IN-SITU MEASURING INDOOR ENVIRONMENTAL QUALITY IN PUBLIC KINDERGARTEN IN SLOVENIA. A CASE STUDY

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ABSTRACT

The number of children in Slovenia, who are enrolled in kindergartens, is increasing, however, the indoor environmental quality (IEQ) in kindergartens remains poorly investigated. Younger children are a vulnerable population, so the IEQ is extremely important for their well-being and growth. Therefore, it is essential to investigate and evaluate indoor conditions of kindergartens.

This study presents the results of the IEQ assessment based on objective evaluation by monitoring crucial indoor conditions in the public kindergarten located within a residential area in the city of Maribor, Slovenia. The research includes *in-situ* measurements in the kindergarten classroom during the heating season. Selected comfort parameters were simultaneously measured and investigated: the concentrations of carbon dioxide (CO_2), air temperature and air humidity. Measurements were taken continuously during a period of twelve days. Besides monitoring, other analyses were conducted: the building thermal envelope, building construction, building site and environment, heating, occupant`s behaviour, etc.

The purpose of this study is to investigate and analyse elements of IEQ in the chosen kindergarten. Moreover, the aim is to investigate whether selected comfort parameters fulfil the requirements of regulations and standards for the kindergartens. The goal is also to analyse the occupant's behaviour and to study its relation to the IEQ pattern during the day and among working and non-working days. The results clearly indicate periods of high air temperature, dry air and high level of CO_2, therefore measures for improvement of IEQ elements are discussed.

KEYWORDS _ *Indoor Environmental Quality (IEQ), kindergarten, in-situ measurements*

INTRODUCTION

The environment, where children live, grow and learn, plays an important role in their growth and development. Most of the children in Slovenia spend their early childhood in kindergartens; statistical data of the Republic of Slovenia show that 81.7% of all children aged between 1 and 5 are enrolled in kindergartens [14].

A kindergarten presents the child's physical, biological and social environment. Children daily spend approximately 9 hours in an educational institution, therefore it is important that this does not present the health hazard for them. Poor quality of the indoor environment in the kindergartens can negatively affect the comfort and health of the users – children as well as employees [6]. Numerous studies of educational institutions in Slovenia and worldwide have exposed the problem of thermal discomfort [3], light discomfort [5], poor quality of the indoor air [16], and acoustic discomfort [8]. However, the topic of pre-school buildings in Slovenia is poorly researched, there is a lack of studies with continuous in situ measurements of the parameters of the indoor comfort in the rooms, where children spend lots of their time.
This research aims to evaluate parameters of the Indoor Environment Quality (IEQ) in the playroom of the chosen kindergarten in Maribor, Slovenia. The estimation includes the analysis of the single parameters of the thermal comfort and the quality of the indoor air based on the results of the in situ measurements in the kindergarten playroom. The goal is to determine each parameter of thermal comfort and the quality of the indoor air in the playroom and to compare the results with applicable legislation and standards. Potential deficiencies in the quality of the indoor living environment will result in the definition of the problems and the suggestion for possible improvements.

IEQ PARAMETERS – APPLICABLE LEGISLATION AND RECOMMENDATIONS

The appropriate Indoor Environment Quality (IEQ) is guaranteed by suitable thermal comfort, proper air quality (IAQ), light and acoustic comfort. Thus, IEQ is very complex and depends on numerous interdependent parameters and tremendously affects health and well-being of people, especially children. Namely, children's respiratory and immune system is much more sensitive than the adult system, so children are very sensible to the environmental influences. Therefore, the IEQ is even more important in pre-school buildings. This research includes determination of the optimal value of each parameter of thermal comfort and air quality according to critical assessment of applicable legislation, recommendations and previous studies considering the pre-school buildings. Comparison with the measured values would be also conducted.

Thermal comfort

The assessment of the thermal comfort includes continuous measurements of the indoor air temperature Tai [°C] and relative air humidity RHai [%] in the playroom of the kindergarten. Previous studies show that poor thermal conditions in the room negatively affect children's health, well-being and ability to learn [2]. In addition, children are more sensitive to high air temperatures than adults and also to changes in thermal comfort which impact their metabolism [16].
Indoor air temperature Tai [°C] in the kindergartens is determined in Slovenia by Rules of standards and minimal technical conditions for kindergarten premises and equipment which prescribe minimum air temperature 20 °C, but do not limit maximal air temperature [11]. Regulations about air conditioning in building determine the parameter for the thermal comfort of the sitting person in the living area which includes the air temperature in heating season between 19 °C and 24 °C, although recommended temperature is 20 °C to 22 °C [12]. In addition, regulations define the surface temperature of the floor between 17 °C and 26 °C. However, numerous studies recommend the air temperature in kindergartens 21 °C and point out that children feel more comfortable at lower temperatures.
Relative air humidity RHai [%] in pre-school buildings is also determined by Regulation of standards and minimal technical conditions for kindergarten premises and equipment [11], which declares that the area of ventilation and its parameters is determined by applicable technical standards, i.e. with Rules on ventilation and air conditioning of buildings, which define that the air temperature between 20 °C and 26 °C requires relative humidity between 30 % in 70 % [12]. Moreover, the Rules define the necessary additional mechanical ventilation in the changing rooms and toilets for kids. The ideal air humidity in the rooms, where children stay during the day, is between 45 and 55 % at a suitable air

temperature between 20 in 22 °C [10].

Air quality

One of the basic parameters which indicates the poor air quality is carbon dioxide concentration (CO_2) in the air. The most CO_2 in the room is produced by the human breathing, therefore is the number of occupants and their activities a key factor for CO_2 concentration. In proportion to their weight, children breath larger air volume than adults; besides a playroom is occupied by higher concentration of occupants comparing to office for example, so the indoor air pollutants accumulate much faster [9]. In addition to human factor (breathing), the factors which also impact the concentration of CO_2 in the scientific literature are: ventilation equipment, furniture and activities in a room (the number of occupants and activities).

The Rules on ventilation and air conditioning of buildings of the Republic of Slovenia determines value 1660 ppm as the maximal allowed CO_2 indoor concentration [2]. According to the recommendations of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the acceptable CO_2 concentration level depend on outdoor CO_2 concentration [1]. The difference between indoor and outdoor CO_2 concentration should not exceed 700ppm. Assuming that the average CO_2 concentration values in the outdoor air are 400 ppm, the indoor CO_2 concentration values should be under 1100 ppm. In this respect, the ASHRAE recommendations are much stricter than Slovene Rules.

IEQ parameters – impact on human health and well-being

The inappropriate indoor air temperature and humidity is especially dangerous for the vulnerable group such as small children. The indoor air temperature is analysed in the heating season and depends on the heating regime, while the indoor air humidity is influenced by user activity, their living habits and the frequency of room ventilation. The consequences of insufficient air humidity control and high air humidity are good conditions for mould growth and development which negative health influence is proved [17]. On the other hand, the consequences of the dry air can be dried mucous membranes, lips, skin and scalp, increasing infections and respiratory illness, tension, tiredness and lack of concentration.

The impact of CO_2 on health and well-being of occupants is the subject of many international studies. The exposure to higher concentrations of carbon dioxide could results in many different symptoms such as cold, eye irritation, dry mucous membrane, headache, dry skin and lethargy (a pathological state of sleepiness). The normal outdoor CO_2 concentration is between 250–350 ppm, whereas the indoor CO_2 concentration with effective ventilation should be between 350–1000 ppm. The indoor air CO_2 concentration higher than 1000 ppm can result in potential complaints of sleepiness and poor air quality, while the indoor CO_2 concentration above 2000 ppm indicates the used, stuffy air. This can cause headaches, sleepiness, insufficient concentration, lack of focus, accelerated heart rate and slight nausea [18]. In addition to acute health problems, the increased CO_2 concentration can mean higher risk for different respiratory diseases. The studies show that children in kindergartens are subjected to higher risk for asthma and allergy problems in comparison with children who do not attend kindergartens [14].

In addition, high CO_2 concentration can be an indicator of the presence of other pollutants in the air such as carbon monoxide and formaldehyde which can negatively impact respiratory organs [1]. Occurrence of the most chemical and biological pollutants can hurt respiratory organs, especially children's, who are more sensitive due to undeveloped immune system [13]. The other air pollutants are not the subject of this research; however, their presence is indicated if there is highly increased measured CO_2 concentration in the playroom of the kindergartens.

A CASE STUDY

The building of the chosen kindergarten was constructed in 1981. It is located in a peaceful residential neighbourhood. In terms of design, architecture and structure, it composes a whole with a block of flats, which was built at the same time. The kindergarten is built in a massive structural system; the area of the kindergarten is 3217 m², it includes basement, ground floor and two floors. The kindergarten homes 17 groups (playrooms). The service facilities (kitchen, storage, etc.) are in the basement. The building has a remote heating, regulated according to the outdoor air temperature. Two radiators are placed directly under the window in the playroom. During the heating season, the heating is not turning off, the temperature in the system gets lower.
The measurements in this research were performed in the south oriented playroom on the ground floor of the building. During the measuring period, a mixed group of children, aged 1 to 3, occupied the playroom. The number of children enrolled in group is 14 and two educators (during the working days among the holidays, the maximal number of children were exceeded due to a technical reason; playroom was occupied by 15 children). The playroom is mostly in its original state from 1981, the majority of the built-in furniture is also from 1981, with an exception of some pieces of movable furniture. The original windows are replaced by the double-glazed PVC windows. The hard wood floor is original. The playroom area is 47.3 m² without associated sanitary facilities, the playroom volume is 104.06 m³, its orientation is south. The windows are shaded by exterior blinds and decorative curtains inside. The playroom does not have air conditioners. The ventilation is only natural by opening windows, without ventilations system (Figure 1).

_ Figure 1: The playroom

The chosen playroom presents a typical playroom in a Slovene kindergarten, built in the decade between 1970 and 1980, when the majority of the pre-school buildings was erected. In terms of energy renovation, the only intervention was the windows replacement, which is the most common intervention on the most of the buildings from this period. Therefore, the case study can indicate the current thermal comfort and indoor air quality state of the Slovene pre-school buildings in general.

MEASUREMENTS IN SITU

The experimental analysis of the IEQ included continuous in situ measurements of the chosen parameters of thermal comfort and indoor air quality. In terms of thermal comfort, the measurements of the indoor air temperature Tai [°C], relative indoor air humidity RHai [%] and surface temperature

of the floor Tsurf [C°] were carried out. The measured parameter of the indoor air quality was the carbon dioxide concentration CO2 [ppm]. The light and acoustic comfort in the playroom are not the subject of this research.
The measurements in situ were performed continuously for 15 days. The chosen period included working days, weekends and holidays during the heating season. The winter was chosen for the measurements because of the increased indoor air pollution and high concentration of the harmful substances in the air, due to the structure seal and low level of ventilation [7]. The number of present children and their activities in the playroom were daily recorded as well as the ventilation intervals. The playroom was occupied each working day from 5:00 am to 3:30 pm. During the day the average ventilation lasted from 10 to 20 minutes three times a day, the dynamics and intensity of ventilation was chosen by the educators. Namely, they noticed that the room was too warm. During the measurements the daily range of outside air temperatures was from -8°C up to 15°C.
The location and height of the measurement devices were tailored according to the activities of the playroom occupants. The obstacle in the measurement process was the fact that the playroom was used by toddlers, so the devices should not present the potential dangerous and at the same time the devices should be secured or hidden so that children could not jeopardize the measurement procedures. The main device was situated on the shelf above the educator's desk at the height of 1.5m. The devices recorded the data every fifteen minutes. The following measurement devices were used: the data logger rotatronic CL 11 was used for Tai, RHai and CO2 measurements, the additional devices volcraft were installed for Tai, RHai measurements and the belmet flir mr 77 was used for Tsurf measurements. The aim of multi measurement devices was the comparison of result deviations and monitoring of parameters of indoor comfort in different specific points in the playroom: room for nursing, sleeping, staying, etc. The measurements were carried out in the frame of the research project VRTEC+, which included measurements in pre-school buildings throughout Slovenia.

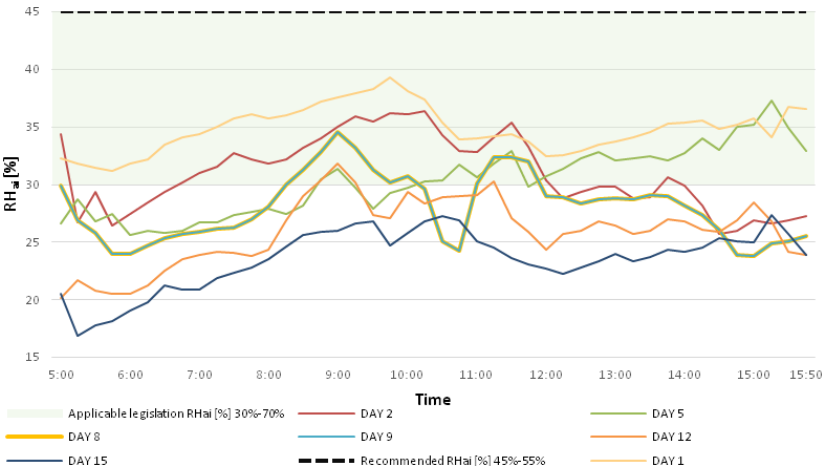
RESULS

Measurement results of the Tai, RHai and CO2 are shown in Table 1. Minimal, maximal and average values of all measurement points are displayed for the period when occupants were in the playroom, daily from 5.00 am to 3.30 pm. The recorded measurement points during the time when the playroom was closed, was not considered (Day 3,4,6,7,10,11,13,14 in table). The register of the number of present children and also two educators, who were present every day, was kept on a daily basis.

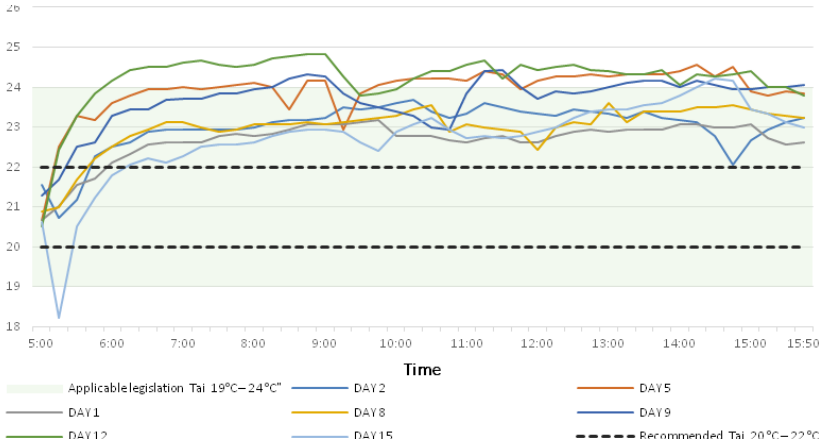
_ Table 1: Measured data

	No. of occupants	RH_{ai} [%]			T_{ai} [°C]			CO_2 [ppm]		
		min	max	avg	min	max	avg	min	max	avg
Day 1	7	31.2	39.3	35.1	21.7	23.2	22.7	499	1524	1027.7
Day 2	10	25.7	36.4	30.9	20.3	23.6	22.9	469	1807	1029.0
Day 3	/									
Day 4	/									
Day 5	10	25.6	37.3	30.3	20.7	24.6	23.9	472	1687	1087.2
Day 6	/									
Day 7	/									
Day 8	15	21.8	37.2	26.8	20.9	23.6	22.9	461	2452	1112.3
Day 9	15	23.8	34.6	28.1	21.3	24.4	23.7	496	2035	1095.3
Day 10	/									
Day 11	/									
Day 12	14	20.2	27.4	25.9	20.5	24.83	24.2	457	2009	1112.0
Day 13	/									
Day 14	/									
Day 15	15	16.9	27.4	23.6	18.2	24.2	22.7	410	1536	1008.0

The measured results of the air humidity RHai [%] show rather dry air with the average values between 25.9 to 35.1%, although within the range of applicable legislation demands. Not even one measurement point reached recommended values from 45 to 55%. Therefore, the children stayed in considerably dry rooms (Figure 1).
The average measured air temperature Tai [°C] is between 22.7 to 23.9 ° C, which meets the recommended values. Also all single measurement points are between 19° C and 24° C. Therefore, the indoor air temperature also meets the applicable legislation demands. Overall indoor air temperature in playroom is a bit higher compared to international standards, health recommendations and recommendations of the previous studies which consider the optimal air temperature 22 °C (Figure 3).



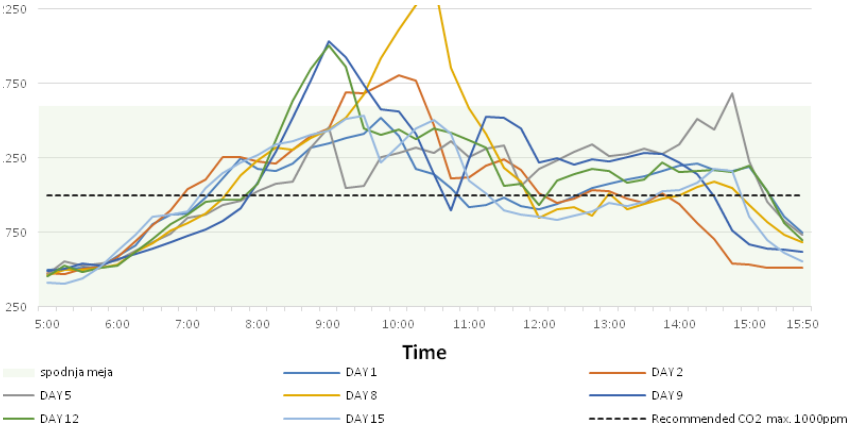
_ Figure 2: Chart, relative air humidity



_ Figure 3: Chart, air temperature

The average concentration of carbon dioxide CO2 [ppm] exceeds recommended value of maximum 1000ppm every day. Maximal measured values were over 2000ppm. On average, the children are exposed to the carbon dioxide concentration over 1000ppm (Figure 4) more than half a time spent in the kindergarten. Even though this concentration is in line with Slovene legislation, it exceeds recommendations of health organizations, previous studies, etc. This analysis takes into consider-

ation the time of the actual presence of children in the playroom. The days when the playroom was occupied 50 to 70% (7 and 10 toddlers), the children were exposed to the CO2 concentration over 1000ppm more than 1/3 of the time spent in kindergarten. Moreover, the children spent almost 2/3 of their time in kindergarten exposed to the carbon dioxide concentration over 2000 ppm during the days when the playroom was occupied 100 to 110% (14 and 15 toddlers).



_ Figure 4: Chart, carbon dioxide concentration in the air

The kept record of activities in the group show that the playroom is ventilated three times a day, according to the activities in the kindergarten: before the children entered the playroom (at about 5:00 am), during the time when the children have outdoor activities and the playroom is empty (between 10:00 and 11:00 am) and after the lunch. The measurements show that natural ventilation in the playroom reduce the CO2 concentration for short time, but it does not achieve the desired level of CO2. The analysis of the measured parameters proves that the CO2 concentration in the air decreases rapidly even with the lower number of the occupants in the playroom. The interaction between different parameters of indoor comfort is hard to define, however, it can be concluded that the CO2 concentration in the air depends on the number of users and it is dramatically increased with the higher number of children. Additionally, this study measures floor surface temperature Tsurf [°C]. The average measured value of the floor temperature is 24.1 C° which corresponds the provisions of the Rules on ventilation and air conditioning of buildings which define the floor temperature between 17 °C and 26 °C.

CONCLUSIONS

This study analysed elements of IEQ in the chosen kindergarten. Particularly the research deals with indoor air quality and thermal comfort parameters in the kindergarten, which in terms of quality of the indoor living comfort fall into a rather unexplored area. Although studies include analysis of the indoor comfort in kindergartens, they mostly discuss the temperature and the quality of the indoor air in general, whereas continuous measurement for a longer period of time, such as those in this research, can hardly be found.

The parameters of indoor air quality and thermal comfort in the chosen playroom of the kindergarten in Maribor is evaluated according to the legislation and recommendations. The comparison of the measured parameters with the demanded values of the Slovene legislation shows that the indoor air temperature meets prescribed values, while the carbon dioxide concentration in periods during the day exceeds prescribed value and relative air humidity mostly does not achieve the prescribed range value. Moreover, the comparison of the measured parameters with recommendations of health or-

ganisations, previous studies and international standards leads to the conclusion that the majority of measured values do not meet the recommended values and the indoor environmental quality can be evaluated as poor according to the measured parameters. It can be concluded that the legislation of the Republic of Slovenia is quite insufficient in terms of thermal comfort and indoor air quality in educational, nursery and preschool education. The parameters in the current legislations are determined by general provisions which often do not consider problems of the rooms occupied by children and are less strict than numerous international recommendations.
The results clearly indicate periods of high air temperature, dry air and high level of CO2. According to the analyses in this case study, the biggest problem is dry air and increased CO2 concentration for longer periods of time in the heating season. Based on measurements from this research, the natural ventilation of the room is not sufficient to assure quality of the indoor environmental comfort and should be improved. Improvement should be provided by intensive natural ventilation or with providing additional mechanical systems for ventilation. However, natural room ventilation in winter is aimed only for assuring fresh air, and it is not the way to increase the air humidity. The intensive heating of the playroom results in dry air and overheated playroom, therefore also better control over heating system is recommended.

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