program contains informations on measurements of air velocity, temperature, relative humidity, CO_2 content, difference in pressure between different zones, so being able to obtain a profile of indoor air quality and the necessary budget for its improvement.

E. The School Advanced Ventilation Engineering Software (USETA, 2009) (Saves) contains two programs

a) Energy Recovery Ventilation Financial Assessment Software Tool (EFAST), which determines the ventilation rate, based on ASHRAE 62-2001, estimates the installation cost of ventilation and energy recovery systems and calculates the energy savings resulting from recovery measures.

b) Indoor Humidity Assessment Tool (THAT) establishes the criteria for moisture control with impact on indoor air quality.

F. In the USA, the annual events IAQ Tolls for Schools (IAQ TFS) are designed to help officials to assess, solve and prevent indoor environmental quality problems, thereby reducing the risk of disease.

3. Analysis of the Actual Education Building Resources in Terms of Indoor Environmental Quality. Case Study

The existing education building resources in Romania are heterogeneous, including many buildings raised before the First World War. They are part of the built heritage, having a specific architecture.

Indoor air quality studies have been conducted on several educational institutions, from which it was selected the case of “Octav Băncilă” School of Iaşi (old body building dating from the nineteenth century). This building has exterior walls of solid brick masonry, with a thickness of 50 cm and the twofold windows are of wooden carpentry. No work has been done to increase thermal protection.

The diagnosis–analysis of indoor air quality, defined by the concentration of main pollutants (CO_2) and natural ventilation rate, involved the steps presented in Fig. 1.

3.1. Standardized Values of Indoor Air Parameters Characteristic for Education Spaces

The standardized value of natural ventilation rate expressed as the minimum number of air exchanges per hour is given by

$$n_a = \frac{N_{\text{pers}} g}{\left(C_L - C_{\text{ex}}\right) V_a}, \tag{1}$$

where: n_a is the required minimum ventilation rate, [h^{-1}]; g – the flow of pollutants (CO_2) released by one person (18 L/h person) (Ştefănescu & Velicu, 2009); C_L – maximum permissible concentration of pollutants in the space (1,600 mg CO_2/m^3 air or 1.06 L/m^3 according to NP008-97); C_{ex} – the pollutants concentration characteristic for the natural outdoor environment (750 mg/m^3 or 0.50 L/m^3 CO_2 (Niculescu *et al.*, 1982), but it was used the value derived from measurements, *i.e.* 500 ppm or 500 mg/m^3); V_a – air volume of the room, [m^3]; ρ_a – air density, [kg/m^3], for T = 20°C, ρ_a = 1,205 kg/m^3.

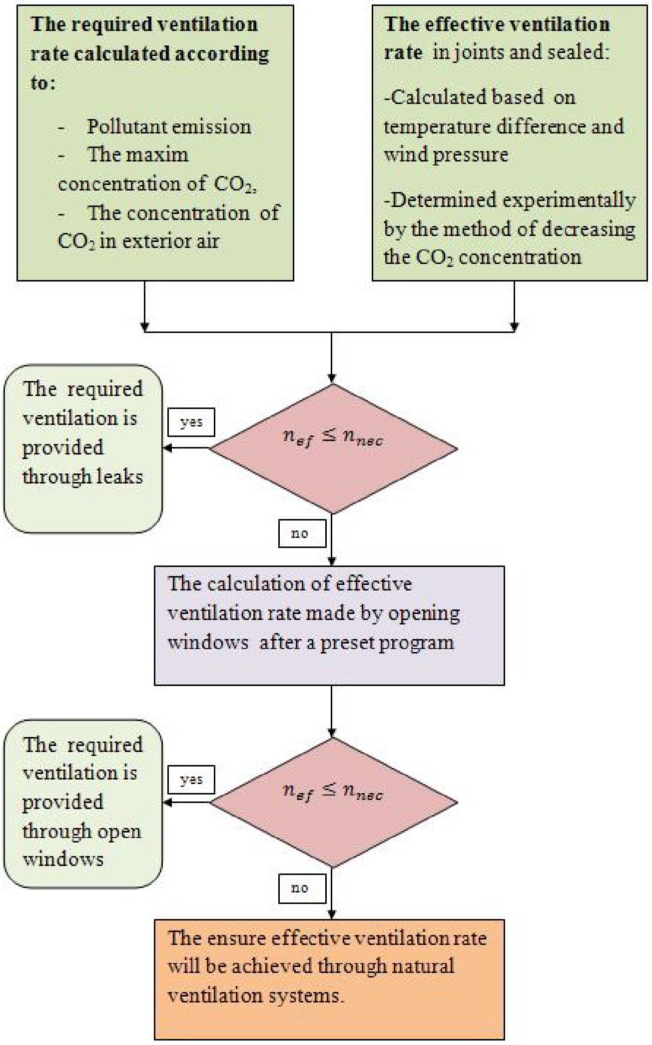

Fig. 1 – Flowchart of how to ensure the required ventilation rate in an room space.

For a classroom from the analysed building it results a required ventilation rate of 5,096 h^{-1}, considering a number of 28 occupants (27 students and one teacher) and a volume of 176.59 m^3.

3.2. Effective Values of the Parameters Characterizing the Indoor Environment Quality Get by Recordings

In order to assess the actual rate of natural ventilation, which is produced by joints and leaks, it was used the tracer gas method, in the decreasing gas concentration version. The method principle is based on knowing how a specific gas concentration decreases, the gas being introduced or existing in the analysed space atmosphere, without occupants, while the source does not work. As tracer gas it was used carbon dioxide resulted from the occupants' respiration. The advantages of the method are that CO_2 does not require special effort to be purchased or precautions in use and the concentration recording devices are simple and easily to use.

The effective ventilation rate, n_{ef}, is calculated with relation

$$n_{\text{ef}} = \frac{\ln C_i - \ln C_f}{t_i - t_{\text{ef}}}, \ [\text{h}^{-1}], \qquad (2)$$

where: C_i is the initial concentration of CO_2 corresponding to the time when the space is no longer occupied and, as a result, the emission of tracer gas was stopped; C_f – final CO_2 concentration corresponding to the time when it becomes equal to the concentration in outside air, which remains quasi-stationary; t_i – initial and final time, [h].

The recordings were made during three days between 25.02.2010 and 27.02.2010, by means of a Data loger, device that allows the recording temperature, humidity values and CO_2 concentration.

The recorded values of microclimatic parameters and of CO_2 concentration averaged over a period of two hours, are presented in Table 1.

During the recordings, the outdoor temperature presented values in the range of 2.6 ... 8°C.

Analysing the CO_2 concentration evolution during the time, it can be selected three periods, during which it can be noticed a decrease of it, the concentration tending to become equal to that from the outside, the room being unoccupied (Fig. 2). The ventilation rate values calculated with eq. (2) are shown in Table 2.

The ventilation rate value corresponding to the interval 2, much higher than the other two, is explained by the sudden decrease of the CO_2 concentration, caused by the presence of some open windows during the break.

Table 1
Averaged Values for Inside Temperature, Humidity and CO_2 Concentration

Date	Hourly	Inner temperature °C	Humidity %	CO_2 concentration ppm	Comments
25/02/2010	17–19	24.49	43.53	1,219.20	Free room
idem	19–21	24.02	40.07	853.46	Free room
idem	21–23	24.03	39.43	695.38	Free room
idem	23–01	24.01	38.90	621.97	Free room
26/02/2010	01–03	24.00	37.65	574.43	Free room
idem	03–05	24.98	36.62	546.90	Free room
idem	05–07	24.95	35.47	515.36	Free room
idem	07–09	24.72	36.89	964.51	Room occupied
idem	09–11	25.60	45.27	2,021.00	Room occupied
idem	11–13	25.53	41.46	1,702.57	Room occupied/free
idem	13–15	25.29	36.21	876.87	Room free/occupied
idem	15–17	25.59	37.65	1,120.27	Room occupied
idem	17–19	25.43	33.38	666.77	Free room
idem	19–21	25.48	32.52	532.57	Free room
idem	21–23	25.44	33.29	526.90	Free room
26/02/2010	23–01	25.32	33.12	510.57	Free room

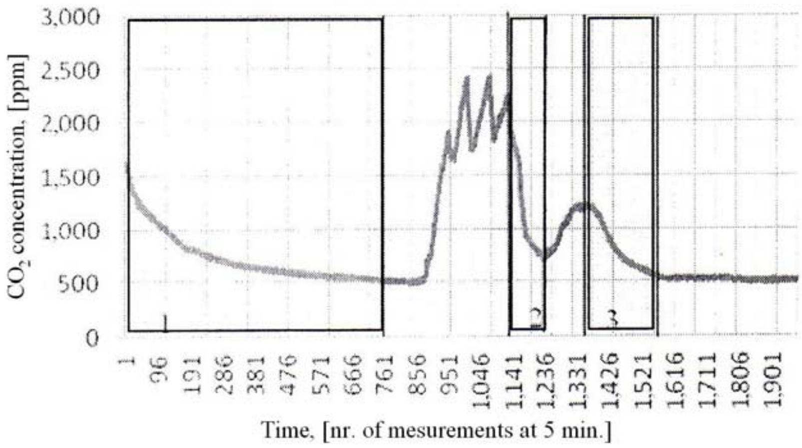

Fig. 2 - Variation of CO_2 concentration in the analysed classroom.

Table 2

Values of Effective Ventilation Rate through the Joints Corresponding to the Three Periods Shown in Fig. 1; The Values are Experimentally Determined

Interval	t_i, [h]	t_f, [h]	C_i, [ppm]	C_f, [ppm]	n, [h^{-1}]
1	17.09	5.55	1,630	500	0.10
2	11.46	13.40	2,239	705	0.75
3	15.34	23.54	1,230	500	0.12

It should be pointed out that the recorded value of the outdoor air CO_2 concentration is about 500 ppm, less than the standardized value taken into consideration to determine the flow of fresh air required (750 ppm), which reflects a lower level of pollution in the area.

3.3. Determination by Calculation of the Flow Rate of Air Infiltrated and Ventilation Rate

The infiltrated air flow through leaky joints of the windows, D_y, caused by the thermal draught, can be evaluated (Bliuc, 1993) with the following relation:

$$D_y = \sum a_j L_j \Delta p(T), \quad [\mathrm{m^3/h}], \tag{3}$$

where: a_j is the air permeability coefficient of the carpentry, depending on type of carpentry, [m^3/m.h.Pa$^{2/3}$]; here value is 0.654 for the double wooden joinery; L_j – total length of joints, [m]; $\Delta p(T)$ – pressure difference which causes the flow, [Pa].

In this case the pressure difference caused by indoor–outdoor temperature difference is calculated with relation

$$\Delta p(T) \cong 0.044h(T_i + T_e), \tag{4}$$

where: h is the height of window opening, [m]; T_i , T_e – indoor–outside air temperature, [K].

The ventilation rate, n, is

$$n = \frac{D_v}{V}, \tag{5}$$

where V is the volume of ventilated space, [m^3].

For the analysed classroom with a glazed surface consisting of two windows with double wooden joinery in good state, of 1.37 × 2.55 m, and a total length of 20.41 m of joints of windows and the temperature difference corresponding to the mean values recorded, the ventilation rate through leaky joints of the carpentry is determined by calculus, for the time intervals previously considered. Table 3 shows these values calculated using relations (3),…, (5).

Table 3
Effective Ventilation Rate Values through the Joint, Corresponding to the Three Intervals Shown on the Graph in Fig. 1, Determined by Calculation

Intervals	t_i, [h]	t_f, [h]	$T_{\text{int med}}$, [°C]	$T_{\text{ext med}}$, [°C]	N, [h^{-1}]
1	17.09	5.55	24	5	0.16
2	11.46	13.40	24	7.5	0.14
3	15.34	23.54	24	3.5	0.17

Comparing the values get by calculus with those obtained experimentally, it can be noticed a good concordance for the intervals 1 and 3 due to the fact that for the calculus there were taken into account the values of indoor/outdoor temperature recorded during measurements. The resulted difference for interval 2 is explained by the fact that the presence of open windows was not taken into account.

3.4. Discussions; Comparison with Standardized Values

Comparing the recordings results with the standardized values, it results that

a) the indoor air temperature has a tendency to exceed the standardized value for education spaces, starting with the third course hour;

b) the humidity increases within allowable limits.

Analysing the CO_2 concentration variation it can be emphasized the following issues:

a) On the first day, after 17^{30}, when the classroom was not used, it could be seen how the pollutant concentration decreases due to the untight joints from the door or windows.

b) During school activity it was observed that during the class hours, the peak concentration of CO_2 (2,423 ppm) is reached, and it exceeds the maximum level allowed in a classroom (1,260 ppm) (Niculescu *et al.*, 1982), even when windows and the door are opened during a break time of 10 min.

c) The effective ventilation rate caused by joints and untightness during school hours does not meet the ventilation rate required in the given circumstances.

4. Conclusions

The education spaces, by their specific operation way and characteristics of occupants, require a permanent insurance of a certain level of quality indoor environment, determined primarily by maintaining the optimum air composition, its effects on health and intellectual performance being emphasized by systematic and long-term studies.

According to the diagnosis-analysis carried out in the presented case study, it results the followings conclusions:

1. The indoor microclimate parameters (temperature and humidity) are within standardized values during the occupancy time of the room, the temperature having the tendency to exceed the maximum value prescribed for classroom spaces.

2. The CO_2 concentration shows a variation depending on the schedule of classes: in the presence of CO_2-generating source (students); it can be noticed an accelerated increase of the pollutant concentration, much more than the allowable limit in a classroom.

3. The spontaneous ventilation rate trough the leaks, determined experimentally and calculated, is less than the standardized value.

4. The CO_2 concentration, recorded during the occupancy time, continuously exceeds the allowable value; it results the necessity of an organized ventilation system which may supplement or replace the ventilation achieved by the periodically windows opening.

The emphasized aspects lead to a very important conclusion for occupants' health: the issue of indoor environment quality inside education spaces through unorganized natural ventilation cannot be solved. This issue should remain a concern, both in the rehabilitation process and for future designing and achievement of new buildings for education at all levels.

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CALITATEA AERULUI INTERIOR ŞI VENTILAREA NATURALĂ ÎN CLĂDIRILE DE ÎNVĂŢĂMÂNT

(Rezumat)

Cercetările în domeniul calităţii aerului interior şi a ventilării naturale au stabilit, cu certitudine, legătura cauzală dintre calitatea scăzută a aerului interior din clasele de elevi şi studenţi şi performanţele şcolare slabe şi chiar incidenţa crescută a bolilor respiratorii la copii. În consecinţă se caută posibilităţi de îmbunătăţire a calităţii aerului interior în aceste spaţii. În studiul de caz prezentat se evidenţiază o rată a ventilării neorganizate în sălile de clasă mult inferioară standardului în vigoare. Prin urmare se impun măsuri de mărire a frecvenţei schimburilor de aer prin ferestre în prima etapă, pentru ca în etapa ulterioară să se prevadă canale şi orificii de ventilare cu deschidere automată programată în funcţie de rata necesară de ventilare în acele spaţii.