Quality of the Indoor Environment in the Nursery School: Monitoring, Analysis and Optimization

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Abstract. The paper aims to assess and evaluate the hygiene and quality of the indoor environment in selected indoor areas of the kindergarten, to analyse the construction, technical and technological solutions of the building in accordance with the concept of designing healthy buildings and their environment. The paper will propose the operation of the building in terms of hygiene and perceived air quality. The paper assumes in-situ monitoring of the indoor environment of the nursery school using a multifunctional measuring instrument for analysing the quality of the indoor environment and comfort (Testo 480 + accessories). The research goal is to update and expand information on the quality of the indoor environment of kindergartens during the heating season. The aim is to design a concept for improving the quality of the environment in nursery schools and to prepare documents for relevant recommendations, including recommendations concerning, for example, construction or utility materials for nursery schools and the mode of their operation.

1. Introduction

The lifestyle of a large part of the European population is focused on spending most of the day indoors [1]. At present, the topic of the quality of the indoor environment of buildings is an increasingly discussed issue. The importance of the quality of the indoor environment and especially hygiene is growing in connection with the global epidemiological situation regarding coronavirus disease SARS-CoV-2 [2-4]. Increasing attention is paid to the quality of the indoor environment in schools, and therefore in nursery schools. The main reason for focusing on school’s environment is the fact that children are gathered in large numbers in closed rooms, in which the overall air quality is often forgotten for reasons of thermal comfort. School classes tend to have up to 3–4 times more people than in office spaces (with regard to floor area m² and air volume m³). Another reason for the increased interest is the fact that children, especially the youngest, are considered to be the most vulnerable group that can be most harmed by poor air quality [5-7]. Generally, harm to the child's body is greater due to the inhalation of a larger amount of air per unit body weight compared to an adult. The quality of the indoor environment also affects the perception of comfort or the feeling of health and well-being. At the same time, it creates an environment that can have both positive and negative effects on the study environment for children and pupils, but also teacher performance [8].
The relevant legislative regulations establish requirements for spatial conditions, equipment, operation, lighting, heating, climatic conditions, water supply, cleaning and kindergartens and other school equipment and even for children younger than 3 years. The interior of the preschool classroom must include space for instruction, free play, rest, personal hygiene with hardening, physical exercise and catering (possibly in another canteen, such as a school canteen nearby). Premises intended for physical education must be ventilated, the floor must be made of flexible material, the surfaces must be washable, and the radiators must be secured against injury to the child.

2. Experimental method
The researched nursery school building is designed from a modern modular cellular system. The cells are assembled into two floors so that the first floor is for the youngest children, approximately 2 to 4 years of age, and the second for preschool children, approximately 4 to 6 years of age.

![Scheme of the monitored class of nursery school.](image)

Figure 1. Scheme of the monitored class of nursery school.

Figure 1 schematically shows the arrangement of the monitored class. The red dot shows the position in which the measuring instrument was placed throughout the measurement. According to the children's activity, the sensor sensing the data was moved towards their current position. Children spend most of their time at tables where food is served or where children learn and play. Children spend less time on the carpet, where games, learning and exercise take place in both classes.

The monitored class is rectangular with dimensions of 14,735 x 7,175 mm with a clear height of 2,750 m. The total volume of the class is 290.74 m³. There are 5 window openings in the class with dimensions of 2,060 x 2,000 mm filled with three types of window assemblies. These are assemblies of two windows, of which one window is always openable and the other window, placed vertically or horizontally, is tiltable. The plate radiator is under each of the window. The dimensions of which reach a maximum height of the windowsill, which is 450 mm high from the floor. Above the door to the washroom and about 3 meters further, there are two air conditioning units. The class is also equipped with plants. In the classroom are two potted plants placed on higher shelves.
The multifunctional measuring instrument Testo 480 type K was used to measure climatic variables in the classes of the selected kindergarten. In this work, the concentration of carbon dioxide [ppm], temperature [°C], humidity [%] and lighting intensity [lx] were measured. The IAQ probe was used to measure carbon dioxide concentration, temperature and humidity, which is used to quickly control the indoor climate. As stated by the manufacturer, the range of the temperature probe is from 0 to +50°C with an accuracy of ± 0.5°C. The range of the humidity capacitive sensor is from 0 to 100% with an accuracy of ± (1.8% + 0.7% of the measured humidity). And for CO₂ measurements, the scale is in the range from 0 to +10,000 ppm, with an accuracy for values from 0 to +5,000 ppm ± (75 ppm + 3% of the measured value) and values from 5,001 to +10,000 ppm ± (150 ppm + 5% of measured value). The second probe used is a probe for measuring light intensity [lx]. The measuring range of the probe used is from 0 to +100,000 lux. The accuracy of the probe is according to DIN EN 13032-1 for \( f_1 = 6\% \) V-Lambda and \( f_2 = 5\% \cos \), and at the same time it is classified in class C according to DIN 5032-7.

The measurement site should be chosen in close proximity to the building users for the most accurate results and at the height at which they breathe. The respiratory zone of children is located approximately 1 m above the ground, this height of the device was observed. However, for safety reasons, the meter accessories were placed at the wall of the room, as shown in Figure 1 above, at a close distance from the users of the building.

3. Results
Measurements and examinations in the classroom took place in the winter. The outdoor daytime temperature on these days ranged from -4 to 8°C. The daily schedule of the children did not change much, but the number of children present changed considerably. The device was switched on every day at 7 o'clock and 15 minutes. In the resulting graphs, however, only the values measured at 7 hours and 25 minutes are recorded in order to acclimatize the device and thus prevent errors in the initial measurements. To compare the values from the monitored days, the values are entered into individual graphs. In each of the following graphs, the values of one indicator during the whole week are recorded. Figure 2 shows occupancy by operating time. At 10 o'clock the children regularly went for a walk outside.

![Figure 2. Occupancy during the operation day.](image)

For an overview of the concentration of carbon dioxide in the classroom during the entire measurement, the data are entered in the following figure. The figure shows the course of CO₂
concentration each day, and this course can be compared with the value indicating the maximum allowable concentration. The maximum permissible limit of carbon dioxide concentration was exceeded only on the second day of the measurement. The measured space became an unsuitable environment in the case of the fourth day of measurement, when the limit of 1,200 ppm was exceeded twice. The limits were exceeded due to low air volume exchange caused by the absence of ventilation. CO$_2$ concentrations are shown on Figure 3.

![Figure 3. CO$_2$ Concentration [ppm].](image)

The following graph (Figure 4) clearly shows the light intensity [lx] during operating hours. The value indicating the minimum permissible value (80 lx) for a well-lit space is also shown here. During the third day, the lighting intensity was exceeded over 4000 lx, which most likely caused dazzling users. Such a high value was measured due to direct irradiation of the sensor at the time the value was recorded. During the measurement, the light intensity fluctuated considerably due to the variability of solar radiation. The measured values were almost every day in lower or higher values than the ideal, which was caused by fluctuations in solar radiation.

![Figure 4. Light intensity [lx].](image)
Figure 5 shows clearly the course of the relative humidity (RH) of each day. A value indicating the minimum permissible relative humidity (30%) is shown. Values below the minimum permissible relative humidity were monitored each day of the measurement.

Figure 5. Indoor relative humidity [%].

Indoor air temperature is shown in Figure 6. The values of maximum and minimum permissible temperatures of air are shown (boundaries). The maximum or minimum value of the permissible air temperature was not exceeded during the whole week. Most of the time, even the measured values were in the ideal range of 20 to 24 °C.

Figure 6. Indoor air temperature [°C].
4. Discussions
Table 1 shows a summary of the minimum, maximum and mean values in the measurement of the quality of the indoor environment determined by the nursery school. Color-coded values indicate that the recommended minimum and maximum values for the indoor environment have been exceeded.

The set limit of carbon dioxide concentration of 1500 ppm was exceeded only once in the class and once the values approached the limit. Also, in the monitored class, the CO₂ concentration did not fall below 1000 ppm, which is the limit value for an ideal environment. In terms of average values, the results correspond to ideal conditions.

The intensity of lighting fell several times below the limit of a well-lit room. In the first class even 4 out of five cases. According to the observations, these were mostly sunny days with significant fluctuations in the intensity of sunlight, or the switching off of artificial lighting in the absence of children. The average values correspond to the ideal light intensity, which should be between 200 and 300 lx.

In the case of relative humidity, values are indicated where the humidity is lower than 30% (too dry) or, conversely, higher than 60% (too humid). According to the table, it is clear that the monitored class is facing a dry environment problem. Minimum relative humidity values below 30% were recorded on all days.

The table shows that during the 4 days of measurement, values higher than values in the ideal range from 20 to 24°C were recorded. On average, however, the values were increased compared to the ideal only in two days, at a temperature higher by a maximum of 0.3°C.

| Day 1   | CO₂ concentration [ppm] | Light intensity [lx] | Indoor relative humidity [%] | Indoor air temperature [°C] |
|---------|-------------------------|----------------------|----------------------------|-----------------------------|
| Min     | Max                     | Ø Min                | Max                         | Ø Min                        | Max             | Ø |
| 581     | 1040                    | 829                  | 13                          | 429                         | 202             | 28.5          | 36.0          | 31.5          |
| Day 2   | 618                     | 1518                 | 944                         | 50                          | 1684            | 421           | 26.3          | 36.6          | 31.3          |
| Day 3   | 502                     | 1181                 | 831                         | 81                          | 4299            | 839           | 21.6          | 32.9          | 26.0          |
| Day 4   | 643                     | 1402                 | 897                         | 31                          | 1141            | 351           | 22.9          | 31.2          | 26.8          |
| Day 5   | 454                     | 935                  | 667                         | 31                          | 1742            | 591           | 19.2          | 30.0          | 24.1          |

The indoor air relative humidity is the biggest problem in the quality of the monitored nursery school. The relative humidity of indoor air was below the limit values for the vast majority of the measured time, and therefore it is necessary to focus primarily on increasing its humidity, depending on the indoor air temperature. Ensuring an optimal heat-humidity microclimate is one of the most important factors needed to achieve a healthy environment and indoor air. It is necessary to set a temperature that will not cause the air to dry out, as is the case with overheating. The higher the indoor air temperature, the drier the air becomes. It is necessary to ventilate effectively. The most ideal way is short but intensive ventilation. During the monitoring of the class, it was observed that the ventilation is performed on the contrary, weakly and continuously. Most of the time the measurement took place, one to four windows were opened for ventilation at the same time as the heating was switched on. This method of air exchange takes place in a cycle that is inefficient for indoor air quality. Cold air enters the open window, causing an unpleasant cold environment, which causes an attempt to heat the environment by heating, but a large part of the heated air escapes through the window from the room. The result is a dry environment with high energy consumption spent on equalizing the room temperature. Due to the higher recorded temperatures than the ideal values, with at the same time low
values of relative air humidity, it should be a proposal to optimize the efficiency of the ventilation method at the same time as adjusting the heating intensity. Ventilation should take place at least 3 times a day for 10 to 15 minutes. In the winter months, ideally reduce the ventilation time to two minutes and turn off the heating a reasonable time in advance (approximately 30 minutes) and switch it on again after ventilation. If the relative humidity is still low, it would be appropriate to combine the air exchange method with other elements that increase the humidity, i.e. steam humidifier, ultrasonic humidifier, natural evaporation humidifier, evaporator for radiators or plants.

Improvement of ambient air conditions in the context of CO₂ concentration can only be achieved by supplying fresh air. According to the methodological guidelines for the design of school ventilation, the amount of air supplied to the classrooms can be reduced to 10 m³/h per child due to the age of the children. The maximum capacity of the class is 28 children, which is 280 m³ of air needed in a one-hour exchange. There are one or two teachers in the class, for whom the volume required for air exchange is 20 - 30 m³/h per person. Together, for all persons, at least 320 m³/h of the total volume of the class of 290.74 m must be replaced. It follows that when the maximum capacity of the class is filled, a complete air change will be required more often than once an hour.

During the measurement, the light intensity fluctuated considerably due to the variability of solar radiation. The measured values were almost every day in lower or higher values than the ideal, which was caused by fluctuations in solar radiation. The windows are equipped with blinds, but except for one case, they were not used for the whole ten days, despite the considerable dazzling of children at the moment when they were learning or forming at tables. At the same time, in at least seven measured days, the light intensity dropped to a limit of 80 lx for several tens of minutes and even exceeded this limit a few times. In the case of such decreases in light intensity, there was considerable gloom in the room, and yet no artificial lighting was used. Both extremes can be avoided by using blinds with the slats tilted downwards so that the sun illuminates the room but does not dazzle the children, and by promoting artificial lighting. At the same time, the blinds can be used to reduce any unwanted heat gain by turning the slats upwards.

5. Conclusions
The quality of the indoor environment is a great phenomenon today. Quality and healthy indoor environment is very often at odds with the current trend of low energy consumption. Nursery schools are sensitive places for children due to the exposure of a large number of factors to the indoor environment of buildings. The aim is to design a concept for improving the quality of the environment in nursery school and to prepare the concept for relevant recommendations, including recommendations concerning, for example, construction or utility materials for nursery schools and the mode of their operation.

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