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Indoor environmental quality (IEQ) in Slovenian children daycare centres. Part I: Results of in-situ measurements

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ABSTRACT
The number of children enrolled in daycare centres is increasing, while indoor environmental quality of Slovenian children daycare centres remains insufficiently investigated. The purpose of this paper, as Part I of the larger study "Indoor environmental quality (IEQ) in Slovenian children daycare centres", was to holistically assess indoor environmental quality of 24 playrooms in 17 publicly funded children daycare centres in Slovenia. The performed holistic assessment included simultaneous in-situ measurements of the selected comfort parameters (i.e. indoor air quality, thermal, visual and acoustic comfort), which were compared with legal requirements and recommendations. The results of in-situ measurements showed that the most critical field was the indoor air quality (in 63% of playrooms $cCO_{2i,avg}$ >1667 ppm) and that the indoor environmental quality conditions met all of the legal requirements and recommendations only in 8% of the investigated playrooms. In general, if compared to other EU countries, the conditions in Slovenian facilities were slightly worse. Therefore, a holistic approach to the assessment of indoor environmental quality is vital to achieve a universally comfortable and healthy indoor environment. Part II of this study presents further investigation of interrelationship between different building characteristics and IEQ.

Key words: indoor environmental quality, in-situ measurements, comfort, public buildings, daycare centres

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INTRODUCTION

The statistical data of EU over the last decade show that the amount of enrolled children in children daycare centres (DCCs) has increased [1], while in Slovenia almost 77% (84750) of children aged one to five were enrolled in DCCs in September 2014 [2]. As the number of children enrolled in Early Childhood Education and Care (ECEC) is high and seems to be increasing, it is essential that child's stay in an educational institution is comfortable and without adverse health effects [3–12], especially due to the fact that children are more susceptible to environmental influences, thus being a vulnerable population with particularly higher risk of adverse health effects.

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Therefore, besides executing field measurements of IEQ parameters in the selected DCCs, one of the goals of our study was also to get a bigger picture in the field of IEQ in DCCs. We were particularly interested in existing studies in the field of IEQ all across the Europe and wider. In order to analyse the state-of-the-art in the field of IEQ in educational building facilities, a comprehensive literature review was carried out. Table 1 represents study summary of 24 selected research papers dealing with indoor environment quality in buildings intended for education (e.g. DCCs, schools).

Among the referenced studies (Table 1), the most investigated indoor comfort field is IAQ, while the least investigated is visual comfort. Thermal comfort [12–15], indoor air quality (IAQ) [4, 7, 10, 16–23, 30–32], visual comfort [5, 6, 8] or acoustic comfort [3, 25–27] and/or their impact on human health is relatively well investigated either in DCCs or in schools. In many cases studies identified the conditions as inadequate and hazardous for children. Cano et al., Teli et al. [11] and De Giuli et al. [29] presented a wider aspect as they investigated two IEQ fields, for example, by taking into account thermal comfort and indoor air quality at the same time. Very few studies of IEQ were made in Slovenian DCCs, mostly focusing only on acoustic comfort, for example a study made by Kacjan Žgajnar et al. [25]. In addition, the literature review showed that there is no such study, which would simultaneously consider all of the four comfort fields (i.e. thermal, visual, acoustic comfort and IAQ).

Table 1: An overview of the selected reviewed research papers

Comfort field	Author (year)	Location	Study area	Study population	Study parameters
Thermal comfort	Fabbri (2013) [13]	Italy, Reggio Emilia, N = 1 DCC	Thermal comfort (PMV, PPD)	Playrooms with 4–5 year old children	T_{ai}, RH_{ai}, v_{ai}, T_{mr}, ***PMV, PPD***
	Hwang et al. (2009) [14]	Taiwan, N = 14 schools	Thermal comfort (TSV)	Children 12–17 years old	***TSV***
	Mors et al. (2011) [15]	Netherlands, Eindhoven, N = 3 schools	Thermal comfort (PMV, TSV)	Classrooms with 9–11 years old children	T_{ai}, RH_{ai}, v_{ai}, T_{mr}, ***PMV, TSV***
	Yun et al. (2014) [12]	S. Korea, Seoul, N = 10 DCCs	Thermal comfort (PMV)	Naturally ventilated playrooms with children 4–6 years old	T_{ai}, RH_{ai}, v_{ai}, T_{mr}, ***PMV***

Comfort field	Author (year)	Location	Study area	Study population	Study parameters
Indoor air quality	Araújo-Martins et al. (2014) [16]	Portugal, Lisbon and Porto, N = 45 DCCs	IAQ and health	Playrooms with 3 months to 6 year old children	**cCO_{2i}, biological and chemical hazards, T_{ai}, RH_{ai}**
	Cars et al. (1992) [17]	Sweden, Teleborg (Växjö), N = 7 DCCs	Infectious diseases and IAQ	Playrooms in DCCs and in renovated dwellings	**cCO_{2i}, absence due to an infectious disease**
	Daneault et al. (1992) [18]	Canada, Montreal, N = 91 DCCs	IAQ	Randomly selected playrooms	**cCO_{2i}, T_{ai}, RH_{ai}**
	Gładyszewska-Fiedoruk (2013) [19]	Poland, Białystok, N = 3 DCCs	Correlation between IAQ and RH	Playrooms with 3–6 year old children	**cCO_{2i}, T_{ai}, RH_{ai}**
	Roda et al. (2011) [20]	France, Paris, N = 28 DCCs	IAQ	Playrooms with toddlers	**cCO_{2i}, biological and chemical hazards, T_{ai}, RH_{ai}**
	Ruotsalainen and Jaakkola (1993) [21]	Finland, Espoo, N = 30 DCCs	IAQ	Old and new playrooms	**cCO_{2i}, ventilation rate, chemical hazards, odours, T_{ai}, RH_{ai},**
	St-Jean et al. (2012) [10]	Canada, Montreal, N = 21 DCCs	IAQ	Playrooms with a capacity of at least 40 children	**cCO_{2i}, chemical hazards, T_{ai}, RH_{ai}**
	Stankeviča and Lešinskis (2012) [22]	Latvia, Riga, N = 6 DCCs	IAQ	Playrooms in old, new and renovated DCCs	**cCO_{2i}, T_{ai}, RH_{ai}**
	Zuraimi et al. (2008) [23]	Singapore, N = 104 DCCs	IAQ of DCCs in tropical climate	Randomly selected playrooms	**cCO_{2i}, cCO_i, T_{ai}, RH_{ai}, v_{ai}, biological hazards**
Visual comfort	Hathaway et al. (1992) [5]	Canada, schools	Impact of artificial and natural light on children	Children in classrooms with artificial or natural daylight	**Performance and health analysis of children**
	Heschong Mahone Group (1999) [6]	USA, California, N = 3 schools	Impact of daylight on children	Children in well and under-lit classrooms	**Performance analysis of children**
	Nicklas and Bailey (1997) [8]	USA, N. Carolina, N = 5 schools	Impact of daylight on children	Children in well and under-lit classrooms	**Performance analysis of children**
Acoustic comfort	Chatzakis et al. (2014) [3]	Greece, Crete, Heraklion, N = 10 DCCs	Noise level	18 playrooms	**L_{eqi}, impact of noise on health**
	Kacjan Žgajnar et al. (2009) [24]	Slovenia, Ljubljana, N = 3 DCCs	Noise level in the workplace	Educators in playrooms intended for children between 3 and 6 years old	**L_{eqi}, impact of noise on health of educators**
	Kacjan Žgajnar et al. (2009) [25]	Slovenia, Ljubljana, N = 3 DCCs	Noise level in playrooms	Playrooms intended for children between 3 and 6 years old	**L_{eqi}, impact of noise on health**
	McAllister et al. (2009) [26]	Sweden, Linköping, N = 3 DCCs	Noise level in playrooms	10 children without reported hearing problems	**L_{eqi}, impact of noise on health**
	Sjödin et al. (2012) [27]	Sweden, Umeå, N = 17 DCCs	Noise level in the workplace	Educators	**impact of noise on health**
Multiple comfort analysis	Cano et al. (2012) [28]	Portugal, Lisbon, N = 19 DCCs	IAQ and thermal comfort	125 playrooms intended for children old between 3 months and 6 years	**T_{ai}, RH_{ai}, v_{ai}, T_{mr}, cCO_{2i}, cCO_i, biological and chemical hazards**
	De Giuli et al. (2014) [29]	Italy, Padua, N = 3 schools	IAQ, thermal comfort and visual comfort	8 classrooms in primary schools	**T_{ai}, RH_{ai}, v_{ai}, T_o, PMV, PPD, cCO_{2i}, E_i**
	Teli et al. (2012) [11]	England, Hampshire, N = 1 school	IAQ and thermal comfort	Classrooms with children between 7 and 11 years old	**T_{ai}, RH_{ai}, v_{ai}, T_{mr}, *PMV*, *PPD*, *TSV*, cCO_{2i}**

T_{ai} – indoor air temperature; RH_{ai} – indoor air relative humidity; v_{ai} – indoor air velocity; T_{mr} – mean radiant temperature; T_o – operative temperature; *PMV* – predicted mean vote index; *PPD* – predicted percentage of dissatisfied; *TSV* – thermal sensation vote; cCO_{2i} – indoor concentration of carbon dioxide; cCO_i – indoor concentration of carbon oxide; L_{eqi} – indoor equivalent noise level; E_i – daylight illuminance of work plane

Therefore, it can be concluded that these four areas of comfort in DCCs are not treated equally, as some are represented in the research less often than others. In this respect, in recent years the importance of high quality ECEC is reflected in a high volume of joint reflection on policies and programmes between the European Commission and the Member States [33]. As can be seen, the IEQ of children daycare centres as well as other educational institutions was relatively well investigated throughout the facilities across the EU and wider, which was found out through the review of the published papers. Surprisingly, the quality of indoor environment in Slovenian DCCs has not been sufficiently investigated. Consequently, the objective of our study was to examine the situation in Slovenian DCCs from the IEQ perspective. Therefore, measurements of selected parameters of visual, thermal and acoustic comfort, as well as indoor air quality were carried out. Several playrooms were sampled from the selected DCCs in Slovenia in order to execute in-situ measurements of the selected comfort parameters. Hence, the above mentioned factors affecting human comfort in buildings were investigated in 24 playrooms in 17 DCCs. The study took place from March to June 2013. The indoor environment was investigated in order to improve IEQ conditions in DCCs. The latter was done by examining minimal criteria according to national and EU legal requirements, applicable recommendations or standards.

METHODS

Area and time of observation

The research was carried out in 17 randomly selected children daycare centres (anonymised and denominated by letters A–R) located in Slovenia, which included 24 playrooms intended for children aged 3 to 5. The research took place at targeted DCCs from March to June 2013. The conducted research protocol is presented in Figure 1.

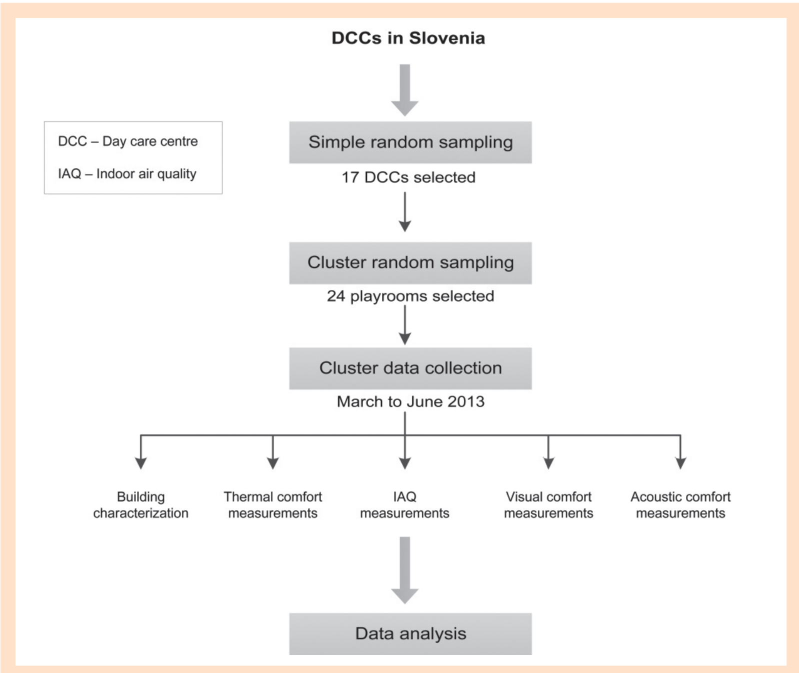

Figure 1:
Research protocol

Measurements

The required data were collected in-situ in the selected DCCs by researchers conducting measurements of the studied parameters. Measurements took place in forenoon, particularly between 9 and 12 am (i.e. after breakfast and before lunch) in occupied playrooms. Holistic evaluation of IEQ included the following measurements. Indoor air temperature (T_{ai}), indoor air relative humidity (RH_{ai}), indoor air velocity (v_{ai}) and surface temperature (T_{surf}) were measured to evaluate thermal comfort of the investigated playrooms. Field technicians measured daylight illuminance of work plane (E_i) and window glass light transmittance (LT) as the selected visual comfort parameters. To evaluate the IAQ, indoor concentration of carbon dioxide (cCO_{2i}) was measured. Indoor equivalent noise level (L_{eqi}) was the selected and measured parameter of acoustic comfort. In addition, two selected outdoor parameters were measured: outdoor noise level (L_{eqe}) and outdoor concentration of carbon dioxide (cCO_{2e}). For the purpose of the study the following measurement equipment was used: Testo 445 (T_{ai}, RH_{ai}, v_{ai}), Testo 535 (cCO_{2i}, cCO_{2e}), Raytek Raynger MX (T_{surf}) and Voltcraft DT 8820 (L_{eqi}, L_{eqe}, E_i). Outdoor air temperature (T_{ae}), relative humidity of outdoor air (RH_{ae}) and air velocity (v_{ae}) were provided by Slovenian Environment Agency [34].

All the selected indoor parameters were recorded every 20 minutes, with the exception of carbon dioxide concentration, which was recorded every 5 minutes. Measuring instruments were placed out of children's reach. A typical selection and position of measuring points is presented on a floor plan of playroom A1 (Figure 2).

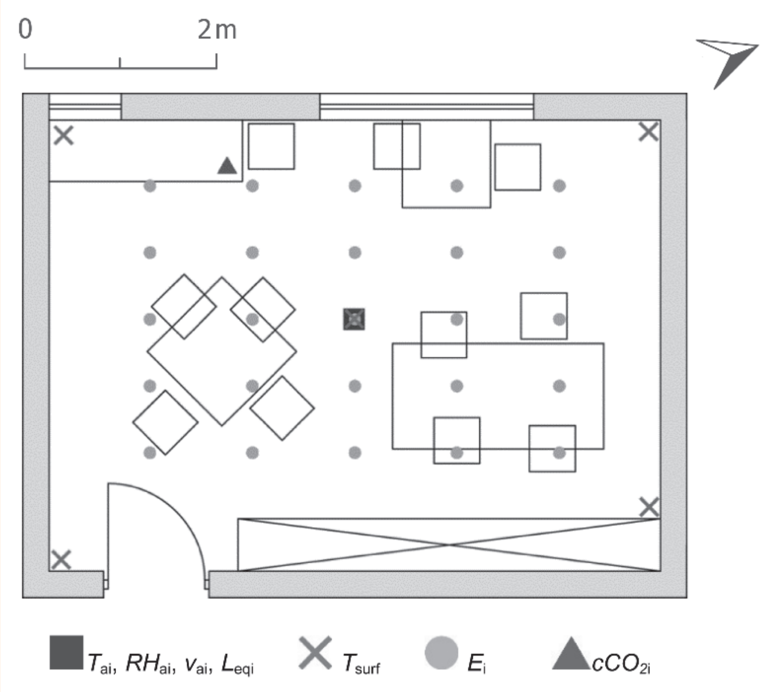

Figure 2: Measurement points in playroom A1

All of the measurements were taken at a height of 0.70 m above the floor, with the exception of surface temperature measurements, which were taken on all the circumferential surfaces. Although the work plane for horizontal illuminance measurements in DCCs should be positioned lower than at 0.70 m above the floor, this distance was nevertheless used in order to prevent inquisitive children interfering with the measurements. However, presuming that the illuminance at lower work planes is higher than at 0.70 m, the measurements are on the safe side. Measurements of daylight illuminance were performed for the actual state of playrooms – positions of furniture and shading systems were preserved. All the sources of artificial light were turned off. Indoor environment conditions were evaluated and compared to legal requirements and recommendations for DCCs, defined in the following documents:

- Slovenian national legislation: O.J. RS, No. 42/02, 105/02 [35]; O.J. RS, No. 73/00, 75/05, 33/08, 126/08, 47/10, 47/13 [36]; O.J.RS, No.17/06, 18/06 – ed., 43/11 – ZVZD-1[37];
- Slovenian national guidelines: TSG-1-005:2012 [38];
- International standards and recommendations: ANSI/ASHRAE Standard 62.1-2007 [39]; CEN CR 1752:2001[40]; EN 12464-1:2011[41]; EN 15251:2010[42]; ISO 7730:2005 [43].

Preparation of data

All the required data were collected and prepared for further investigation. The dimensions (i.e. floor space, height, window openings) and orientation of the DCC playrooms were recorded by the field technicians. DCC managers provided information regarding lists of children present in the analysed playrooms and the age of buildings. For the purpose of evaluating indoor environmental quality, additional calculations of playroom floor area per occupant, playroom volume, mean radiant temperature (T_{mr}), predicted mean vote index (PMV), predicted percentage of dissatisfied (PPD), window to floor ratio (WFR), illuminance uniformity (i.e. $E_{i,min}$/ $E_{i,avg}$ and $E_{i,avg}$/ $E_{i,max}$) and percentage of dissatisfied with the air quality (PPD_{IAQ}) were made. Thermal comfort parameters were calculated according to ISO 7730:2005. The calculation of PPD_{IAQ} parameters was performed with the use of Equation 1 based on CEN CR 1752:2001.

$$PPD_{IAQ} = 395^{(-15.15(cCO_{2i,avg} - cCO_{2e})^{-0.25})} \quad (1)$$

RESULTS

Sample building characteristics

For the purpose of further analysis, in initial step sample building characteristics were investigated, as one of the potential factors that could affect IEQ. All of the investigated DCCs were publicly funded; none of them was privately run. In 2013 the average age of the selected buildings was 43 years, with the average year of construction 1970. The oldest building in the entire sample was constructed in 1899, as a residential villa; the newest was constructed in 2013 as a low-energy children daycare centre. Eight out of seventeen buildings were recently renovated with the aim to lower their energy demand. All of the DCCs were renovated only by replacing windows. Playrooms in every DCC were naturally ventilated, with the exception of DCCs P and R, which were ventilated mechanically. The latter DCCs were also classified as low-energy buildings and were at the same time the youngest buildings (Table 2) included in the study. The average floor area of the selected playrooms was 41.3 m^2 and the average volume 132.2 m^3. The average floor area per occupant was 2.2 m^2. Only minority of playrooms (17%) had the average floor space equal to or higher than what is required by the Slovenian legislation (i.e., at least 3 m^2/child) [36]. None of the investigated playrooms had north orientation, with most of them (i.e. 9) oriented south. Basic information and building characteristics of each selected DCC facility are presented in Table 2.

Table 2: Basic information and building characteristics of the selected DCCs

Daycare centre	Year of construction	Recent renovation[b]	Playroom No.	Playroom occupation (children + staff)	Floor area [m^2]	Floor area per occupant [m^2/occ]	Volume [m^3]	Area of windows [m^2]	Orientation of majority of windows, azimuth [°]
A	1952	Yes	A1	14 + 2	35.7	2.2	102.2	7.3	W, 290
			A2	20 + 2	35.8	1.6	112.2	10.3	W, 290
B	1979	Yes	B1	19 + 2	52.7	2.5	155.5	16.8	W, 292
C	1899	Yes	C1	14 + 2	35.2	2.2	131.5	11.5	E, 100
D	1963	No	D1	18 + 2	44.6	2.2	161.1	20.8	NW, 310
			D2	16 + 3	37.2	2.0	116.8	15.5	S, 178
			D3	16 + 1	46.9	2.8	142.6	13.8	SE, 130
E	1906	No	E1	14 + 2	36.3	2.3	127.4	3.3	W, 275
F	1979	No	F1	19 + 3	39.0	1.8	116.5	14.8	E, 100
G	1979	Yes	G1	14 + 2	41.9	2.6	151.7	10.0	S, 160
			G2	14 + 2	36.0	2.3	164.2	13.1	SE, 150
H	1976	Yes	H1	16 + 2	44.6	2.5	133.8	16.7	SW, 210
I	1973	Yes	I1	18 + 2	43.7	2.2	128.6	15.0	SE, 142
J	1982	No	J1	20 + 2	33.8	1.5	113.3	11.5	SE, 128
			J2	15 + 2	32.9	1.9	111.0	11.8	S, 149
K	1976	Yes	K1	18 + 2	38.2	1.9	99.4	10.7	E, 80
			K2	21 + 2	46.8	2.0	145.9	13.4	SE, 128
L	1976	No	L1	20 + 2	41.0	1.9	132.8	18.4	S, 172
M	1979	No	M1	14 + 3	42.4	2.5	122.1	9.9	SW, 220
N	1971	No	N1	17 + 2	50.3	2.6	174.5	21.5	S, 180
O	1972	Yes	O1	13 + 2	44.7	3.0	134.1	11.6	S, 200
			O2	17 + 2	49.1	2.6	146.3	13.2	S, 158
P[a]	2013	No	P1	21 + 2	39.2	1.7	118.0	17.3	S, 178
R[a]	2012	No	R1	17 + 2	43.6	2.3	132.2	15.4	S, 164

[a] Low-energy DCCs; [b] Energy retrofit: replacement of windows

Measurement and calculation of the selected IEQ parameters

The highest measured outdoor air temperature during the measurement time interval (9–12 am) was 32.4 °C, and the lowest –1.4 °C [34]. In the same way, the average value of measured outdoor CO_2 concentration was 387 ppm (330–445 ppm), the average outdoor equivalent noise level 50 dB (30–75 dB). Table 3 represents general characteristic values of measurements and calculations of the selected IEQ parameters in all the playrooms among the analysed DCCs. The measured values of thermal and visual comfort parameters were largely dispersed. Thus, in Table 3 the median values were used instead of arithmetic mean, to represent general conditions in playrooms. The main results of IEQ measurements compared with legal requirements and recommendations are presented in the subsections below.

Table 3: Measured and calculated values of indoor environmental quality parameters among all the 17 DCCs (24 playrooms)

Parameters					
Symbol	**Description**	**Unit**	**Min**	**Max**	**Median**
T_{ai}	indoor air temperature	°C	19.3	27.4	23.7
T_{surf}	surface temperature	°C	13.5	34.2	22.3
RH_{ai}	indoor air relative humidity	%	29.1	68.5	47.2
v_{ai}	indoor air velocity	m/s	0.00	0.50	0.04
PMV	predicted mean vote	-	–0.33	1.10	0.19
PPD	predicted percentage of dissatisfied	%	5	29	6
LT	light transmittance of windows	-	0.52	0.89	0.69
WFR	window to floor ratio	%	9.1	45.0	30.0
E_i	average indoor daylight illuminance	lx	44	2655	352
-	uniformity of illumination[a]	-	0.01	0.38	0.17
cCO_{2i}	indoor CO_2 concentration	ppm	389	3613	1400
PPD_{IAQ}	predicted percentage of dissatisfied with IAQ	%	9	43	27
L_{eqi}	indoor equivalent noise level	dB	30	95	70

[a] Ratio between minimal and average illuminance.

Thermal comfort

During the conducted measurements indoor air temperature did not meet the required values (i.e., 19–24 °C) according to Slovenian legal requirements [35] in 37% of playrooms. In those playrooms the air temperature was too high, with the highest values reached in playroom R1 (25.5–27.4 °C). However, in relation to the recommendations [42]) (i.e., 17.5–22.5 °C), the recommended indoor air temperature was ensured only in 8% of the playrooms, with too high air temperatures in the majority of the playrooms. Radiant temperature asymmetry was not detected in any of the analysed playrooms. Nevertheless, the lowest surface temperature of 13.5 °C was measured on the external wall surface in playroom G1, as a consequence of present thermal bridge. Indoor air relative humidity was within the acceptable limits of 40 to 60% [36, 42] in 54% of the playrooms, while in other playrooms the air was mostly too dry (i.e. RH_{ai} < 40%). The measured indoor air velocity exceeded the permitted value (i.e., v_{ai} < 0.19 m/s) [35] in 17% of the playrooms and the recommended value (i.e., < 0.15 m/s) in 29% of the playrooms. However, according to the recommendations [35, 42], appropriate PMV and PPD (i.e.,± 0.7 PMV, PPD < 15%) values were still achieved in 83% of the playrooms.

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Indoor air quality (IAQ)

In 63% of the playrooms the measured concentrations of CO_2 exceeded the value permitted by Slovenian legislation (i.e., < 1667 ppm) [35]. Overall, nearly 80% of the playrooms had mean CO_2 concentrations exceeding 1000 ppm, which is recommended as the highest value in the

In 63% of the playrooms the measured concentrations of CO_2 exceeded the value permitted by Slovenian legislation.

ANSI/ASHRAE Standard 62.1-2007 [39]. The highest achieved mean CO_2 concentration measured in playroom B1 was 2584 ppm, while the highest measured value of 3613 ppm was reported in playroom R1. According to standard EN 15251:2010 [42] and Equation 1, 8% of the investigated playrooms were classified as indoor air quality class I (PPD_{IAQ} < 15%), 17% of playrooms were classified as class II (PPD_{IAQ} < 20%), 33% as class III (PPD_{IAQ} < 30%) and the rest as class IV (PPD_{IAQ} > 30%). In more than half of the playrooms, the PPD_{IAQ} value was higher than 25%.

Visual comfort

One playroom (E1) did not meet the requirement of Slovenian legislation for the WFR in DCCs (i.e., > 20% of the floor plan) [36, 42]. Playroom L1 had the highest percentage of lighting openings in relation to the floor area (45%) due to its supplementary clerestory windows. The maximum ratio between the height and the depth of the playrooms is limited by Slovenian legislation to 2.5 [36, 42]. In contradiction to the legal requirements, in 18% of playrooms the room depth was more than 2.5 times greater than the room height. According to standard [42], in 54% of the playrooms the recommended average work plane illuminance of at least 300 lx was ensured by daylighting during the time of conducted measurements.

Maximum noise levels in some playrooms exceeded 90 dB due to high children activity (e.g. playing, singing).

Acoustic comfort

In general, high noise levels in the selected playrooms were a consequence of children activity in the playrooms. In most cases the internally generated noise was dominant over the external ambient noise sources. According to Slovenian legislation [38], indoor noise level was in general too high during the measurements. Only 58% of the playrooms met the Slovenian legal requirements for noise exposure at work (i.e., < 70 dB) [37]. However, it has to be noted that noise level measurements were performed only for the period of three hours, while the legal requirements consider the noise exposure during the entire time span of operating hours. The highest and the lowest mean indoor noise levels were 83 dB (playroom A2) and 51 dB (playroom F1). Although indoor equivalent noise level was adequate in the majority (67%) of playrooms, it has to be noted that also the impulse noise should be taken into consideration. Maximum noise levels in some playrooms exceeded 90 dB due to high children activity (e.g. playing, singing).

Holistic assessment

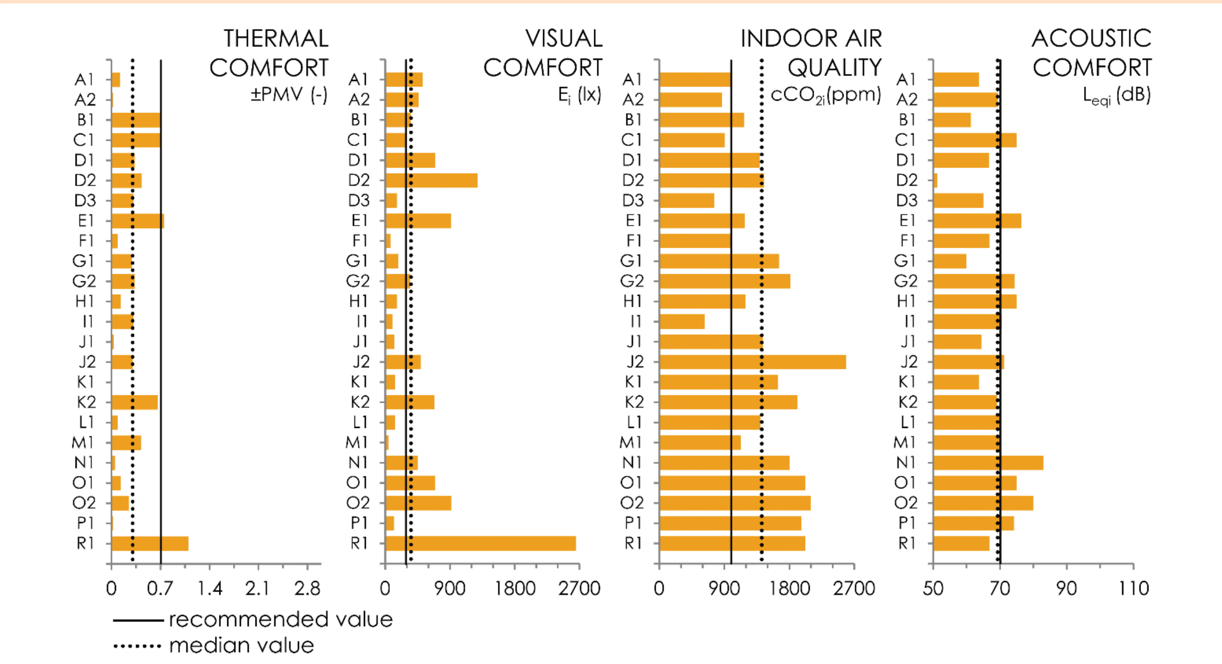
In order to holistically assess the IEQ in the analysed DCCs, all of the four aspects of comfort must be simultaneously evaluated. For each aspect one parameter was selected for a holistic assessment. Thus, PMV was selected to evaluate thermal comfort; average work plane illuminance with daylight was selected to evaluate visual comfort, indoor CO_2 concentration for IAQ and equivalent noise level for acoustic comfort. Table 4 represents the selected parameters of observation and general measurement results in all the 24 investigated playrooms.

Table 4: Measurement results of the selected basic parameters in each playroom

	Thermal comfort	Visual Comfort	IAQ	Acoustic comfort
Playroom No.	PMV [-]	$E_{i,avg}$ [lx]	$cCO_{2i,avg}$ [ppm]	$Leq_{,i,avg}$ [dB]
A1	0.01	139	1643	64
A2	–0.05	449	1805	83
B1	–0.30	492	2584	71
C1	0.09	136	1400	70
D1	0.33	697	1389	67
D2	0.25	918	2094	80
D3	0.69	356	1176	61
E1	0.09	74	1000	67
F1	0.43	1285	1449	51
G1	0.03	126	1433	65
G2	0.29	183	1657	60
H1	–0.33	347	1812	74
I1	0.13	690	2020	75
J1	0.66	682	1910	69
J2	0.31	162	761	65
K1	0.72	294	905	75
K2	0.31	97	628	71
L1	0.12	521	1012	64
M1	–0.02	121	1967	74
N1	–0.02	463	867	69
O1	0.42	44	1125	70
O2	0.13	163	1192	75
P1	0.75	915	1181	76
R1	1.10	2655	2023	67

Furthermore, the measured values were compared to the recommended ones. Such comparison is presented in Figure 3. The measured values of thermal and visual comfort parameters were largely dispersed. Thus, in Figure 3 the median values were used for all of the comfort types.

Figure 3:
Comparison of the selected IEQ fields and their parameters for playrooms A1–R1, considering parameters of thermal, visual, acoustic comfort and indoor air quality. Solid line represents the recommended value and dotted line represents the median value of the playrooms. The PMV values are shown as absolute numbers.



If the results are holistically observed, in playrooms A1 and A2 (8% of playrooms) all of the IEQ fields were within the recommended values. In 10 playrooms (42%), only one IEQ field did not meet the recommended values. In the rest of playrooms (50%), two or three uncomfortable IEQ parameters were identified simultaneously. None of the investigated playrooms had all the selected IEQ parameters inappropriate.

DISCUSSION

Poor thermal conditions of indoor environment can have negative impact on comfort and learning skills or may even cause adverse health effects, since children are more sensitive to high air temperatures than adults [12]. The measured air temperatures in the playrooms, which were considered within this paper, were similar to those in the studies conducted in Canada [18], Portugal [16] and Latvia [22], but higher than those in Portugal [44] and lower than those measured in South Korean [12] or Singaporean [23] facilities.

Inadequate control over air humidity of living environment can result in suitable conditions for the growth of mould, which has adverse effects on occupants' health [45–47]. The RH values, which were measured in DCCs during the presented study, were found to be less appropriate (i.e. lower) than those measured in Canada [18], Portugal [28], Italy [13], France [20] or South Korea [12]. At the same time, they were more suitable than in Singapore DCCs [23]. However, the latter is climate consequence of Singapore's high humidity climate.

The measured mean air velocity in the selected DDCs was similar to the values identified by Mors et al. [15] in Netherlands and Yun et al. [12] in South Korea. On the other hand, they were lower than those measured in Singapore by Zuraimi and Tham [23]. In contrast to previously conducted studies [16, 22, 28], where occupants were satisfied with thermal comfort or the reasons for discomfort were too cold thermal conditions, the PPD values identified by measurements of this study were more affected by too warm indoor environment.

The identified CO_2 concentrations (an indicator of ventilation rates) in the investigated Slovenian DCCs were similar to those measured in Portugal [16], Canada [10, 18], Latvia [22] and Poland [19], where in most cases the measured CO_2 concentrations exceeded 1000 or 2000 ppm. However, in comparison to studies conducted in Scandinavian countries [17, 21, 31], France [20] and in Singapore [23], where the average CO_2 concentrations rarely exceeded 1000 ppm, the measured CO_2 concentrations in Slovenian DCCs were higher and, thus, less appropriate.

The results of the conducted measurements of horizontal daylight illuminance show that in 37% of the analysed playrooms the average illuminance values were below the recommended value of 300 lx defined in EN 12464.

The results of the conducted measurements of horizontal daylight illuminance (Figure 3) show that in 37% of the analysed playrooms the average illuminance values were below the recommended value of 300 lx defined in EN 12464. However, it has to be emphasized that only daylighting was investigated (i.e. measured), although the recommendations of the EN 12464 standard relate to lighting in general (i.e. daylighting and artificial lighting). Among the studied playrooms in Slovenian DCCs, the most common reasons for poor daylighting were the window properties (i.e. area, shape, type of glazing, etc.). In addition, the penetration of daylight was often obstructed by various items attached to the glazing (e.g. shaped paper, drawings). One of the reasons for visual discomfort was also the inappropriate use of shading devices. In other words, in some playrooms shades were in shading position when shading was not needed (e.g. overcast sky, shading of western windows in forenoon). In several playrooms the shading system was even damaged and therefore inoperable for the users. This is a common problem in public buildings, as identified also by De Giuli et al. [29] in their study.

Excessive noise levels in DCCs represent health risk and discomfort for children and staff, which has been considered by numerous studies [25–27]. The measured noise levels in the investigated playrooms were comparable to the findings of some other studies [25, 26] and were relatively high. The problem of excessive noise levels in Slovenian DCCs might be additionally amplified by inappropriate reverberation times, which were highlighted by the findings of Kacjan Žgajnar et al. [48].

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CONCLUSIONS

Holistic approach to the assessment of indoor environmental quality with all the IEQ fields taken into consideration is vital to achieve a universally comfortable and healthy indoor environment. All the parameters of IEQ are by some means directly or indirectly interconnected. Thus, they cannot be assessed separately one at a time. Although some authors (see references [29, 49]) do not advise ranking of buildings with a combined assessment index, a holistic approach is still necessary, where as many comfort parameters as possible should be investigated simultaneously, but not necessarily combined into a single rating. Therefore, a multi-discipline approach and cooperation of experts from different professional fields is encouraged. There are very few studies that would comprehensively and simultaneously investigate thermal comfort, indoor air quality, visual and acoustic comfort. Within the presented paper such approach was used to assess playrooms in the selected DCCs. The IEQ conditions in some of the investigated playrooms did not meet the recommended criteria. However, it must be noted that there was no playroom where all of the four considered comfort types would be inadequate. Moreover, it has to be stressed that the measurement results showed that in 42% of the investigated playrooms only one comfort field deviated from the minimal required and the recommended values (Figure 3). The one uncomfortable condition could stay unidentified if not all the comfort fields were analysed. Contrasting other studies, which deal predominantly with IEQ, the presented results show the importance of holistic approach.

Contrasting other studies, which deal predominantly with IEQ, the presented results show the importance of holistic approach.

An in-depth analysis of the collected data showed that among the 24 studied playrooms the most critical field of indoor environmental quality was IAQ with 75% of playrooms above the recommended value (1000 ppm). The percentage of playrooms that exceeded the recommendations in the fields of visual and acoustic comfort was also relatively high, with 46% and 38%, respectively. Comparatively, thermal comfort recommendations were exceeded only in 8% of considered playrooms, thus defining

This study or similar ones can be used to provide a useful evidence base for the formulation and targeting of policies for improving IEQ in school or daycare buildings.

thermal comfort as the most controlled. According to previously conducted studies (see references [11, 12, 15]), the IEQ recommendations and legal requirements for buildings intended for children should be reconsidered, since children response to the indoor environment differently than adults. In addition, the results of this paper indicate that the legislation regarding IEQ in Slovenian DCCs might be insufficient, since the identified IEQ was better in some other EU countries with generally stricter legal requirements for indoor environment, e.g. Denmark, France and Sweden [50]. This study or similar ones (see reference [30]) can be used to provide a useful evidence base for the formulation and targeting of policies for improving IEQ in school or daycare buildings. Part II of this study further examines the interrelationship between various building characteristics, occupants' behaviour and several parameters of IEQ.

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