Effects of Indoor Environmental Quality on Concentration

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***Abstract* – There is a lack of long-term research on the effects of indoor environmental quality on concentration in real environments using objective measurements. Concentration is an essential part of learning and processing information. Since pupils and students spend large parts of their days indoors, it can have major effects on their concentration. This paper presents an environmental monitoring system for collecting continuous indoor environmental quality data and studies the relationship between indoor environmental quality and pupil concentration in a real-life environment. An 18-week pilot was conducted in one school in Northern Finland during the autumn in 2018. Pupils (n=83) and teachers (n=4) in four classrooms participated in the study. Data on pupil concentration was collected twice a week via paper-format concentration tests. Additionally, teachers evaluated pupil concentration on a daily basis. A non-parametric correlation analysis (Spearman) was performed to investigate the associations between indoor environmental quality and pupil concentration. A statistically significant inverse association was found between pupil concentration and the relative humidity in all four classrooms, but no consistent associations with other indoor environmental quality parameters were found.**

Keywords- indoor air quality; indoor environmental quality; concentration; school; pupil.

I. Introduction

People spend most of their time indoors, and students and teachers spend a large portion of it in school buildings, up to 700 to 900 hours on average per year [1]. This is why the Indoor Environmental Quality (IEQ) notably affects public health. There are 76.1 million students [2] and 5.8 million teachers [3] in Europe spending time in school environments, which often have poor Indoor Air Quality (IAQ).

IEQ comprises air quality pollutants, mainly gases and particulates, and other factors, such as temperature, relative humidity, lighting, sound level and vibration [4]. The concentration of carbon dioxide (CO_2) and Volatile Organic Compounds (VOCs) are well-known key parameters affecting IAQ [5]. Poor long-term IEQ is known to be associated with several health effects such as respiratory illnesses, allergic reactions, asthma, sick building symptoms, and reduced cognitive performance, which are estimated to generate high costs for society [6].

Concentration is essential for learning and performing school tasks. It is also highly important in information-intensive work. Concentration is affected by different environmental factors. It has been found that the IEQ affects pupils' cognitive performance when thermal conditions, pollutants such as VOC, particles, and CO_2 levels were reviewed [7][8]. Moreover, inadequate IEQ can cause general symptoms, such as headaches, dizziness, tiredness, and eye complaints, which may have a direct effect on learning and, therefore, test performance [9]. Increased ventilation has been associated with pupils' faster performance in tasks [10][11] and more accurate responses [11]. In a study, where 70 elementary schools were monitored for a weeklong period, better mathematics test scores were found when ventilation rate was higher [12]. It seems that increased levels of CO_2 due to insufficient ventilation as well as thermal discomfort can reduce students' vigilance and concentration. However, all the previous experiments have been rather short-term and conducted in controlled environments. An 8-month study in a real office environment showed that perceived thermal discomfort, noise annoyance and lighting discomfort were associated with reduced work performance and objectively measured cognitive performance [13]. The study excluded objective measurements of the IEQ parameters as the study parameters, including temperature, light, sound, and performance, were measured with a self-reporting questionnaire. There is also evidence that noise can adversely affect children's learning [14]. Environmental factors have been found to cause diminished motivation, tiredness, and feelings of helplessness, which can result in reduced cognitive performance [13][15]. In contrast to this, natural light can improve students' concentration. However, the only study on this was based on students' perceptions of IEQ factors and lacked objective measurements of IEQ [16]. More long-term studies in real life environments with objective measurements would be required to confirm the results.

Measuring real-life IEQ should be non-invasive and continuous, but to date, real-time IEQ data with interpretable information have rarely been available. However, recent improvements in wireless and electronics technologies have enabled the development of low-cost, low-power, and multifunctional sensors, which can be embedded in environments and can provide new means to acquire real-time information about indoor conditions.

This paper describes an 18-week pilot which aimed to study associations between objective IEQ parameters and pupil concentration in an uncontrolled, real learning environment. Additionally, it describes an environmental monitoring system for measuring IEQ parameters, including: CO_2, relative humidity, temperature, ambient lighting, sound levels, and an IAQ index. This paper is structured as follows: Section 2 describes the methods, Section 3 presents the results, which are discussed in Section 4, and Section 5 presents the conclusions.

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II. Methods

A. Pilot Environment

The 18-week pilot was carried out in a school in Northern Finland between August and December 2018. Four classrooms were monitored in two separate buildings. Building 1 was constructed in 1999 and building 2 was constructed in 1936 (renovated in 2005). The heating season started in the end of September. All the classrooms had a mechanical ventilation system, which the school personnel could not control. The ventilation rates in classrooms 1 to 4 were 8.6, 9.5, 10.0 and 11.9 L/s/person, respectively (Table I).

B. Participants

Four teachers and their 83 pupils (n=19+18+23+23=83) participated in the study. The average age of the teachers was 43.5 years and all of them were women. The average age of the pupils was 8.6 years. Of the pupils, 33 (39.8%) were girls and 50 (60.2%) boys. The teachers and pupils spent most of the school days in the same classroom during the study.

C. Data Collection

The data were collected from three sources: 1) IEQ sensors (IEQ data), 2) paper-format concentration tests performed by the pupils (pupil concentration data), and 3) an Android self-reporting application used by the teachers (teacher-reported pupil concentration data). The 18-week pilot contained 5 phases. In the 1st phase (2 weeks), the collection of the pupil concentration data was rehearsed. In the 2nd phase (6 weeks), the data collection (sources 1-3) was ongoing. Data collection continued until the end of the study. In the 3rd phase (3 weeks), the teachers were provided access to visualizations of IEQ data. In the 4th phase (3 weeks), air purifiers (UniqAir [17]) were brought into the classrooms (2 real, 2 mock-ups). In the 5th phase (4 weeks), the air purifiers were relocated so that each classroom had a real purifier in phase four or five.

1) Indoor Environmental Quality

All four pilot classrooms were equipped with an IEQ sensor system built of commercially available professional quality sensor devices. The temperature, relative humidity, CO_2, ambient lighting and IAQ index were measured using MCF-LW12CO2 environmental sensor devices [18]. The IAQ index represents breath Volatile Organic Compound (b-VOC) concentration for the most important compounds in the exhaled breath of humans and is the output of a proprietary algorithm for the Bosch BME680 VOC gas sensor [19]. The sound level was monitored with PeakTech PT8005 sound level meters [20].

TABLE I. CLASSROOM DESCRIPTIONS.

	Room 1	Room 2	Room 3	Room 4
Building	1	1	2	2
Pupils in the room	20	18	23	23
Area (m^2)	59.7	59.7	49.8	64.2
Ventilation rate ($L/s/m^2$)	3.0	3.0	4.8	4.4
Total ventilation (L/s/room)	180	180	240	285
Personal ventilation rate (L/s/person)	8.6	9.5	10.0	11.9

All the sensors were positioned according to the national legislative recommendations [21]. IEQ sensor devices were installed next to teacher's post at about 1.1 meters above the floor level in the classrooms. Sound level meters were positioned in an open space at least 0.5 meters away from any obstacles, including but not limited to floors, walls, ceilings, and furniture, in the residence zone of the classrooms. The sampling rate was once per 15 minutes and 5 seconds for the MFC sensor and sound level meter, respectively. Data transfer from the MCF sensor devices to the Microsoft Azure cloud platform was set via a LoRaWAN gateway and from PeakTech devices using Raspberry PI (RPI) gateways. In the implemented IEQ system, message queue telemetry (MQTT) was the utilized data communication protocol from the IEQ gateways to the cloud service. All the sensor data were stored in the Microsoft Azure TableStorage. An overview of the system architecture and details on the sensor hardware are depicted in Figure 1 and Table II.

2) Pupil Concentration

The pupil concentration data was collected using a paper-format concentration test administered twice a week by the teachers. The concentration test had to be short (max. 5 min to administer), feasible for large group testing, performed without computers, suitable for children aged from 7 to 12 years, and suitable for repeated testing. Liukkonen [22] presented a test (numbers in a 10-by-10 grid from 1 to 100) that was considered feasible to administer by the teachers and could easily be varied by sorting numbers in a different order each time. A random generator was used to create unique number grids for each test. The pupils were given four minutes time to find numbers in numerical order. The duration was determined by two training tests with the pupils so it would not give too many close to zero or close to full scores. Teachers considered it infeasible to administer the concentration test more than twice a week (between Tuesday and Thursday). The test was conducted at the end of a 45-minute lesson, when teachers considered the entire class to be

TABLE II. DETAILS OF THE COLLECTED DATA.

Parameters		Source	Range	Accuracy	Samp-ling
Indoor Environmental Quality	***Temperature***	MCF-LW12CO2	-10…60°C	±0.5°C	Every 15min
	Relative humidity		0…100%	±3% for 20…80% @25°C ±5% for 0…20% and 80…100% @25°C	
	CO_2		300…5000 ppm	±50ppm + ±3% of reading	
	Ambient lighting		0.01…80000lux	±15%	
	IAQ Index		1…500	±15% for b-VOC sensor 500…50000ppb	
	Sound level	PeakTech PT8005	30…130dB	± 1.4dB	Every 5s
Pupil concentration		Concentration tasks on paper	0…100	±1	Twice a week
Teacher-reported pupil concentration		Android self-reporting app	1…5	±1	Daily

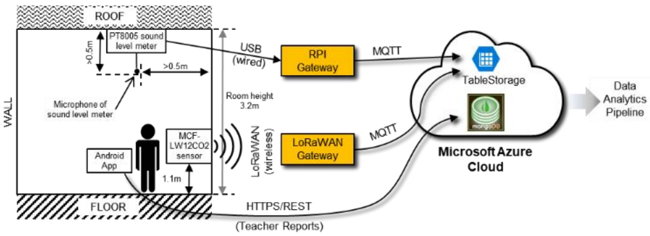

Figure 1. An overview of the data acquisition system used in the study.

in the classroom in order to maximize the number of the pupils and the time spent in the classroom. If there were changes in the school week, the test was conducted on another day or in another lesson if possible. Teachers reported any variance related to performing the test (day, contextual factors etc.). The number of girls and boys taking the test was recorded.

3) Teacher-Reported Pupil Concentration

A teacher-reported pupil concentration was the teachers' evaluation of the pupils' concentration during the day and it was collected every school day with an Android self-reporting application made by VTT Technical Research Centre of Finland Ltd (VTT). Teachers answered daily the question "How would you evaluate the concentration of the pupils today?" A 5-point answer scale was used consisting of the following options: 1) Extremely concentrated, 2) Concentrated, 3) Neutral, 4) Non-concentrated, 5) Extremely non-concentrated. The data were stored via an HTTP/REST interface in a MongoDB database in the Azure cloud (Figure 1).

D. Data Analysis

1) Indoor Environmental Quality

The concentration tests were performed at the end of a 45-minute lesson. Thus, the average for the IEQ sensor parameters over a 45-minute time span before the test occasion was calculated and used in the analyses. The average was calculated for the temperature, relative humidity, CO_2, ambient lighting, IAQ index, and two sound level sensors.

2) Pupil Concentration

The pupil concentration test results were converted to digital format by one researcher. The final score was the total number of the marked numbers. Among the test papers, there were a few zero results indicating that the subjects had given up, and few full scores indicating potential cheating. In some cases, the pupils were given more than 4 minutes by mistake, and therefore only the tests that were conducted exactly in four minutes were included in the analysis. Median, mean and trimmed mean values (excluding 25% of the outlying values) were counted and preliminary correlation tests were performed to see whether the results would be similar. The median was chosen for being more resistant to extreme outliers, and because there were no obvious differences between correlations.

3) Teacher-Reported Pupil Concentration

The answers from the day the pupils performed the concentration task were included in these analyses.

4) Statistical Analyses

The data were analyzed using the IBM SPSS Statistics tool (version 24). The IEQ and concentration data were investigated for the four classrooms and the differences between the classrooms were compared using a Kruskal-Wallis test because the data were not normally distributed. The association between the IEQ and pupil concentration data was assessed using Spearman's correlation.

E. Ethical Considerations

This study was performed in accordance with ethical guidelines and Regulation EU 2016/679 (General Data Protection Regulation). The study for the school environment was reviewed and accepted by the Ethics Committee of VTT. A bulletin on the study with contact details was sent to the pupils' parents via the school's electronic messaging system. The principal presented the study in a parents' meeting. Individual pupils were neither identified nor connected to a specific concentration test in the study. The teachers gave general information about the class (the number of girls and boys and their ages). The participating teachers provided informed written consent.

III. RESULTS

The data characteristics (see Table III) on the averaged IEQ parameters show that most parameters were close to the recommended target values. In all rooms, the ambient lighting surpassed the targets and even the action limit (limit calling for action when surpassed) occasionally. The relative humidity fell outside the targets occasionally, and the sound levels were always above the targets. In detail, the CO_2 levels slightly surpasses the recommended limits in two classrooms. The recommended target value is 350 ppm, plus outdoor CO_2 (about 430 ppm in Northern Finland) [23], but remained below the action limit (1150 ppm + outdoor CO_2) in all classrooms [21]. The relative humidity exceeded the target values in all classrooms (target 30-40%) [23], while remaining just below the action limit (>60%) [21]. A low relative humidity is quite typical during the heating season. Additionally, the minimum ambient lighting values were very low, occasionally even surpassing the action limit in all rooms (target >400 lx, action if <200 lx) [23]-[25]. The temperatures were slightly below the recommended target level in one classroom (target 21.5±1.5°C) [23], but still within the action limits (<18 or >26°C) [21]. The sound levels were high in all classrooms with the minimum 47 dB (daytime average target 35 dB), but values were clearly below the action limit (>80 dB) [21]. The IAQ index was high compared to the sensor manufacturer target in all classrooms (target ≤150) [19].

There was a statistically significant difference across all four classrooms in all IEQ parameters except relative humidity and pupil concentration. The selected three IEQ parameters (CO_2, relative humidity, and temperature) and pupil concentration are shown in Figure 2. The graphs show a slight increase in pupil concentration results throughout the pilot, but no remarkable changes after the change of phase. From the IEQ parameters, the variation is very small in temperature. The relative humidity seems to drop at the end of September to a lower level indicating the start of the heating season. The CO_2 level varied around a similar base level throughout the pilot.

TABLE III. DESCRIPTIVES OF IEQ PARAMETERS AND CONCENTRATION FOR THE CLASSROOMS WITH P-VALUES FROM A KRUSKAL-WALLIS TEST.

	Room 1	Room 2	Room 3	Room 4	*P*-values
CO_2 (ppm)					
Min	421	429	433	456	
Max	827	797	645	731	
Median	658	600	580	629	0.001
IQR[a]	611-762	529-682	556-599	587-676	
Relative humidity (%)					
Min	20	22	19	20	
Max	58	59	56	59	
Median	32	37	31	32	**0.381**
IQR	27-37	29-42	26-39	25-42	
Ambient lighting (lx)					
Min	43	52	116	27	
Max	481	264	234	536	
Median	433	124	204	343	<0.001
IQR	107-462	108-243	201-214	198-488	
Temperature (°C)					
Min	20.5	19.5	20.3	20.0	
Max	22.9	22.0	22.1	22.0	
Median	21.8	20.9	21.5	21.2	<0.001
IQR	21.3-22.5	20.4-21.5	21.2-21.8	20.9-21.6	
Sound level (dB)					
Min	47	48	48	53	
Max	66	65	64	74	
Median	56	57	58	63	<0.001
IQR	54-58	53-61	57-60	58-66	
IAQ Index					
Min	48	48	122	54	
Max	230	250	250	250	
Median	175	192	237	226	<0.001
IQR	127-207	147-215	222-244	199-244	
Pupil concentration					
Min	14	12	15	16	
Max	29	24	30	33	
Median	22	19	24	24	<0.001
IQR	19-24	16-21	22-25	21-26	
Teacher-reported pupil concentration					
Min	2	2	2	2	
Max	4	4	4	4	
Median	3	3	3	3	**0.077**
IQR	3-4	3-4	3-3	3-3	

a. interquartile range

The correlations between the IEQ and pupil concentration are shown per classroom in Table IV. The strongest correlation was found between the relative humidity and pupil concentration with the correlation coefficient ρ varying from -0.73 to -0.57. This negative correlation indicates an inverse relationship between relative humidity and pupil concentration. This parameter exhibited variation outside the target range. No consistent and strong relationships between other IEQ parameters and pupil concentration were found. However, the following discrete correlations were found: a weak positive correlation with CO_2 in room 1 (ρ=0.493, *P*=.012) and room 3 (ρ=0.491, *P*=.011), a negative weak correlation with ambient lighting in room 3 (ρ=-0.468, *P*=.016), a weak negative correlation with temperature in room 2 (ρ=-0.642, *P*=.001), and a moderate (positive) correlation with the sound level in room 2 (ρ=0.460, *P*=.014). There was no significant correlation in individual rooms between the measured pupil concentration and teacher-reported pupil concentration.

TABLE IV. SPEARMAN CORRELATION COEFFICIENTS (Ρ) IN RELATION TO THE CONCENTRATION TEST SCORE MEDIAN.

	Room 1	Room 2	Room 3	Room 4
CO_2 (ppm)				
ρ	**0.493**[*]	0.274	**0.491**[*]	0.162
Sig.[a] (2-tailed)	0.012	0.185	0.011	0.410
N	25	25	26	28
Relative humidity (%)				
ρ	**-0.620**[**]	**-0.728**[**]	**-0.568**[**]	**-0.706**[**]
Sig. (2-tailed)	0.001	P<0.001	0.002	P<0.001
N	25	25	26	28
Ambient lighting (lx)				
ρ	-0.335	-0.116	**-0.468**[*]	-0.147
Sig. (2-tailed)	0.101	0.582	0.016	0.454
N	25	25	26	28
Temperature (°C)				
ρ	-0.374	**-0.642**[**]	0.082	-0.199
Sig. (2-tailed)	0.065	0.001	0.690	0.311
N	25	25	26	28
Sound level (dB)				
ρ	-0.052	**0.460**[*]	0.324	0.103
Sig. (2-tailed)	0.787	0.014	0.092	0.582
N	30	28	28	31
IAQ Index				
ρ	0.253	0.223	-0.062	0.215
Sig. (2-tailed)	0.222	0.284	0.763	0.271
N	25	25	26	28
Teacher-reported pupil concentration				
ρ	-0.315	-0.182	0.112	-0.197
Sig. (2-tailed)	0.153	0.385	0.603	0.298
N	22	25	24	30

a. Significance

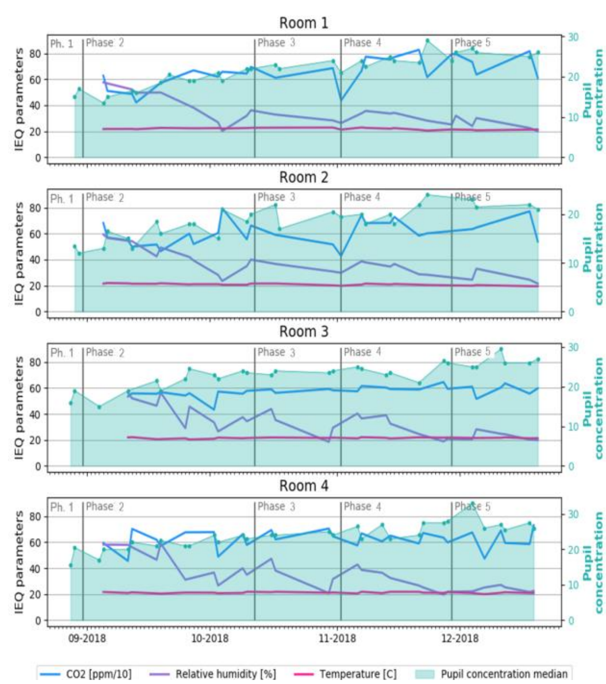

Figure 2. IEQ parameters and pupil concentration median value trends across the study phases.

IV. Discussion

A. Reflecting Results

Differing from the majority of the related work, the experiment was conducted over the long-term in a real school environment, and the IEQ parameters were not modified for the study. During the study, the overall IEQ was mainly within approved limits, except for the relative humidity, ambient lighting, and sound levels at times. This makes it difficult to reveal strong correlations between the IEQ and concentration.

Our analysis indicates moderate negative correlation between relative humidity and pupil concentration across all the classrooms. That is, the lower relative humidity, the higher the concentration test score. The relative humidity exhibited variation outside the recommended target range of 30-40% showing a decreasing trend, which was due to the progressive heating of the buildings during the pilot. However, a drop in the relative humidity below the target range did not seem to reduce concentration. There were no clear, strong, and consistent relationships between other IEQ parameters and concentration.

There were slight positive correlations between CO_2 and pupil concentration, being significant in two classrooms. This indicates that a higher CO_2 level was associated with better pupil concentration in those rooms. This is not in line with earlier studies implying that increased CO_2 levels reduce performance [10]-[12]. However, the CO_2 remained generally at good levels in all the classrooms during the study and no clear conclusion can be drawn based on these results.

There were slight negative correlations between the ambient lighting and pupil concentration. This indicates that the higher luminosity is the weaker the pupil concentration. This could be explainable by variation in diurnal daylight and human vigilance variation. In the earlier hours, when the pupils are more alert, there is less natural light in the autumn. Later in the afternoon, the pupils become more tired and their concentration decreases even though there is more natural light. In addition, the location of the sensor was not optimized considering the lighting conditions, which might have caused some degree of error.

There were negative correlations between temperature and pupil concentration in three classrooms, one of which was significant. In general, this indicates that higher temperatures and weaker pupil concentration are associated. This is in line with earlier studies [8]. However, in this pilot, the temperatures rise was moderate and did not rise above 22.9°C in any of the rooms during the pilot period.

There was a significant positive correlation between the sound level and pupil concentration in one room. This means that the more noise there was during the preceding lesson the better the performance the pupils had in the concentration test.

B. Concentration Task

The paper-format concentration test itself was easy and short to administer. However, the digitization took a long time and was prone to mistakes. In the future, when all the pupils have smartphones or tablets, the test could be performed with a mobile device and the results would be natively in digital form. Electronic test would reduce the chance of mistakes both in the digitization process and in performing the test. If the test accepts only one correct number at a time, there would be no missing values in the number sequence as it often happened in the paper version. There was a slight learning effect on the pupil concentration throughout the pilot. Even though there was a two-week "training" period before the IEQ sensors were installed, the concentration test results kept improving slightly throughout the 18-week pilot.

Both the pupils and the teachers liked the concentration test. It also benefitted teachers unexpectedly by offering perhaps the only silent moment during class hours in the day.

C. Limitations of This Study

The sampling rate for the MCF-LW12CO2 environmental sensor was infrequent, at only every 15 minutes. As a result, a single exceptional value can distort the average in the 45 minutes epoch easily. By averaging the measurements before the concentration test, the longer-term exposure was taken into consideration. However, neither the variation range nor the trend in the IEQ parameters during the 45-minute period were analyzed. It is also uncertain whether the concentration test was performed exactly 45 minutes after a recess. If the first measurement took place during the recess, it would affect the average. Another uncertainty was caused by the MFC sensors' IAQ index, which was based on a proprietary non-open algorithm of the sensor manufacturer and may have ±15% sensor-to-sensor deviation in values. Although the IAQ index can be mapped to a 7-step classification scale from very polluted to excellent, data interpretation is informal and indicative only without any precise action limits. However, the IAQ index was not shown to be of significant importance in our analyses.

Even though the study was long-term (18 weeks), there were not enough samples to get significant results at these correlation levels. If the correlation was around 0.4 and a power of 0.75, then 26 samples would be enough, corresponding to 13 weeks at the current concentration test rate. However, if the correlation was around 0.3 and a power of 0.75, it would have required approximately 75 samples corresponding to 38 weeks. I.e., it would require collecting data for one whole school year if the tests were administered twice a week. In Northern Europe, changes in meteorological conditions and the building heating season have effects on indoor conditions, which also favors a full-year measurement.

Although, the study could confirm only association between relative humidity and concentration, continuous monitoring of the IEQ is important because it enables the detection of adverse changes in the environment. It can also reveal smaller long-term changes that the humans might not detect as we adapt quickly to the prevailing conditions.

V. Conclusion

This paper presents a study on the associations between objective IEQ data and objective pupil concentration. The study deployed an environmental monitoring system for collecting objective IEQ data using commercial sensors. The system was utilized in a long-term experiment (18 weeks) in a real school environment, where the IEQ parameters were not arranged or modified for study purposes. During the study, the overall IEQ was mainly within approved limits, except for the relative humidity, ambient lighting, and sound levels at times. The associations between objective IEQ measures and objective pupil concentration were analyzed. A statistically significant inverse association was found between the relative humidity and pupil concentration in all the classrooms. Correlations between other IEQ parameters and pupil concentration could not be confirmed. The performance of the pupils and students in varying IEQ requires further studies. It is recommended to have a longer pilot (e.g., one year), with concentration testing more than twice a week. Despite the challenges in measuring associations between IEQ factors and concentration, it is important to monitor indoor conditions to ensure the well-being of the children. Future work should also study the interaction between concentration, IEQ conditions and, e.g., cognitive factors. Several IEQ factors may cause a significant reduction in perceived work performance indirectly together with individual state factors, including motivation, alertness, focus etc. Thus, the interaction between the individual and indoor environment is a multifaceted topic.

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References

[1] E. Csobod et al., "SINPHONIE - Schools Indoor Pollution and Health Observatory Network in Europe - Final Report," Publications Office of the European Union, Luxembourg, 2014. Available at: https://doi.org/10.2788/99220.

[2] Eurostat, Students and Teachers in the EU, 2020, available at: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/DDN-20200604-1 [retrieved: September, 2020].

[3] Eurostat, "Teachers in the EU", 2019, available at: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/EDN-20191004-1 [retrieved: September, 2020].

[4] A. Steinemann, P. Wargocki, and B. Rismanchi, "Ten questions concerning green buildings and indoor air quality," Build. Environ, vol. 112, pp. 351–358, 2017.

[5] M. Kraus, "Airtightness as a key factor of Sick Building Syndrome (SBS)," 16th International Multidisciplinary Scientific GeoConference (SGEM 2016), pp. 439–445, Curran Associates, Inc., 2016.

[6] W.J. Fisk, "Health and productivity gains from better indoor environments and their relationship with building energy efficiency," Annu. Rev. Energy Environ., vol. 25, pp. 537–566, 2000.

[7] T. Salthammer et al., "Children's well-being at schools: Impact of climatic conditions and air pollution," Environ. Int., vol. 94, pp. 196–210, 2016.

[8] P. Wargocki and D.P. Wyon, "Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork," Build. Environ., vol. 112, pp. 359–366, 2017.

[9] I. Annesi-Maesano et al., "Indoor air quality and sources in schools and related health effects," J. Toxicol. Environ. Heal, Part B, vol.16, pp. 491–550, 2013.

[10] P. Wargocki and D. Wyon, "The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children (RP-1257)," HVAC&R Res., vol. 13, pp. 193–220, 2007.

[11] Z. Bakó-Biró, D.J. Clements-Croome, N. Kochhar, H.B. Awbi, and M.J. Williams, "Ventilation rates in schools and pupils' performance," Build. Environ., vol. 48, pp. 215–223, 2012.

[12] U. Haverinen-Shaughnessy and R.J. Shaughnessy, "Effects of classroom ventilation rate and temperature on students' test scores," PLoS One 10, e0136165, 2015. Available at: https://doi.org/10.1371/journal.pone.0136165.

[13] S. Lamb and K.C.S. Kwok, "A longitudinal investigation of work environment stressors on the performance and wellbeing of office workers," Appl. Ergon., vol. 52, pp. 104–111, 2016.

[14] G.W. Evans and S.J. Lepore, "Nonauditory effects of noise on children: a critical review," Child. Environ., vol. 10, pp. 31–51, 1993.

[15] G.W. Evans and R. Stecker, "Motivational consequences of environmental stress," J. Environ. Psychol., vol. 24, pp. 143–165, 2004.

[16] L.J. Rayneri, B.L. Gerber, and L.P. Wiley, "The relationship between classroom environment and the learning style preferences of gifted middle school students and the impact on levels of performance," Gift. Child Q., vol 50, pp. 104–118, 2006.

[17] UniqAir Air purifier. Available at: https://www.uniqair.fi/en/product/uniqair-pro/ [retrieved: September, 2020].

[18] mcf88. mcf88 MCF-LW12CO2. Available at: https://www.mcf88.it/prodotto/mcf-lw12co2/ [retrieved: September, 2020].

[19] Bosch Sensortec. Bosch BME680. Available at: https://www.bosch-sensortec.com/bst/products/all_products/bme680 [retrieved: September, 2020].

[20] PeakTech. PeakTech 8005. Available at: https://www.peaktech.de/productdetail/kategorie/schallpegel messgeraete/produkt/p-8005.html [retrieved: September, 2020].

[21] Finnish Ministry of Social Affairs and Health. Decree of the Ministry of Social Affairs and Health on Health-related Conditions of Housing and Other Residential Buildings and Qualification Requirements for Third-party Experts (545/2015), 2015.

[22] J. Liukkonen, "Psyykkinen vahvuus–Mielen taitojen harjoituskirja" (Eng. Psychological resilience- Training book for mind). Jyväskylä, Finland: PS-kustannus, 2017.

[23] Finnish Society of Indoor Air Quality and Climate, "Sisäilmastoluokitus 2018" (Engl. Classification of Indoor Environment 2018 - Target Values, Design Guidance, and Product Requirements), 2018.

[24] The Finnish Standards Association standard SFS-EN 12464-1.

[25] "Occupational safety and health administration." Tampere, Finland: Multiprint Oy, 2014.

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