THE FIRST TEST OF INDOOR AIR QUALITY IN KINDERGARTENS OF THE REPUBLIC OF SRPSKA

by

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The first experimental results of the indoor air quality in two kindergartens located in the Republic of Srpska are presented in this paper. Kindergarten representatives for the year of construction (old and new), building materials, and energy efficiency have been chosen. Indoor air quality measurements (air temperature, relative humidity, ventilation rate, CO_2, and radon concentration) were performed during the winter of 2015/2016. Measured indoor air quality parameters are discussed and compared to the international standards BAS EN 16798-1, ASHRAE 62.1, and ISO 7730. The average measured radon concentrations for both buildings have not exceeded the level of 200 Bq/m^3, but for reliable results, long-term measurement needs to be performed. The CO_2 concentration in the old kindergarten fulfills the BAS EN 16798-1 requirement for Category I during 62.43% of total occupancy time, while for the new kindergarten, it is only 5.79% of full occupancy time. Results of CO_2 concentration confirm that good sealing of the envelope of new buildings and user behavior (number of users and natural ventilation) does affect air quality. Furthermore, a high correlation between CO_2 concentration and relative humidity in both buildings and a more considerable correlation for the new building have been observed.

Key words: *indoor air quality, kindergarten, temperature, relative humidity, number of air changes, CO_2 concentration, radon concentration*

Introduction

Indoor environmental quality is a comprehensive term that includes various factors: indoor air quality (IAQ), lighting, thermal comfort, acoustics, drinking water, ergonomics, electromagnetic radiation, and many other factors [1].

Per the EPA definitions, IAQ refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants [2]. To evalu-

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ate IAQ, pollutant concentrations, thermal conditions (temperature, air-flow, relative humidity – RH), light, and noise are generally analyzed [3]. Indoor air pollution has been determined by the concentrations of pollutants present in the air (formaldehyde, volatile organic compounds, particles, pesticides, radon, fungi, bacteria, and NO_x), while its elevated concentrations can cause Lung cancer Legionnaires' disease, CO poisoning, allergy, and asthma [4]. According to some papers, thermal comfort represents the most crucial aspect of IAQ [3]. The concept of IAQ in science became significant during the global energy crisis in the 70's when there was an increase in energy prices. Consequently, there was a need for economical consumption of thermal energy to protect the environment and reduce CO_2 emissions [5]. The essential action required was to decrease the heat losses in buildings by addressing both transmission and ventilation lower energy consumption for heating buildings. Reduction of ventilation losses due to infiltration is achieved by better sealing of the envelope, which, on the other hand, causes more significant indoor air pollution. The IQA and pollution of the air are essential aspects of the comfort and health of inhabitants in all building types. Still, they are vital for kindergartens, where children spend most of their time during the day in the most sensitive period of their growth and development. The kindergarten opening hours are 7 a. m. to 5 p. m. from Monday to Friday. On average, that time is eight hours per day and five days per week, which is around 50 weeks or 2000 hours on a year level. In addition, children spend at least the same amount of time in a closed space at home. The IAQ and pollutants that could be present in the air can cause discomfort, affect the learning performance of children, and, last but not least, cause long and short-term health problems [6, 7]. Furthermore, children are more sensitive to air pollutants and at higher risk for developing diseases and cancer than adults [8, 9]. A precondition for good IAQ is adequate fresh air supply (ventilation), quantified by the required air changes per hour. It depends on the quality of the outdoor air. Also, the indoor concentration of CO_2 can give insights into the air quality in the room, but it depends on occupancy and ventilation rate. According to papers [10, 11], a high correlation between CO_2 concentration, RH, and indoor air temperature in naturally ventilated buildings is expected. The International Standard BAS EN 16798-1 [6] introduces different categories of building materials depending on the pollution. The building is *very low polluting* if all of the materials are very low polluting and if smoking is prohibited and not practiced. The standard defines *very low polluting materials* as traditional natural materials, such as stone, glass, and metals, which are known to be safe with respect to emissions*, etc.*

As important aspects of IAQ in kindergartens, the radon concentration, the concentration of CO_2, the internal air temperature and RH, and air changes per hour are measured and analyzed in this paper.

Methodological approach

To evaluate the air quality in the kindergarten's indoor space, measurement methodology has been introduced, fig. 1. In the theoretical part, the definition of the radon concentration, CO_2 parameters, and their prescribed values are discussed. Furthermore, the case studies of kindergartens taken from different construction periods, showing typical representatives of old and new kindergarten construction and their characteristics, are considered. The representative of the old construction is a kindergarten built 40 years ago, as are most existing kindergartens that need to be renovated. On the contrary, the exemplar of modern construction is the kindergarten, constructed according to the parameters prescribed in the currently valid rulebook, as a low energy building. Moreover, the measuring instruments, their characteristics, and the standards used to perform measurements are introduced. The characteristics of the rooms where the measuring devices were installed are also taken into consideration. The experimental part of the research was carried out in selected kindergartens. The air quality parameters in typical, characteristic rooms for children were carried out in the experimental part of the research, fig. 1.

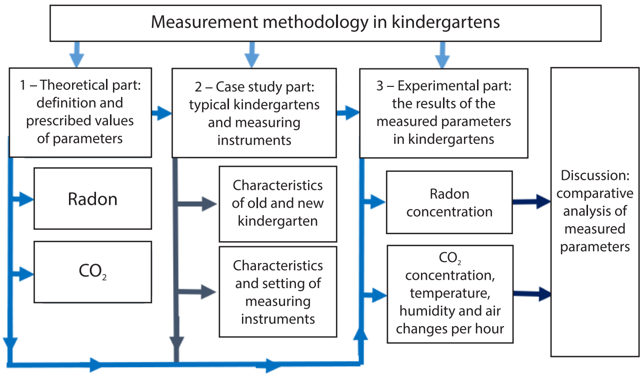

Figure 1. Scheme of the methodological approach

The results of the measurements are discussed in a comparative analysis of two kindergartens. The radon in the indoor space and the CO_2 concentration, temperature and air humidity in the indoor and outdoor spaces, and the number of air changes per hour are measured and analyzed in order to have an adequate discussion about the quality parameters of the indoor environment. Finally, the correlation coefficients between CO_2 and temperature and CO_2 and RH are presented and discussed.

Theoretical part: definition and prescribed values of parameters

The theoretical basis for parameters used to evaluate internal air quality (the radon concentration, the CO_2 concentration, and the number of air changes per hour) is introduced in this chapter.

The radon concentration

According to the UNSCEAR 2000 report, the annual global average effective dose from natural radiation (cosmic radiation, external terrestrial radiation, inhalation, ingestion) is 2.4 mSv (public exposure). Almost half of this total received dose comes from radon inhalation [12].

Radon (^{222}Rn) is the most widespread natural radioactive gas, tasteless, colorless, odorless, and inert. Generally, the ground under (and around) the building is the primary source of radon in indoor air [13]. Building material is the second leading source of radon in indoor air, particularly on the upper floors [14, 15]. The results from the previous papers confirmed that usually, the most significant influence on the total radon concentration up to the second floor in an enclosed space is radon from the soil. Radon emanating from the material used during construction, *i.e.*, built into the walls or floors, is more significant for the upper floors. The other sources of radon indoors are gas, water supplies, and outdoor air. It should be noted that the global average indoor radon concentration is found to be 46 Bq/m^3 with a geometric mean of 37 Bq/m^3, while its typical outdoor concentration is of the order of 10 Bq/m^3 [12, 16].

Special attention must be paid to the energy-efficient buildings which, due to energy saving for heating and cooling, strive to lower air exchange with the outdoors (airtightness). Increased concentrations of this gas are dangerous to health. The danger of radon human health arises from inhaling short-lived decay products (polonium isotopes) that can deposit in lung tissue and damage it by emitting alpha particles. According to the results of studies, radon and its short-lived daughters are considered the second leading cause of lung cancers after smoking. Furthermore, it is essential to emphasize that children are more susceptible to radiation exposure than adults from slightly enhanced natural radiation [8, 9].

Regulations concerning the population's exposure to radon and its descendants differ in different countries. However, new recommendations have been introduced recently in light of new scientific data. The EU Directive 2013 requires establishing a national reference level for indoor radon annual average activity concentration not exceeding 300 Bq/m^3 – for residential dwellings and workplaces [17]. To minimize health risks due to radon exposure, the WHO recommends a reference level of 100 Bq/m^3, and certainly not higher than 300 Bq/m^3 [18].

The CO_2 concentration

The CO_2 is a colorless and odor-gas component of atmospheric air. The amount of CO_2 in the outdoor air is variable (around 0.04%). It is one of the indoor pollutants emitted by humans, furniture, buildings, and HVAC systems, affecting humans to experience drowsiness, develop headaches, and so on. Since kindergartens are buildings with special requirements as susceptible persons use them as young children, they have classified the building category I according to the standard BAS EN 16798-1 [6]. Some recent studies indicate that the indoor concentration of CO_2 is strongly influenced by the number of occupants in the rooms and their times of stay. The CO_2 measured values might indicate problems with ventilation adequacy, but the CO_2 concentration does not indicate air pollutants that are not perceivable by humans, such as radon. According to international standards, including The American Society of Heating, Refrigerating and Air-Conditioning Engineers – ASHRAE [19], acceptable indoor levels of CO_2 should not exceed 1000 ppm. At the same time, the difference between the indoor and the outdoor concentration should satisfy specific criteria depending on the building category. The CO_2 concentration, as a parameter of IAQ, is directly affected by the ventilation rate.

The air change rate is characterized by the number of air changes per hour, representing the ratio of the exchanged air volume in one hour and the total net volume of the room n [per hour]. The number of air changes per hour is one of the parameters that directly shows the IAQ. From the design point of view, a specific air change rate is required depending on the building envelope's thermal characteristics, the building's position the surroundings, the microclimate conditions, and the use of the building. Also, health and comfort criteria directly influence required ventilation and the number of air changes per hour. According to the national regulations in the Republic of Srpska [20], the measured number of air changes per hour, when the difference in pressure between the indoor and the outdoor air is 50 Pa, has to be three per hour for naturally ventilated buildings.

The measured indoor and outdoor values of air temperature, air humidity, and the concentration of CO_2 are presented separately, as well as through the correlation coefficients between CO_2 and temperature and CO_2 and RH.

Case study part: Typical kindergartens and measuring instruments

Two kindergartens (Neven and Kolibri) in Banja Luka in the Republic of Srpska have been chosen for the presented case studies.

Characteristics of analyzed buildings

Kindergarten Neven, with design documentation dating back to 1974, represents an example of an old building, while kindergarten Kolibri, with design documentation dating back to 2008, has been taken as an example of a new and modern built kindergarten according to energy efficiency rulebooks of the Republic of Srpska [20-22]. The two buildings are similar in terms of site, size, and design number of users, fig. 2. They both accommodate ca. 220 children aged 1-6, divided into eight groups.

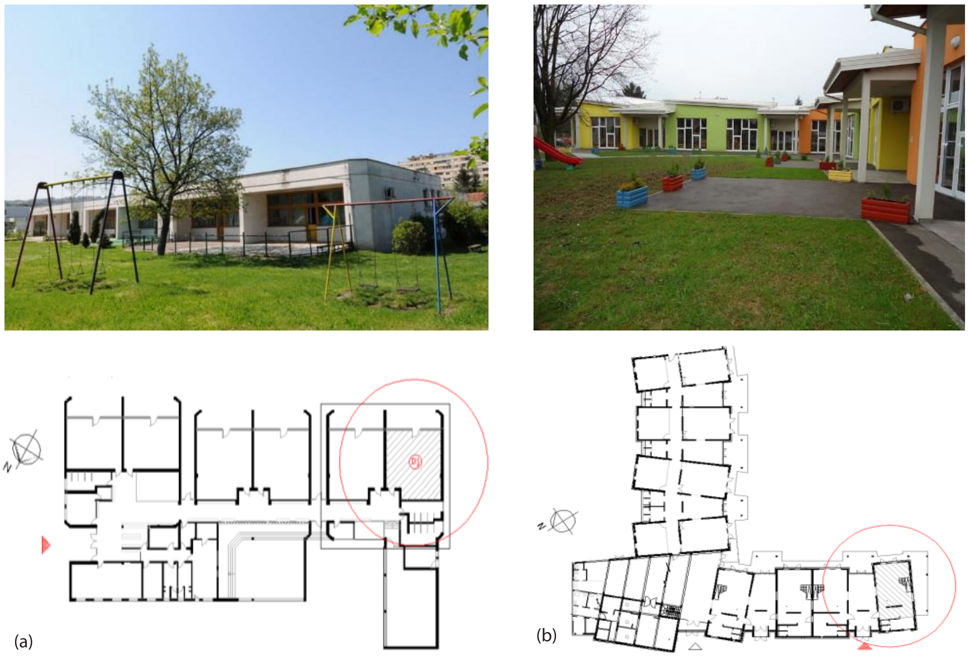

Figure 2. The view of the kindergarten from the yard and lay-out of the ground floor; Neven (a) and Kolibri (b)

Both kindergartens are located in an urban area, surrounded by other buildings, and have similar ventilation conditions since they are both naturally ventilated. Neven has a central heating system with radiators installed on the external walls. In contrast, Kolibri has a floor heating system (low temperature regime) heated through a water-water heat pump with an underground thermal spring. Furthermore, Neven has no compact form, and its building shape factor is 0.94. On the other hand, Kolibri has a widespread ground floor size with a larger part that

Table 1. Characteristics of the Kindergartens

	Neven (old)	Kolibri (new)
No. of floors	P	P + G
Heated space area [m^2]	1014	1110
Heated space volume [m^3]	3044	4157
U-value walls [Wm^{-2}K^{-1}]	1.47	0.41
U-value windows [Wm^{-2}K^{-1}]	3.55	1.51
U-value roof [Wm^{-2}K^{-1}]	0.77	0.20
U-value floor [Wm^{-2}K^{-1}]	1.12	0.33
g-value	0.77	0.61
A/*V* ratio [m^{-1}]	0.94	0.77
Number of users	217 children, 18 nurses/ nursery/preschool teachers	224 children, 16 nurses/ nursery/preschool teachers
Number of users per room	28	25

includes a gallery, which increases kindergarten volume with a building shape factor of 0.77. The old kindergarten, Neven, is a prefabricated reinforced concrete frame structure with brick infill walls. The new kindergarten is a masonry structure with load-bearing brick walls and reinforced concrete ring beams. The average *U*-value of the elements of the envelope is presented in tab. 1 and for two buildings, they are different due to the different designs and materialization of the envelopes, resulting in Kolibri satisfying the criteria of energy-efficient buildings.

Characteristics and setting of measuring instruments

Table 2 lists measured IAQ parameters, the names of devices used for measurement, and the corresponding standards.

Table 2. Characteristics of the equipment

Parameter	Equipment	Standard
The airtightness	Minneapolis Blower Door, Model 4 220V SYSTEM	ISO 9972 ISO 13789
The radon concentration in indoor air	RAD7 DURRIDGE Radon Detector	Active method
The CO_2 concentration, air temperature, and RH	TESTO 435-2 with the adequate IAQ probes	BAS EN 16798-1
Thermal irregularities	Testo 885-2	EN 13187

The electronic detector of alpha particles, the RAD7 DURRIDGE Radon Detector, fig. 3, has been used to measure the radon concentration in indoor air. The detector produces a signal with a 50% probability. This signal is amplified electronically and transformed into a digital signal. The microprocessor stores the energy level of the signal and produces the spectrum. The manufacturer recommends that the device works at standard room temperature and air humidity up to 6% when the device error is 4%. All deviations from these values are corrected by the program which controls the detector RAD7.

(a) (b) (c) (d)

Figure 3. Devices used for measurement: RAD 7 (a), Testo 435-2 (b), Minneapolis Blower Door (c), and Testo 885-2 (d)

According to the standard BAS EN 16798-1 [6], air quality can be determined by measuring the CO_2 concentration in a fully occupied building. The measurement was performed using TESTO 435-2 with adequate IAQ probes for CO_2 concentration, RH, indoor air temperature, and absolute pressure, fig. 3. The data logger records CO_2 concentration in the range 0-10000 ppm, with accuracy ± (0-5000 ppm CO_2: 75 ppm CO_2 + 3% mv). The measurement range for air temperature is 20-70 °C and RH 0-100%, RH with the accuracy ±0.5 °C and ±3% RH, respectively.

The standard defines different acceptable levels for each building category depending on the indoor CO_2 concentrations above the outdoor level. Since users of kindergartens are children in their most sensitive period of growth and development, these types of buildings can be defined as buildings of category I due to the high level of expectation according to BAS EN 16798-1.

Both kindergartens are ventilated naturally. The airtightness of analyzed buildings is tested with the Minneapolis Blower Door, fig. 3, measuring equipment according to the methodology defined in the standard ISO 13789 [23]. Due to kindergartens' large net heated space volume, only representative rooms are tested following ISO 9972 [24].

During measurements, qualitative detection of thermal irregularities on the envelope was carried out using an infrared method with Testo 885-2, fig. 3, following EN 13187 [25].

Experimental part: The results of the measured parameters in kindergartens

The measurements of IAQ parameters were performed on the ground floor of kindergartens Neven and Kolibri during December 2015 and February 2016, respectively. The analysis of the obtained measurements of the radon and CO_2 concentration, air temperature and RH, and number of air changes in the representative room in each kindergarten was made.

The radon concentration

In Neven, measurements were done during one week from February 12th to February 18th, 2016 (the 13th and 14th were weekend days), fig. 4. The measuring room was located on the ground floor of the building, it was used during measurements, but attention was paid to the fact that air circulation in the room is low. The measured mean value of radon is 175 ±3 Bq/m^3, tab. 3. As can be seen from fig. 4 the maximum radon concentration was detected on February 15 at 13.30 p. m. when the kids were sleeping, and it reached a value of 312 Bq/m^3. The radon concentration was relatively high during the few days of measurements, including weekends. Since space is not occupied on weekends, it is worrying that the high radon concentration occurs at the beginning of the working week when the building is occupied; on average, it is above 200 Bq/m^3.

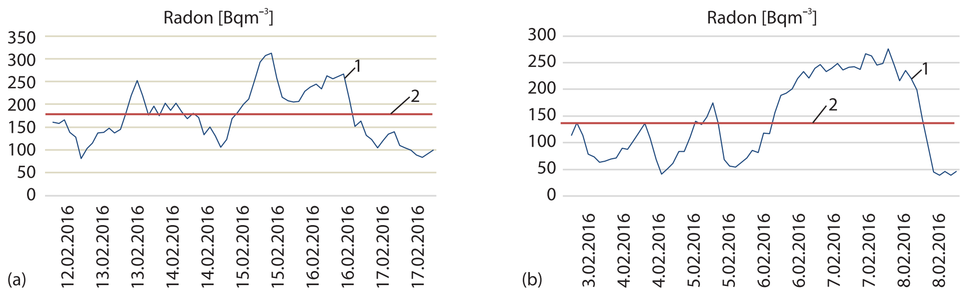

Figure 4. Time-dependent radon concentration (blue line – 1) with mean value (red line – 2); Neven (a) and Kolibri (b)

In Kolibri, radon concentration measurements were done for one week from the 3rd to the 9th of February of 2016 (the 6th and 7th were weekend days), fig. 4. The measurement was carried out in a room located on the first floor of the building. As can be seen from the time-dependent radon measurement shown in fig. 4, the radon concentration during the day was getting higher and reached its maximum value on weekends. On Sunday at 23.14 p. m., the measured value reached 276 Bq/m^3, while on the next day, after ventilation of the room (the draft), there was a drop in radon concentration. The measured mean value is 142 ±2 Bq/m^3, tab. 3, while the mean value was below 100 Bq/m^3 during occupational time. Looking at the obtained results, tab. 3, fig. 4, it is clear that the measured concentration significantly exceeds the global average indoor radon concentration of 46 Bq/m^3, except for the minimum concentration in Kolibri.

Table 3. The results of radon measurements in two kindergartens

	Maximum concentration [Bqm^{-3}]	Minimum concentration [Bqm^{-3}]	Average value [Bqm^{-3}]
Neven	312 ±31	81.5 ±16	175 ±3
Kolibri	276 ±29	38.9 ±12	142 ±2

For comparison, the indoor radon concentrations in 296 kindergartens in Sofia measured during three months by the passive detectors (CR-39) showed an average of 132 Bq/m^3 [26]. On the other hand, a study on radon exposure in Slovenian kindergartens and schools showed that in 45 kindergartens and 78 schools, radon concentrations exceeded the level of 400 Bq/m^3. After such a finding, measures for radon level reduction were successfully performed in 35 buildings [27]. Furthermore, in Montenegro, for example, the average nine month radon activity concentration, measured by the CR-39 in 2855 ground-floor rooms of 468 buildings of pre-university education (including kindergartens), was found to be 275 Bq/m^3. At the same time, 728 rooms showed concentrations above 300 Bq/m^3 and 111 – above 1000 Bq/m^3 [28].

The CO_2 concentration

The indoor CO_2 concentration, fig. 5, and its comparison the outdoor concentration were analysed for the four days of measurements during the heating season from December 22 to 25, 2015 in Neven and from January 26 to 29 in 2016 in Kolibri. The analysis presented here includes only measurements during the occupation time (08:00 a. m to 17:00 p. m., marked with green vertical lines in fig. 5). The length of the time interval in which the indoor CO_2 concentration is below the maximum acceptable level is used as a characterization index. In both buildings, there are high concentrations of CO_2 with significantly higher average levels in Kolibri (2199 ppm) than in Neven (993 ppm), fig. 5, during occupancy time, tab. 4.

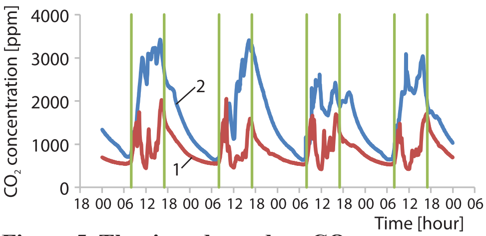

Figure 5. The time-dependent CO_2 indoor concentration in Neven (red line – 1) and Kolibri (blue line – 2)

Table 4. The percentage of the total occupancy time when each building category meets the condition

	Neven	Kolibri
	Total time [%]	
Category I (550 ppm)	62.43	5.79
Category II (800 ppm)	75.00	14.07
Category III (1350 ppm)	97.38	31.72
Category IV (>1350 ppm)	2.62	68.28

The outdoor daily temperature and RH data were obtained from the nearby meteorological station (Budzak – WMO code 14542). The outdoor CO_2 concentration was not directly measured but was estimated based on the indoor measurements during the weekend before and after the reference period. As children do not stay in kindergartens during weekends, there are no sources of CO_2, and after some time, indoor CO_2 concentration comes into equilibrium with the outside one due to the diffusion process. The estimated outdoor CO_2 concentration based on measurements from two consecutive Sundays is 499 ppm for Neven and 525 ppm for Kolibri.

The CO_2 concentration in Neven (blue line in fig. 5) fulfills the BAS EN 16798-1 requirement for category I during 62.43% of total occupancy time. At the same time, for Kolibri, it is only 5.79% of full occupancy time, tab. 4. The highest average air temperature measured at the height of an average child's head (h = 110 cm) during the time of occupancy in Neven leads to more frequent opening of balcony doors/windows and the consequent inflow of external air with the lowest CO_2 content, tab. 5. These moments can be identified as the sudden declines in the indoor CO_2 concentration in fig. 5. Although the more frequent opening of the door and consequently lower concentration of CO_2 in the room can be the result of more favorable external conditions, in this case study, the mean maximum daily outdoor temperature during the measurement period was higher outside Kolibri than Neven. Children generate CO_2 and humidity, and approximately the same number stay in both kindergartens. Considering the lower air temperature in Kolibri, which leads to less frequent opening of doors and windows, we can conclude why the air quality is better in Neven.

All openings, such as windows and doors, which are part of the thermal envelope, were closed, which ensured the prerequisites for creating pressure differences between the inside of the building and the outside air.

Table 5. The average values of the air temperature, RH, and CO_2 concentration by days during time of occupancy and corresponding outdoor whole-day temperature average values

	Indoor			Outdoor		
	t [°C]	φ [%]	CO_2 [ppm]	t [°C]	φ [%]	CO_2 [ppm]
Neven						
22.12.2015.	23.3	38.7	1077	6.4	79.0	499
23.12.2015.	23.2	35.6	936	5.6	79.0	
24.12.2015.	23.4	37.4	1031	5.2	80.5	
25.12.2015.	23.0	37.9	929	5.7	79.5	
Kolibri						
26.01.2016.	19.8	53.7	2589	8.5	66.0	525
27.01.2016.	20	48.7	2075	6.7	74.8	
28.01.2016.	20.8	50.7	1905	9.3	70.0	
29.01.2016.	20.9	54.5	2227	9.6	73.5	

The measurement has been performed at the pressure difference of 50 Pa between the internal and external air. As a result, the numbers of air changes 8.78 per hour and 2.72 per hour were obtained for Neven and Kolibri, respectively. The measured value for Neven is highly different from the maximum value of n_{50} = 3 per hour for naturally ventilated buildings [20]. The demand for airtightness is fulfilled for the other kindergarten according to the Blower Door test results (n_{50} = 2.72 per hour) [20, 29]. Test points to sensitive areas such as air leaks and thermal bridges where increased air infiltration occurs in Neven, fig. 6. It is obvious that there are severe problems with thermal bridges around windows, fig. 6(a), since the temperature of the warmest point is 22.0 °C and of the coldest one is 6.5 °C. The balcony door is shown in fig. 6(b), and as can be seen, the hottest point has a temperature of 19.3 °C, and the coldest one is 2.9 °C. The coldest places where intense air infiltration occurs are at the joints of the windows, with the wall indicating the absence of sealing rubber.

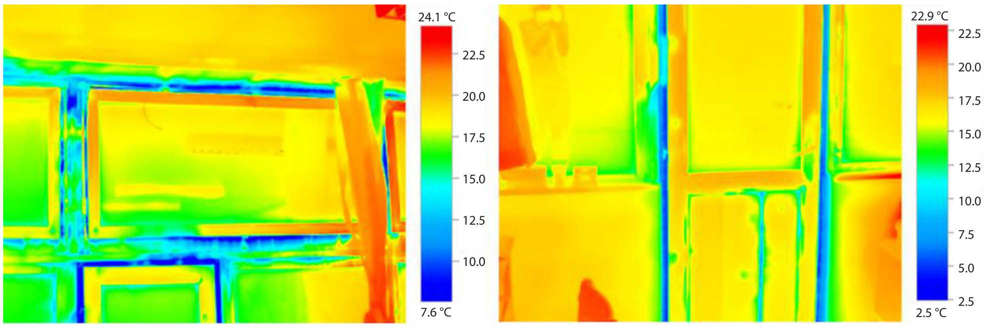

Figure 6. Thermal image of the interior of Neven during the blower door test measurement

A difference in the quality of windows and balcony doors primarily causes a difference in the measured airtightness of kindergartens. Double-glazed windows with ordinary glass and wooden frames were embedded almost 40 years ago in Neven. In contrast, modern windows with double thermal insulation glazing and low emitting coating filled with argon and PVC profiles have been recently installed in Kolibri. In addition, the facade wall has adequate thermal insulation, and thermal bridges at the junction of the window frame to the facade wall are resolved. From the presented analysis, it is evident that poor sealing of windows and balcony doors in Neven causes the appearance of thermal bridges, which significantly influences the increased number of air changes, which is almost three times higher than allowed. Although more significant infiltration is not good from the energy demand point of view, it is evident that it is more favorable for the air quality requirement.

Discussion

Two kindergartens have approximately the same heated volume, the number of users, and the average time users spend in the space is eight to ten hours daily. Nevertheless, they are from different construction periods, and other building materials were utilized. Neven is an energy-inefficient building, but Kolibri meets the minimum energy requirements according to the Republic of Srpska Regulations governing this area, as previously discussed.

It is essential to point out that the results presented here, specifically indoor radon concentrations in two representative kindergartens in Banja Luka, are based on short-term measurements. The average concentration of radon activity is found to be less than 200 Bq/m^3 in both cases. Even the highest measured radon concentration in these two buildings is less than 400 Bq/m^3. Table 3 shows the highest measured concentrations are around 300 Bq/m^3 (slightly lower in the Kolibri), which can be the national reference level for indoor radon concentration according to the EU directive and WHO recommendations, as well as in current Standard EN 16798-1:2019 [17, 18, 6]. However, long-term measurements must be taken since the radon concentration varies with season and weather conditions [30, 31].

The measured mean indoor air temperature in Neven (23.2 °C) is higher than in Kolibri (20.4 °C). Kolibri has a higher average RH of 51.9%, while Neven has 37.4%. These values are within the comfort zone set by BAS EN 16798-1, BAS EN ISO 7730, and ASHRAE 62.1. The measurements showed that the Neven has a higher indoor air temperature, lower RH, higher air infiltration, and lower CO_2 concentration. Kolibri has a lower indoor air temperature, higher RH, lower air infiltration (better sealing), and higher CO_2 concentration. However, the radon concentration is higher in Neven, although the infiltration is better. That leads to the conclusion that the cause might be the geology of the terrain where Neven is located. Still, special attention must also be paid to the built-in construction materials. Natural ventilation is used to ventilate both kindergartens by opening doors and windows and infiltration.

The IAQ measurement is based on indirect ventilation rates in two kindergartens. The ventilation rates measured are 453 L per second for Neven and 249 L per second for Kolibri. According to the standard BAS EN 16798-1, the recommended level of ventilation rate depends on two-components: necessary ventilation for dilution of pollution from users (biowaste) and ventilation for dilution due to emissions from the building and the system.

If it is assumed that the required IAQ category is I, the recommended volume of fresh air is 10 L per second per person and 1.0 L per second for low polluting a building for both kindergartens. The expected percentage of dissatisfied occupants should be less than 15. The standard requires a concentration of 350 ppm CO_2 above external for energy calculation. In this case, it was obtained that the recommended ventilation level is 342 L per second for Neven and 327 L per second for Kolibri. For calculating the recommended ventilation levels, we used as input the following floor areas of investigated rooms in Neven and Kolibri: 62 m^2 and 77 m^2, and the occupancy of 28 and 25 persons. Therefore, using a method based on the person and the building component for the demanding level of ventilation, the conclusion is that the ventilation rate for the new kindergarten (Kolibri) is unsatisfactory. Considering the elevated CO_2 levels in this kindergarten, it is imperative to implement proper ventilation within the space. Additionally, in Standard EN 16798-1:2019 – Annex C, the occupancy parameters for kindergartens are 3.8 m^2 per person, while in Neven, it is 2.21 m^2 per person, and in Kolibri, 3.08 m^2 per person [6]. That indicates that the occupation in the mentioned kindergartens is higher than prescribed in the EU standard.

If it is assumed that the required IAQ is of category II, the recommended amount of air is 7 L per second per person and 0.7 L per second for a low polluting building. Then, the expected percentage of dissatisfied occupants should be below 20. In this case, it was obtained that the recommended ventilation level is 239.4 L per second for Neven and 228.9 L per second for Kolibri. The concentration of CO_2 above the external for the energy calculation is 500 ppm in accordance with the standard. Thus, according to the measured level of ventilation, it can be concluded that both kindergartens are meeting conditions for this category. Although higher infiltration is not good from the point of view of energy consumption, it is more favorable in terms of air comfort and IAQ.

The correlation coefficients between CO_2 and temperature and between CO_2 and RH were calculated for both kindergartens, tab. 6. As seen from the table, correlations are positive, as expected. The correlation between CO_2 and RH in Kolibri is very strong (0.84), which is expected because of its better air tightness.

For comparison, the measurements of CO_2 concentrations in two kindergartens in Slovenia indicated high concentrations during the winter and spring periods, while the mean concentration during the winter in the playrooms was 1708 ppm. Furthermore, most of the measured concentrations (89.3%) in both kindergartens exceeded 1000 ppm, and there was a significant correlation between CO_2 concentration and the number of persons [32]. In four (existing) kindergartens in Poland, concentration values reached even 4500 ppm, and maximum

Table 6. Type of correlation and correlation coefficients between CO_2 and temperature and CO_2 and RH

Correlation coefficient (CO_2-temperature)	Type of correlation	Correlation coefficient (CO_2-RH%)	Type of correlation
Neven			
0.33	Weak positive correlation	0.63	Strong positive correlation
Kolibri			
0.59	Moderate positive correlation	0.84	A very strong positive correlation

values were above 3953 ppm [33]. Increased temperature, compared to recommended values for thermal comfort, was also found, with RH values of 53% during the use of premises [33]. Furthermore, a new study in Slovenia, performed before the COVID-19 Epidemic in 93 kindergarten spaces, showed that the average temperature was 22.6 , while the humidity was 37.1%. Maximum CO_2 concentration in naturally ventilated kindergarten was 3494 ppm, with an average concentration of 1068 ppm. Kindergarten with mechanical ventilation had a maximum CO_2 concentration of 2866 ppm, while the average was 1001 ppm. The values of all quantities during occupancy were lower in mechanically ventilated kindergartens [34].

Conclusions

This research presents the first experimental results of IAQ parameters for kindergartens in the Republic of Srpska. Kindergarten representatives for the year of construction, energy efficiency (Neven-old, energy-inefficient and Kolibri-new, energy-efficient) and building materials have been chosen. Two kindergartens have approximately the same heated volume, the same number of users, and the same average time users spend in the space. Based on the analysis obtained from the experimental results (radon and CO_2 concentration, temperature and RH of the air, and number of air changes per hour) for individual kindergartens with respect to the values prescribed by standards and the comparison of two buildings, few conclusions can be drawn.

- The highest measured radon concentrations are around 300 Bq/m^3 (slightly lower in new kindergarten Kolibri), which can be the national reference level for indoor radon concentration according to the EU directive and WHO recommendations, and in BAS EN 16798-1:2019. The average measured radon concentrations for both buildings have not exceeded the level of 200 Bq/m^3, but for reliable results, long-term measurement needs to be performed.
- The CO_2 concentration in the old kindergarten (Neven) fulfills the BAS EN 16798-1:2019 requirement for category I during 62.43% of total occupancy time, while for the new kindergarten (Kolibri), it is only 5.79% of full occupancy time. Results of CO_2 concentration confirm that good sealing of the envelope of new buildings and user behavior (number of users and natural ventilation) does affect air quality.
- A very strong correlation is found between CO_2 and RH in the new kindergarten Kolibri (0.84), as expected due to its better air tightness. More ventilation in indoor spaces is needed to decrease high CO_2 levels. However, the positive correlation between these parameters indicates that the introduction of outdoor air will reduce not only the CO_2 level but also the temperature and humidity of the indoor space, which can be problematic from the aspect of thermal comfort and in the case of old kindergarten Neven it will lead to a decrease in RH below 30%, and in case of new kindergarten Kolibri, temperature reduction below 19 °C.

- Using a method based on the person and the building component for the demanding level of ventilation, the conclusion is that the ventilation rate for the new kindergarten Kolibri is 453 L per second and unsatisfactory for building category I with respect to the requirement of 327 L per second set by standard BAS EN 16798-1:2019.

Enhancing air quality in kindergartens entails reducing the number of users per unit of surface area and promoting appropriate user behavior, particularly emphasizing natural ventilation, like periodic short-term cross ventilation. The final conclusion is that more attention has to be paid to kindergartens concerning the IAQ requirements and additional studies, including longer-term measurements (monitoring) of air quality parameters in the space itself and the vicinity of the kindergarten.

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