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An Attempt to Improve Air Quality in Primary Schools

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Abstract. Most primary school buildings in Poland rely on natural ventilation. This fact is attributed to the age of these buildings constructed more than dozen or even several tens of years ago. Few of them were fitted with a mechanical ventilation system allowing for the adjustment of microclimate parameters. The national requirements for gravity ventilation provide general guidelines, specifying strict description only for the airtightness of windows and doors and the minimum airflow to be supplied to the rooms. The minimum airflow supplied is independent of the number of occupants and purpose of the room.

Low indoor air quality (IAQ) can impact occupants' health and lead to poor productivity or low academic performance. Therefore the provision of good IAQ in classrooms and laboratories is very important. This paper presents the results of the investigation devoted to the quality of indoor air in classrooms of selected Polish primary school. Six primary school in a town with a population of 200 000 inhabitants were involved in the investigations. The participating school buildings were built between 1976 and 1994 and had gravity ventilation systems. The variability of basic IAQ parameters, i.e., temperature, relative humidity and carbon dioxide level, was analysed and the assessment of the classrooms in terms of microbiological purity was performed. The outcomes confirmed the low quality of the indoor air in these buildings. The maximum value of CO_2 concentration amounted to more than 4000 ppm. Certain modifications aimed at improving IAQ were proposed during the investigations. Two solutions were implemented. The results of this study indicate that the proposed solution offers the potential to improve IAQ within classrooms.

Keywords: building physics, ventilation, air exchange, indoor air quality (IAQ).

Conference topic: Environmental protection.

Introduction

The most of the buildings of the primary schools in Poland were built several years or several decades ago. Due to this fact, they are equipped with the system of natural ventilation. This solution is not optimal. The natural ventilation system depends on the weather conditions. This causes that correct air exchange over all the time of using the classrooms is difficult to reach. In 1999–2004, the team of Professor Wargockiego conducted a study in office buildings, where they analyzed dependence the work efficiency and the air exchange (Wargocki *et al.* 2002, 2004, 2005). The research consisted in: the forcing the pollution in the premises, and in the supplying the external air in the interior in amount of 3, 10, 30 dm^3/(s•person). With the increase in the amount of supply air the work efficiency increase was observed (Fig. 1). These observations are confirmed by the other studies. In this case the additional source of pollution was forced in the room without changing the amount of the ventilation air. In this case, a significant decrease in productivity reaching up to 9% was noted (Bako-Biro *et al.* 2004).

On this basis, it is likely that the same will happen in the case of learning the students and the results achieved learning. However, the Polish standards on natural ventilation in public buildings including schools, are not precise. The standards do not include the purpose of the building, age of the users and way of supplying the air. The requirements of legal acts (Dz. U. No. 75 2002 PN-83 / B-03430 1983 PN-83 / B-03430: Az03 2000) define the general guidelines only. The permissible tightness of windows and the required minimum inflowing air stream is specified. In public utility buildings the required minimum inflowing air stream equals 20 m^3/h for each person. This value is constant regardless of the intended use of the premises, or the amount of occupants. The problems with air quality in the building equipped with the gravitational ventilation system are confirmed by studies presented in the literature (Zender-Świercz, Telejko 2016).

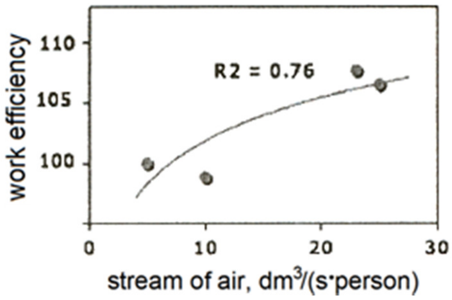

Fig. 1. The dependence of the work efficiency and the flow of ventilated air (source: Popiołek 2005)

Subject of the study

The research was carried out in the buildings which were located primary schools. The buildings selected for research were constructed in the years 1976–1994 and they were equipped with a system of natural ventilation. The external air was supplied by windows vents and exhausted through 1 or 2 ventilation ducts in each room. Measurements were carried out in selected classrooms. During the measurements, there were 14 to 18 people in each classroom. All the buildings selected for analysis have external walls insulated with Styrofoam and they were equipped with PVC windows, with gaskets.

The study consisted in registration of typical microclimate parameters, ie. temperature, relative humidity and carbon dioxide concentration. The last parameter was the indicator of the indoor air quality (WHO Regional Office… 2000; ASHRAE 62.1 2016). Research was conducted in three series. Each of them was lasting 7 days and the measurement interval equaled 150 seconds. In addition, the measurement and the recording the exhaust air flow rate, at the inlet of the ventilation duct, was carried out.

The standard of indoor air quality presents the permissible level of carbon dioxide concentration inside premises equal to 1000ppm (WHO 2000, and it is considered as minimum hygiene. Polish law imposes a maximum value of carbon dioxide concentration in workplace and it equals to 5000 ppm (Dz.U. 2002 No. 217 item. 1833). The categories of indoor air depending on CO2 concentration are specified in the standard (EN 13779:2007) which is in force in many European countries, including Poland. This standard also imposes, for each category of indoor air quality, the required minimum air flow per one person (Table 1).

Table 1. Classification of indoor air quality for rooms with low pollutant emission levels and a smoking ban (source: EN 13779:2007)

Category	Description of indoor air quality	CO_2 level above level of outdoor air [ppm]	Rate of outdoor air [m^3/h]
IDA 1	High	<400	<54
IDA 2	Medium	400 ÷ 600	36 ÷ 54
IDA 3	Moderate	600 ÷ 1000	22 ÷ 36
IDA 4	Low	>1000	>22

It should be noted that according to the law (PN-83/B-03430 1983, PN-83/B-03430: Az03 2000), the minimum required air flow equals 20 m^3/h for each person, and it corresponds to a IDA4 category according to (EN 13779: 2007), so in this case the quality of indoor air is low.

Results

In the course of research outside air temperature ranged from –10 °C to +12 °C, the relative humidity was in terms of 53% ÷ 99%, the carbon dioxide concentrations ranged from 435ppm to 570ppm and the wind speed reached maximum 6.50 m/s. Research was conducted in three stages. The first series was carried out for the premises without improvements. The classrooms with amount of inflow air equal to 150m^3/h were selected to study (there are 3 window vents with efficiency equal to 50m^3/h). In the second stage the amount of inflow air was increased to the value 20 m^3/h for each person. It was according to standard (PN-83/B-03430 1983, PN-83/B-03430:Az03 2000). The third step was relying on increase the size of the stream of ventilating air to value 30m^3/h for each person.

The first series of study showed very low internal air quality in all analyzed classrooms. At the start of the lessons the CO_2 concentration in the classrooms were similar to the values in the outside air. During the use of the classrooms, the value of analyzed parameter grew and reached level even above 2700 ppm. The relative humidity values were also increasing continuously starting from the beginning of the lesson, but it did not exceed 40%. The indoor temperature meanwhile remained almost constant throughout all the time of lesson. It should be noted that these values were very high, it was exceeding even 29 °C. This is a typical phenomenon for schools and kindergartens in Poland (Telejko, Zender-Świercz 2016). The recorded minimum and maximum values of air parameters for selected classrooms in each schools are shown in Table 2. The variability of indoor air parameters during the selected lesson are presented at Fig. 2.

Because of high CO_2 concentration in analyzed classrooms it was decided to increase the stream of supply air. The maximum number of users has amounted to 18. Therefore the amount of supply air was increased to 360m^3/h (18•20m^3/h), what was accordance with national standard (PN-83/B-03430 1983, PN-83/B-03430:Az03 2000). The course of the variation of the carbon dioxide concentration and relative humidity had the same character as before the modification. The values of these parameters were growing from the start of lessons, were slightly going down during the break, and were returning to baseline at late at night. It should be noted, that the maximum values of the CO_2

concentration did not longer exceed the level of 1700 pmm. The registered values of relative humidity were ranged 30–40%, what corresponds to the values reached in the first stage. The internal temperature noticeably declined. This decrease amounted to approx. 3 °C at the same parameters of heating system. The average values of the indoor air temperature fluctuated in the range of 24.1÷26.4 °C. The recorded minimum and maximum values of air parameters in analyzed classrooms are shown in Table 3. The variability of microclimate parameters during the lesson in selected classroom are presented at Fig. 3.

Table 2. The minimum and maximum values of indoor air parameters measured for selected classrooms in each schools – inflow air equals to 150 m3/h

Premises	Maximum values			Minimum values		
	CO_2 [ppm]	Temp. [°C]	RH [%]	CO_2 [ppm]	Temp. [°C]	RH [%]
Classroom 1	2753	29.3	37.3	443	28.3	33.4
Classroom 2	2510	27.9	39.5	492	28.5	30.8
Classroom 3	2698	29.3	39.2	470	27.7	32.1

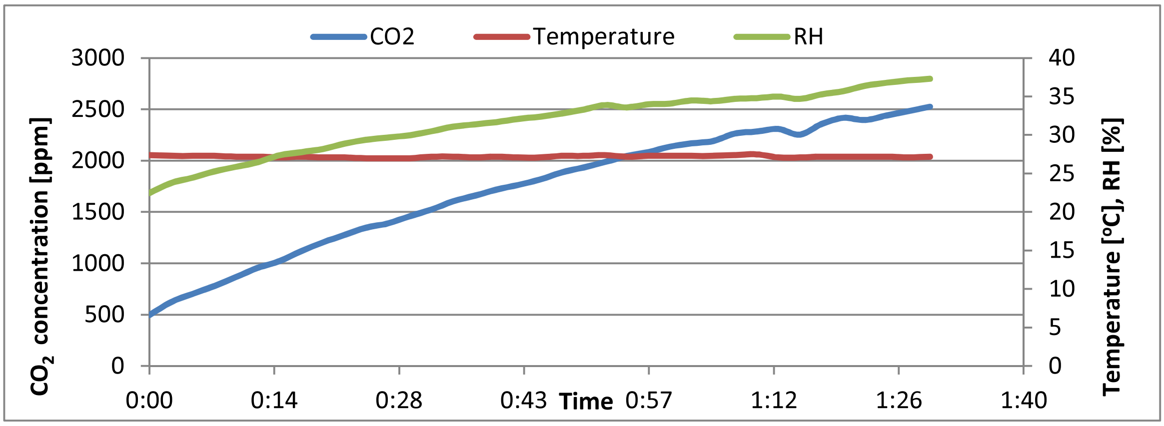

Fig. 2. The variation of the indoor air parameters for the selected classroom before increasing the flow of ventilation air (interval 150 seconds)

Table 3. The minimum and maximum values of indoor air parameters measured for selected classrooms in each schools – inflow air equals to 360 m^3/h

Premises	Maximum values			Minimum values		
	CO_2 [ppm]	Temp. [°C]	RH [%]	CO_2 [ppm]	Temp. [°C]	RH [%]
Classroom 1	1660	26.3	34.1	498	22.5	25.3
Classroom 2	1619	25.9	37.2	625	23.8	25.9
Classroom 3	1564	26.3	36.8	507	24.5	26.5

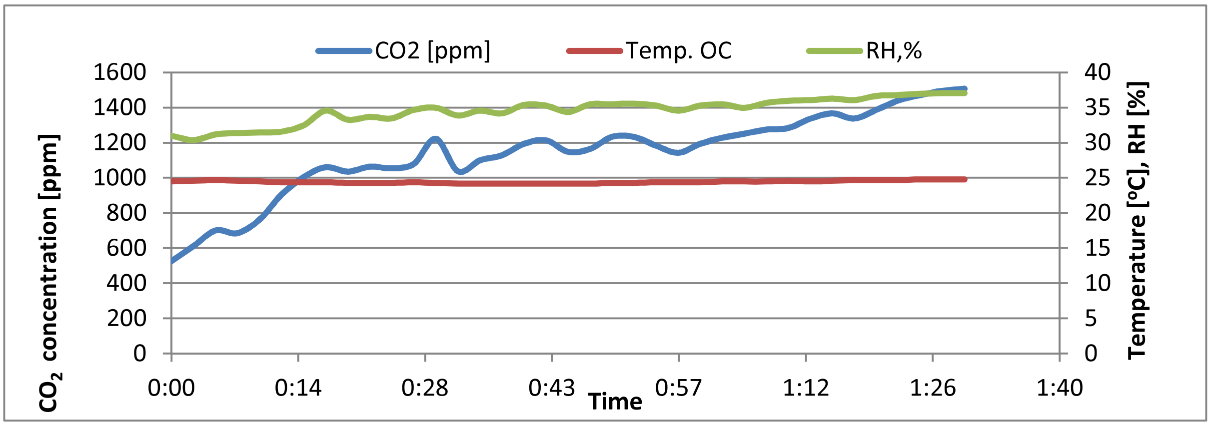

Fig. 3. The variation of the indoor air parameters for the selected classroom after increasing the flow of ventilation air to value equal to 360m3/h (interval 150 seconds)

The observed values of CO_2 concentration had still exceeded 1000ppm, which is the recommended in the literature. Because of it the flow of the supply air was increased up to 30m3/h for each person. This meant that the total flow of ventilation air was equal to 540m^3/h for each classroom. This value corresponded to the air exchange about 3h^{-1}. After this modification the decrease of the CO2 concentration, below the baseline and below the value after the first modification, was observed. The maximum value of the carbon dioxide concentration did not exceed 980 ppm (Fig. 4). Unfortunately, at the same time, in relation to the baseline, the significant decrease of the internal temperature was observed. These values were average 5÷6°C lower compared to baseline and 2÷3°C lower compared to values for the first modification. The recorded values of relative humidity increased slightly and were in the range 29 to 45% (Table 4).

Table 4. The minimum and maximum values of indoor air parameters measured for selected classrooms in each schools – inflow air equals to 540 m3/h

Premises	Maximum values			Minimum values		
	CO_2 [ppm]	Temp. [°C]	RH [%]	CO_2 [ppm]	Temp. [°C]	RH [%]
Classroom 1	962	23.6	44.3	505	22.1	32.4
Classroom 2	948	22.8	39.1	473	20.9	29.4
Classroom 3	915	23.0	42.7	507	21.4	34.7

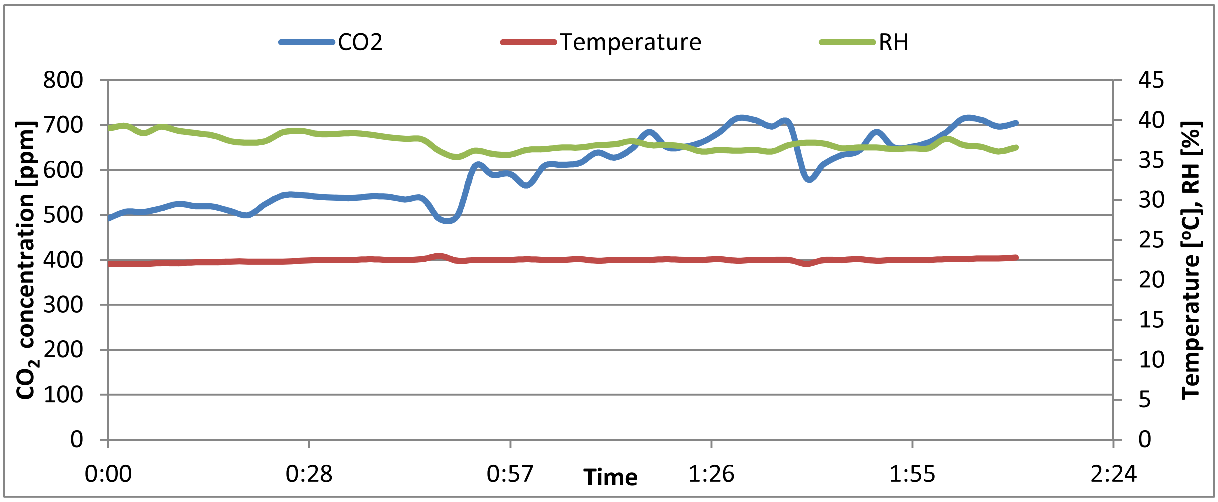

Fig. 4. The variation of the indoor air parameters for the selected classroom after increasing the flow of ventilation air to value equal to 540m^3/h (interval 150 seconds)

Analyzing the described modifications, the air velocity inside premises should be take into account. At the first stage (before modification) the air velocity in the analyzed classrooms was in the range of 0.04 to 0.25m/s and it was not felt by the users. The values in this range are standard for most buildings in Poland. After the first modification i.e. mounting window vents and increasing the air flow to value 360m^3/h, the air velocity increased and reached values in range 0.03 to 0.39m/s. Only a few users have reported feeling a draft. This was even at the greatest values of this range. This was due to very high air temperatures in analyzed classrooms. The second modification consisting in increasing the flow of ventilation air to value 540m^3/h resulted in a further increase in air velocity in the classroom up to 5 m/s. In this case the combination the great air velocity and the low temperature of inflow air from the outside resulted in users feeling a draft. On Fig. 5 the air velocity in one of the classrooms is presented.

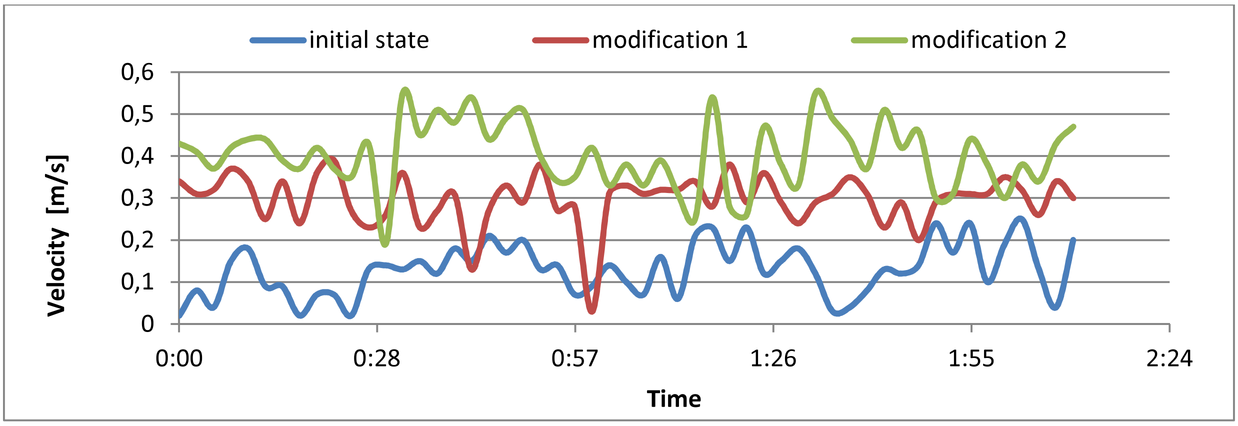

Fig. 5. The air velocity in one of the classrooms at three stages of analysis (baseline, after first modification, after the second modification)

Conclusions

Received during the analysis values of the internal microclimate parameters indicate a low level of air quality in the buildings built several years or several decades ago, where the Polish schools are located. The standards in force in time when the buildings were designed do not meet the standards for IAQ compulsory now. The supplied, at the first stage, air in an amount 150m^3/h proved to be insufficient. As an indicator of air quality the CO2 concentration was chosen. The measured values of this parameter let us classify all analysed classrooms to the IDA4 category because of indoor air quality according to EN 13779: 2007.

The proposed modifications involving enlargement the flow of ventilation air resulted a significant improvement in IAQ. The air flow in amount only 360 m^3/h (20 m^3/h for each person) decreased the CO_2 concentration and made it possible to classify analysed classrooms to the IDA3 category. It should also be noted that this modification did not have a major effect on the relative humidity, and the indoor temperature was in thermal comfort terms. But they were also lower by approximately 3 than initial values.

The again increase, of ventilation airflow, to 540 m^3/h (30m^3/h for each person) resulted in further reduction of the carbon dioxide concentration. The maximum recorded values did not exceed 950ppm. It means that, at an average CO_2 concentration in the outside air equal to 502ppm (which was registered during the study), the premises can be classify to IDA2 category according to EN 13779: 2007. The relative humidity had also slightly improved. It was within the range of 33 to 45%. Unfortunately, such a large supply air flow from the outside caused the reduction of the internal temperature, of approximately 6 °C. Although, the values of the temperature in the premises were within the range of 22÷24 °C, the decrease of this parameter was too large and it will result in negative affect the energy balance of the building.

Reported by the users feeling a draft after increasing ventilation airflow up to 540m^3/h resulted from a low temperature of external air flowing into the classrooms. Therefore the general use of the second analysed modification requires additional study. A solution could be to provide part of the air in an indirect way, eg. from the hall or from the staircases. It could be use the passive solar system to heat supply air, whose modeling is presented in the literature (Piotrowski *et al.* 2013). Another possible solution to this problem could be the use of window vents equipped with heaters instead of the standard window vents. The electric heaters would be used to initially heating outside air at low temperature.

The obtained in schools, results and their analysis clearly indicate the need for studies of indoor air quality in buildings equipped with a system of natural ventilation. Research has shown that air quality in such buildings is low. It means the need for modifications to the ventilation system. Conducted analysis revealed that small improvements have significant influence on the indoor air quality.

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