Indoor Air Quality in Kindergartens in Poland

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Abstract. The universal ventilation system in Polish kindergartens is the natural ventilation system. This is due to the fact that these buildings are several or even several dozen years old. National regulation for natural ventilation define only general guidelines. There are in the legislation acts only the permissible tightness of the building joinery and the minimum value of the air infiltrate to the rooms. The amount of air is constant regardless of the room's purpose or the number of people staying in them. Over the last decade, in such buildings incomplete thermomodernization treatments were carried out, as a result of which the inflow of air to the rooms was most often limited, and thus the indoor air quality decreased. While, the low indoor air quality may lead not only to the poor well-being of users, but also to low efficiency of work and insufficient learning of new messages. This problem is extremely important in the case of a group of people who are not be able to determine the requirements in relation to IAQ. As has been shown in the Scandinavian countries, in the rooms where children are staying there the proper ventilation system several times reduces the chance of allergic symptoms. At the same time, research carried out in Denmark showed that the low indoor air quality in school premises negatively affects the learning efficiency of children. That is why it is extremely important to ensure proper microclimate conditions in the rooms where the youngest children are staying. The article presents the results of research on the indoor air quality (IAQ) in 4 kindergartens in Poland, located in the city with 200,000 inhabitants. The buildings in which research was carried out were built in the years 1970-1993 and were equipped with a gravity ventilation system. The analysis covered the variability of the basic parameters describing the indoor air quality, i.e. temperature, relative humidity and concentration of carbon dioxide.

1. Introduction
The vast majority of buildings where there are government's kindergartens in Poland are buildings of several years or even several decades. Those buildings are equipped with gravitational ventilation systems. Despite of basic advantage of this system i.e. the low operating costs, it has several significant disadvantages. First of all, it is often poorly designed, mounted or operated. The basic requirements for gravity ventilation included in the national standard [1,2] are very poor. It recommends the inflow at least 20m³/h of outdoor air for each person in premises intended for permanent and temporary staying. In public buildings, where smoking is allowed, the air inflow should be increased to 30m³/h for each person. For rooms in nurseries and kindergartens, the inflow of outdoor air can be lowered to 15 m³/h for each child. In the majority of cases, designers of such
objects do not perform calculations for the gravity ventilation system, and they accept the minimum requirements specified in the standard [1,2] as sufficient values to maintain the proper microclimate. However it should be noted that these requirements apply only to newly designed buildings, what is indicated in the standard [1]. Nowadays, due to the high energy consumption for heating, such buildings are undergoing the thermomodernization. The designers and building's managers, because of the minimizing the cost of maintaining buildings, are inclined to minimize the inflow of outdoor air to the premises. In the winter period, the outdoor air has a low temperature what directly affects the energy consumption necessary to maintain the assumed internal temperature. In addition, it should be noted that due to the low budget of such facilities, the modernization works are not carried out comprehensively and they are carried out in stages even for several years. At first there are the building partitions insulating and the window joinery are replacing by the tighter one. There are not taking into account the modernization of the central heating system or ventilation system. At the same time, if the window joinery is replacing, the decision to install window vents is often left to the investor. Even if, the investor decides to mount the window vents, his decision is not preceded by the analysis that would answer the question of how much and which devices should be installed. Such treatments cause sealing of the building envelope, and thus limit the possibility of inflow of ventilation air through the partitions' leaks [3].

During the operation of buildings, users also make the operational errors. When they feel the movement of air of a low temperature as a draft, they do not change the settings of the heating system, but they set the window vents in the "closed" position. This limits the amount of air inflowing to the premises, which in many cases is insufficient for proper ventilation of the rooms. The result of it is noticeable adverse changes in the parameters of the internal microclimate.

Research conducted by a team led by Bornehag among 11,000 Scandinavian children showed that there is a simple relationship between air exchange and the risk of allergic symptoms [4, 5]. They also showed that increasing the air exchange from 0.17 per hour to 0.62 per hour reduced the relative risk of allergic symptoms by almost half. Moreover, research carried out by the team of professor Wargocki showed the effect of increased ventilation efficiency on the performance of learning of 10-year-old students. During the several weeks’ research there were comparing the results of typical student's work: from reading to counting. During the tests, new filters were installed in the ventilation system and the amount of the supply air had been increased. A two-fold increase in the ventilation flow (from 5 to 10 l/s) resulted in 15% increase in student work efficiency [6]. Similar results were obtained in research on the efficiency of office work in Sweden and Denmark. A three-fold increase in the ventilation flow from 10 to 30 l/s resulted in an increase in the work efficiency by 5 ÷ 10% [7]. Therefore, it seems extremely important to know the parameters of the microclimate in kindergartens and to determine if they are correct.

2. Subject of study

Four kindergartens located in Poland in a city with 200 thousand people were selected for the study. These buildings were built in 1980-1995. In recent years they have undergone thermo-modernization, what was the basic criterion for selecting a test object. The modernization works consisted of insulating the external walls of buildings with 100 mm to 150 mm Styrofoam, and insulating the flat roofs with 100mm to 200mm mineral wool. A new, tight PVC window joinery with infiltration coefficient $a = 0.3 \div 0.4 \text{m}^3/(	ext{mhdaPa}^{0.5})$ was also installed. In all buildings, the heating system was supplied from the city heating plant. The kindergartens selected for research were equipped with a natural ventilation system.

There were two premises in each kindergarten selected for analysis. All selected premises were oriented on the same world’s side. The outdoor air was flowing to each premises through window vents. The air was flowing out by two exhaust ducts with a cross-section of 140 x140 mm. The ratio of window’s surface to the floor’s surface in all the rooms was in range 0.31 – 0.33. The characteristics of the analyzed premises are shown in Table 1.
Table 1. The characteristics of the analyzed premises

| Classroom/Kindergarten | Area [m²] | Ceiling [m] | Volume [m³] | Number of occupants (during class period) | Occupancy density [pupil/m²] | Number of air intakes/ Maximum air supply (m³/h) |
|------------------------|-----------|------------|-------------|------------------------------------------|-----------------------------|-----------------------------------------------|
| Classroom 1/1           | 52.56     | 3.56       | 187.11      | 14 (median)                              | 0.27                        | 2/100                                         |
| Classroom 2/1           | 55.13     | 3.50       | 192.96      | 15 (median)                              | 0.27                        | 3/150                                         |
| Classroom 1/2           | 54.64     | 3.50       | 191.24      | 18 (median)                              | 0.33                        | 2/100                                         |
| Classroom 2/2           | 54.70     | 3.50       | 191.45      | 17 (median)                              | 0.31                        | 2/100                                         |
| Classroom 1/3           | 54.51     | 3.51       | 191.33      | 16 (median)                              | 0.29                        | 3/150                                         |
| Classroom 2/3           | 54.60     | 3.50       | 191.30      | 16 (median)                              | 0.29                        | 3/150                                         |
| Classroom 1/4           | 54.94     | 3.51       | 192.84      | 18 (median)                              | 0.33                        | 3/150                                         |
| Classroom 2/4           | 54.65     | 3.50       | 191.28      | 19 (median)                              | 0.35                        | 3/150                                         |

3. Methodology

As an indicator of indoor air quality (IAQ), the concentration of carbon dioxide was selected [8, 9]. Its concentration in atmospheric air measured by authors near the analyzed buildings ranged from 423ppm to 491ppm. In closed premises, the increase of CO₂ concentration is observed because of its sources are primarily living organisms and the gas devices. Its secretion by humans depends on the level of human activity, diet, body weight, health status, etc. [10]. It is obvious that the concentration of CO₂ depends on the number of people in the premises [11] and the air exchange. Nantka [10] gives the amount of the secreted carbon dioxide in the exhaled breath by adults, however, it is difficult to find such values in the literature in relation to children.

According to the current IAQ standards the admissible value of CO₂ concentration in rooms depend on its concentration in the outdoor air [12, 13]. However, in the case of mechanical ventilation controlled by CO₂ sensors, the maximum concentration of this gas is usually defined at 1000ppm [15, 16]. Polish regulations do not specify the maximum concentration of carbon dioxide for accommodation and public buildings. However, in the standard in force in Poland [13], depending on CO₂ concentration of indoor air, the indoor air categories have been defined (Table 2).

Table 2. Classification of indoor air quality for rooms with low pollutant emission levels and a smoking ban [11]

| Category | Description of indoor air quality | CO₂ level relative to outdoor air [ppm] | Volume outside airflow [m³/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 emphasized that the minimum outdoor air inflow specified in Polish regulations [1,2], equaling 30 m³/h for a person, corresponds only to the IDA 3 category according to [13], what means moderate IAQ.

The research was conducted in the period from January to March 2015. During the tests, the values of outdoor air temperature ranged from -12°C to +15°C, relative humidity was in the range of 47% to 99%, the concentration of carbon dioxide ranged from 403ppm up to 630ppm, and wind speed was lower than 6.50 m/s. The average daily values of external air parameters during the research are shown in Table 3.
Table 3. Average daily outside air parameters in the period under investigation

| Parameter                 | January     | February    | March       |
|---------------------------|-------------|-------------|-------------|
| Temperature [°C]          | -3 ÷ 8      | -2 ÷ 7      | 0 ÷ 10      |
| Relative humidity [%]     | 58 ÷ 92     | 73 ÷ 86     | 70 ÷ 99     |
| Atmospheric pressure [hPa]| 1002 ÷ 1026 | 1005 ÷ 1023 | 998 ÷ 1019  |
| CO₂ concentration         | 423 ÷ 462   | 460 ÷ 491   | 429 ÷ 442   |

During the analysis, the basic parameters of the internal microclimate, i.e.: concentration of carbon dioxide, temperature and relative humidity of the indoor air were measuring and recording. The parameters were measured for 3 months in two-week periods with a measuring step of 5 minutes. Two series of measurements were carried out for each premises.

The indoor air quality monitor with the measurement range of CO₂ concentration 0 ÷ 5000ppm, relative humidity 0 ÷ 100%, air temperature 10 ÷ 45°C and barometric pressure 900 ÷ 1100hPa was used to record the measured parameters. In each test, the measuring device was located halfway up the room.

4. Results and discussion

Analysing the obtained results of measurement, it can be concluded that the course of variability of microclimate parameters had the same character in all considered premises. From the moment of using the classrooms in the morning, the values of measuring increased with time. This increase was usually continuous. The rate of increase was dependent on the parameter's type. The changes of value ranged from a few percent in the case of temperature up to several hundred percent in the case of carbon dioxide concentration. The decrease of the parameters' value started in the afternoon hours, when the children left the premises. After a few hours from the end of using the premises, the parameters reached the initial values (figure 1).

![Figure 1. Daily graph of variability of microclimate parameters in the select premises](image-url)

Figure 1. Daily graph of variability of microclimate parameters in the select premises

During the using the rooms, only opening the windows resulted in a change in the microclimate parameters. This is visible because of a rapid decline followed by a progressive increase in CO₂ concentration. These fluctuations were accompanied by small changes in air temperature and relative humidity. However, these were temporary drops, and just after closing the windows, the microclimate
parameters increased again. A similar phenomenon was noted at a time when children with carers stayed outside the premises, for example during a walk, going out to the playground, to the theatre, etc. In this case, the values of the measured parameters also dropped until the children returned to the premises. It should therefore be considered that airing premises by opening windows only temporarily improved the quality of indoor air.

![Figure 2. Weekly graph of variability of microclimate parameters in the select premises](image)

The lowest values of carbon dioxide concentration were recorded at night or in the early hours of the morning. They reached values from 452 ppm to 539 ppm, which roughly corresponded to the values in the outside air. During the children staying in the premises, the concentration of CO\textsubscript{2} was quickly increasing and reached almost value of 4,500 ppm.

In the all analyzed premises, the recorded values of internal temperature exceeded the optimal values for thermal comfort. The maximum values of air temperature reached from 24.0°C to 29.6°C. It should be noted, that there were excluded from the analyze the premises with southern orientation of windows. During the use of premises, lower temperature values were recorded only after intensive and long-term (about 30 minutes) airing. Nevertheless, in such cases temperature were not lower than 20.0°C. The lowest values of indoor air temperature were recorded during the night and morning hours and they ranged from 19.4°C to 23.1°C.

During the classes there were noted in the premises rapid increase in the relative humidity. However, despite of that, this parameter did not exceed the maximum admissible value recommended in [16]. Apart from the hours in which classes were conducted, the relative humidity values usually dropped to approximately 30% (figure 2). The maximum recorded RH values in the premises ranged from 42% to 56%.

The measured, minimum and maximum values of the analyzed parameters of internal air in particular premises numbered C1/1 ÷ C2/4 are shown in the Table 4.
Table 4. The minimum and maximum values of indoor air parameters measured for selected classrooms

| Premises      | Maximum values | Minimum values | Standard deviation |
|---------------|----------------|----------------|--------------------|
|               | CO₂ [ppm] | T [°C] | RH [%] | CO₂ [ppm] | T [°C] | RH [%] | CO₂ [ppm] | T [°C] | RH [%] |
| Classroom 1/1 | 3953      | 29.3   | 55.3   | 452        | 20.3   | 35.4   | 1181.9  | 1.89   | 5.91   |
| Classroom 1/2 | 4180      | 28.5   | 52.5   | 485        | 20.9   | 30.8   | 1210.5  | 1.76   | 7.21   |
| Classroom 2/1 | 4298      | 29.1   | 48.2   | 470        | 20.7   | 30.1   | 1212.1  | 1.37   | 4.58   |
| Classroom 2/2 | 4373      | 29.9   | 49.0   | 458        | 20.2   | 29.3   | 1208.2  | 1.68   | 4.87   |
| Classroom 3/1 | 4479      | 28.6   | 51.7   | 522        | 19.4   | 35.7   | 1225.2  | 1.92   | 5.48   |
| Classroom 3/1 | 4301      | 28.3   | 53.0   | 539        | 19.7   | 34.9   | 1222.4  | 1.81   | 5.29   |
| Classroom 4/1 | 4266      | 28.0   | 48.3   | 493        | 20.5   | 30.4   | 1220.8  | 1.61   | 4.12   |
| Classroom 4/1 | 4318      | 28.4   | 50.8   | 511        | 19.9   | 29.9   | 1221.9  | 1.79   | 5.11   |

5. Conclusions
The results of the conducted research clearly indicate low quality of indoor air in Polish kindergartens from the 80 'and 90' of the last century undergoing thermo-modernization. The recorded values of carbon dioxide concentration reached even 4,500ppm. Despite of the fact that the maximum recorded values of CO₂ concentration were temporary, the values greater than recommended 750ppm over the concentration in the outside air, occurred almost throughout the entire period of use of the premises. Only after leaving the premises or in the case of intensive airing of the premises, the concentration of carbon dioxide dropped to an acceptable level. Short-term (up to 5 minutes) airing did not bring any visible effect. The values of carbon dioxide concentration for the night hours were approximately 500 ÷ 550ppm. This means that when using premises, the value of this parameter increased by as much as 6 ÷ 7 times. Taking into account the obtained results of measurements of CO₂ concentration in both tests' series in the time of use of premises (daily period), the analyzed kindergartens can be qualified only to the IDA 4 category of air quality (according to the standard EN 13779: 2007).

The values of the internal air temperature for the daytime ranged from approximately 24.0°C to even 29.6°C. While, in the night the lowest recorded internal temperature was 19.4°C. Such high temperatures during the day are the result of reducing heat losses by building envelope, while the central heating system settings is insufficient and use of rooms is intensive. As a result, during the use of the premises, there were often recorded the temperature values far exceed the recommended values for thermal comfort. It was also reflected in the recorded values of relative humidity. In the end of the night the relative humidity was dropping to the level of 30 ÷ 40%. During the use of the premises, the RH values increased to a maximum of 53%.

The low quality of indoor air in Polish kindergartens undergone the thermo-modernization is a phenomenon related to the lack of comprehensive works in building. The insulation of external partitions with expanded polystyrene and replacement of window joinery without simultaneous interference in the ventilation system limited the air exchange in these buildings. As shown by the
authors' own research [17] it is possible to adequately increase the ventilation airflow of such buildings. It will improve the quality of the internal air, and will not negatively affect the thermal comfort in the rooms.

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