

Investigating health- and occupant behaviour related IAQ risks in a naturally ventilated child-care facility

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Abstract. Health and well-being in buildings is in the centre of scientific attention for many decades now, especially after the recent world-wide pandemic. At the same time, the energy performance of buildings is also of attention. EU's recent EPBD recast highlights the importance of maintaining adequate indoor environmental quality (IEQ) in buildings, i.e. energy related actions on the building cannot jeopardise e.g. the indoor air. The research in the field of IEQ is broad and many projects focused on office and residential buildings. However, other building types are underrepresented and also majority of studies focus on developed countries with one certain construction type. This study's aim is to investigate the health-related risks emerging from certain IAQ conditions and their causality with occupant behaviour in case of a child-care facility. Methods used include a winter-to-summer season monitoring campaign of 4 group rooms of a child-care facility in rural Hungary which has a regionally typical building structure that has gone through energy renovation lately. The naturally ventilated building has typical heating system and no cooling. The time-series dataset of the monitoring campaign is supplemented by subjective data: in-house occupancy and daily schedule values, weather data and occupant behaviour-related interviews. In three rooms out of 4, indoor CO₂ levels are above 2000 ppm for more than 2 hours in majority of the days. Differences in IAQ are clearly explained by interviews about window opening behaviour. This study clearly shows the direct impact of adults' window opening behaviour on the healthy everyday environment of children.

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1 Introduction

The importance of Indoor Environmental Quality (IEQ) lies in the fact that modern humans spend approximately 90% of their lives indoors [1], where pollutant concentrations can often be significantly higher than outdoors. The consequences of poor IEQ range from acute "Sick Building Syndrome" (SBS) symptoms (headaches, eye irritation, and fatigue) to long-term respiratory diseases. Beyond health, IEQ is a critical driver of economic performance. [2] Studies have shown that improved air quality and the control over the thermal environment can boost work productivity by 5% to 10% in office settings. [3] For example, higher carbon-dioxide (CO_2) levels, common in poorly ventilated spaces, have been directly linked to decreased decision-making performance and slower response times. Prior research indicates that even subtle improvements in IEQ—such as increasing ventilation rates or optimizing temperature—can lead to measurable gains in cognitive function, reduced absenteeism, and enhanced overall mental and physical well-being. [3] Historically, IEQ has been studied most extensively in offices and educational institutions (schools and universities). These environments have been prioritized because they have a direct, quantifiable link to economic output and learning outcomes.

1.1 The case of child-care facilities

In Hungary, the legal framework regulating air quality in child-care facilities primarily sets out general obligations. Specific technical requirements must be based on the decree defining occupational safety requirements for workplaces [4]. This decree stipulates that workplaces, including child-care facility premises, must ensure a supply of fresh air depending on the nature of the activity, typically starting at 20-30 $\text{m}^3/\text{h}/\text{person}$, depending on the level of physical activity.

Although Hungarian public education laws do not specify a specific CO_2 concentration limit, in practice, in line with internationally accepted guidelines [5], a CO_2 level of 1000 ppm is considered the upper threshold for ensuring healthy air quality, which must be adhered to in order to maintain children's ability to concentrate and prevent SBS. As the legal framework focuses primarily on mandatory minimum air exchange, in order to guarantee safe air quality in child-care facilities, in addition to workplace regulations, it is recommended to apply conscious ventilation protocols or integrate mechanical ventilation systems, especially in the case of highly airtight buildings that meet modern thermal insulation requirements.

In the international literature, there are few case studies conducted in child-care facility environments, but their findings draw attention to interesting facts.

In a study conducted in the Czech Republic, Stiborova et al. [6] examined indoor air quality (IAQ) in a 109 m^2 classroom in a modern child-care facility built in 2013, with a particular focus on CO_2 concentrations affecting children's health. The study showed that natural ventilation—through the conscious and frequent opening of windows and patio doors—was able to keep CO_2 concentrations below the 1500 ppm limit set by Czech regulations even during the winter heating season, thus ensuring that indoor air quality was safe for health. Although this method proved effective in maintaining air quality, it resulted in significant heat loss and increased heating costs, while the inaccuracy of temperature control often led to exceeding the 20–22°C comfort zone. The research confirmed that although the manual ventilation strategy is theoretically sufficient to meet the legal limits, in order to achieve a balance between optimal indoor climate and energy efficiency, conscious control and the use of hybrid solutions are essential in addition to natural interventions, i.e., the use of heat recovery ventilation equipment in winter.

In their research in Poland, Zender-Swiercz et al. [7] examined the indoor air quality of four child-care facilities that had undergone partial thermal insulation and window replacement. Measurements taken during the winter period showed that, due to airtight windows and doors and outdated ventilation systems, carbon dioxide concentrations rose to critical levels during the day, exceeding 4000-4479 ppm, which resulted in the lowest (IDA 4) air quality category according to EN 13779. In addition, due to inadequately regulated heating, the temperature often exceeded the optimal comfort zone, and periodical window operation only brought short-term and temporary relief. The researchers concluded that to protect children's health and learning abilities, it is essential to supplement natural ventilation with mechanical heat recovery systems, as the current situation poses a serious long-term threat to air quality in the kindergarten environment.

Telejko et al. [8] also examined the indoor air quality of retrofitted child-care facilities built between 1980 and 1993 in Poland, where natural ventilation also proved to be insufficient due to airtight windows and doors. During the measurements, the CO₂ concentration reached critically high levels of over 4000 ppm during daytime use, which also indicates poor (IDA 4) air quality according to the EN 13779 standard. To improve air quality, the fresh air supply was doubled, and UV-based air purification technologies (RCI) were used, which measurably reduced carbon dioxide levels and mold spore concentrations. However, due to the limitations of passive ventilation, it was still difficult to maintain the recommended limit of 1000 ppm on a consistent basis. The study concluded that natural ventilation alone is not sufficient to maintain a healthy environment in the kindergarten, and that in the future, the complex integration of mechanical ventilation systems and modern air purification will be necessary to achieve a balance between energy efficiency and an appropriate microclimate.

1.2 Aim of Current Study

The goal of this technical paper is to present a case study from a child-care facility and highlight potential health- and occupant behaviour related hazards emerging from poor indoor environmental quality.

2 Methodology

2.1 Introduction to the case study site

The child-care facility of the investigation is located in a rural area of Hungary. The building was built in the 70's using a typical masonry structure for the structural walls and a reinforced concrete slab. The third group room is a later addition to the building and at the same time the outer walls were insulated with 12 cm thick EPS material thermal insulation.

The group rooms' floor area is 51,3 m² except for the 4th room which is a smaller room (23 m²) for younger children, a day-care room. The clear inner height of rooms is 3 m. All group rooms are equipped with operable windows with a window sill height of 90 cm and one terrace door. All of them can be both tilted and turned.

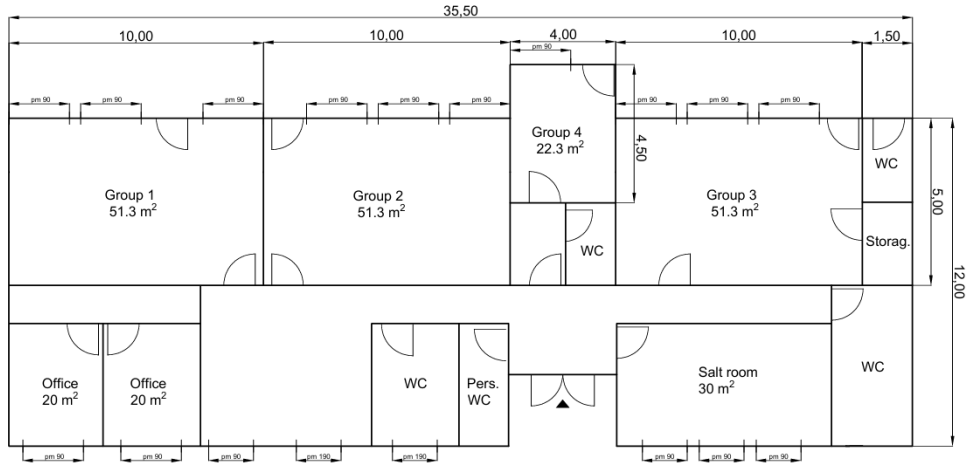


Fig. 1. Floorplan of case study building.

The facility is open from 6:30 to 16:30 on workdays. It has a typical schedule of a kindergarten which can be seen on Table 1.

Table 1. Schedule of the day.

Time	Activity	Occupancy
6:30-8:00	Arrival	1 teacher/room + children
8:00-9:30	Group activities	2 teachers/room + children
9:30-10:00	Morning snack	2 teachers/room + children
10:00-11:30	Group activities/outdoor time	2 teachers/room + children
11:30-12:30	Lunch	2 teachers/room + children
12:30-15:00	Afternoon sleep	2 teachers until 14:00/room + children
15:00-15:30	Afternoon snack	1 teacher/room + children
15:30-16:30	Leave/outdoor time	1 teacher/room + children

2.2 Data collection campaign

2.2.1 Monitoring

During the examination of the air quality of the child care facility, we carried out the measurements using Trotec BZ30 Datalogger instruments in each group room. The devices allowed for the continuous monitoring of the carbon dioxide concentration, temperature and humidity of the air. The measurement period was between February 3 and July 22, 2025, during which time data was collected with a frequency of one minute.

The meters were placed on the tabletop (70 cm height), approximately at the breathing height of the children, next to the official documents of the kindergarten teachers and child care workers, and the equipment necessary for meals, so that the children were not allowed to touch them. In each room, they were located at different distances from the facade, in accordance with the different layouts of the rooms. Sensor distance from the facade: room 1: 0.5 m; room 2: 1.5 m; Room 3: 5 m; Room 4: 5 m.

Meteorological data provided by the official website of HungaroMet from a nearby location were also included in the study. The data sets contained various weather parameters characteristic of the given period including temperature, humidity and precipitation.

2.2.2 Complementary subjective data

In addition to the general schedule of a day which was shown in Table 1, data were provided by the kindergarten teachers which included a detailed schedule with daily activities of each group. The document indicated exactly when they went out into the yard, how long they stayed outdoors, and what other activities they did during the day. For example, it recorded the times when morning and afternoon outdoor games started and ended, and if the children participated in other indoor programs, this was also indicated.

In addition, a ratio of missing and the maximum number of children was recorded for each group on a daily basis.

The kindergarten teachers filled out a questionnaire including interview questions on their ventilation habits and perception of IAQ. Their answers provided relevant information, such as how often and at what times the group rooms were ventilated.

2.3 Data analysis steps

As a basis for the measurement campaign, the four Trotec BZ30 dataloggers were co-located and intercompared with a Testo 400 reference instrument to identify potential measurement offsets. The results of comparison showed minor offsets in the case of two loggers within the measurement error limit. Correction of the relevant datasets was carried out according to need during data processing.

When all measured data was available, time series were synchronized so that they have the same timestamps. Data was checked for out-of-bound values and stuck or missing values. Data loss periods have been identified as well.

Missing data periods were often whole days and these periods were removed from the raw dataset.

After the datasets were cleaned and missing data was filled in, the 4 datasets of the 4 corresponding group rooms were split up into 3 seasons: winter, spring and summer. The cuts were made based on weather data (average daily temperature) of the measurement period.

The first step of data analysis was to use descriptive statistics to characterize measured IAQ conditions by identifying the average, minimum, maximum, modus, median and frequency distributions. As part of this analysis, the relationship between IAQ parameters and hourly occupancy was plotted and investigated.

The second step of the analysis entailed using statistical tests to evaluate these relationships between IAQ and daily and hourly occupancy data.

As a last step for the purpose of current paper, IAQ and thermal conditions were benchmarked according to standard EN16798-1:2019 [9] [5], EN 13779 [10] and also Hungarian regulations.

After the longitudinal time series data analysis, teacher interviews were analysed and compared to actual measured data to find contextual and behavioural causal relationship with IAQ levels.

3 Results

3.1 IAQ and indoor temperature

As a first step, seasonal, weekly and daily datastreams were plotted and analysed for each room and for each season. On figure 2, CO₂ levels can be seen for winter season for rooms 1-3.

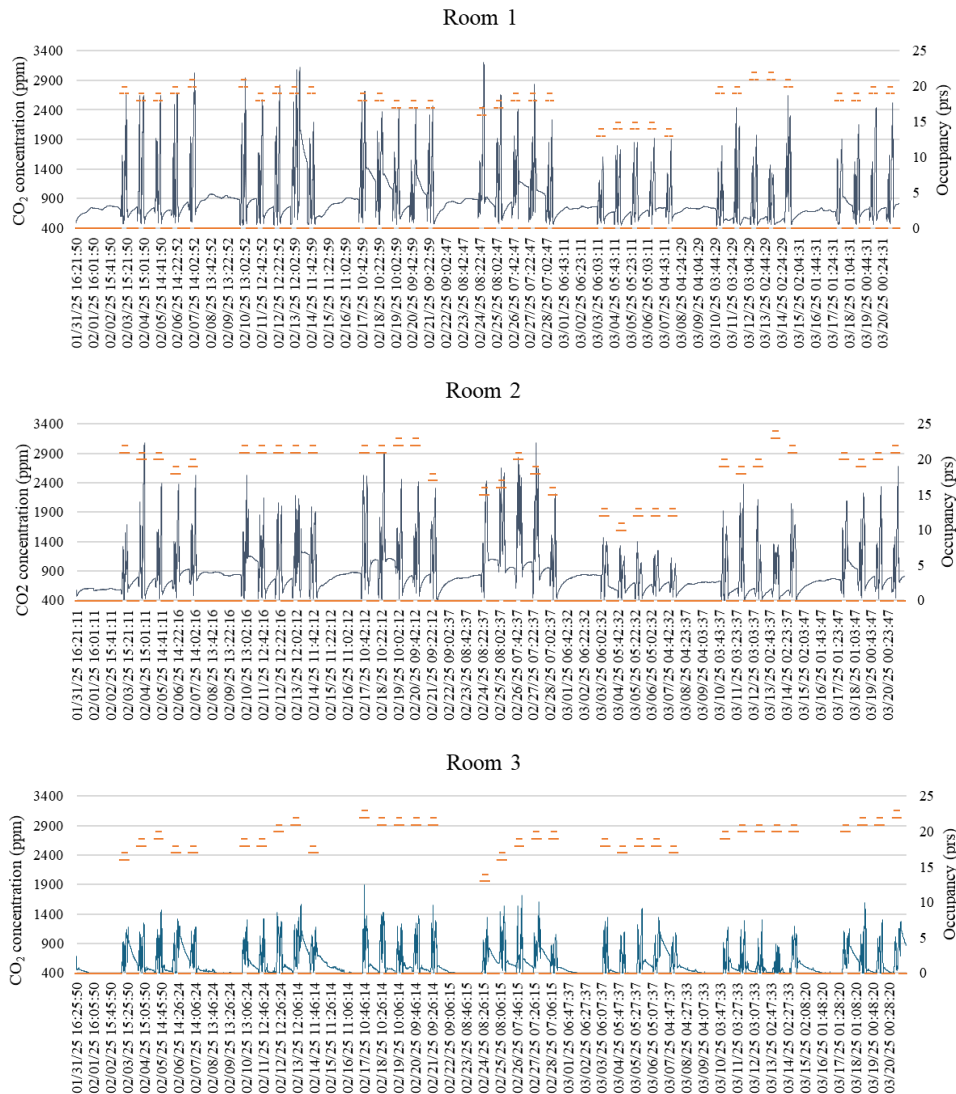


Fig. 2. Winter season CO₂ levels in rooms 1-3.

Although these 3 rooms have the same dimensions and also operable windows facing the same direction, significant variation in IAQ can be seen. Some differences can be seen following the changing occupancy of the rooms caused by missing children. The seasonal data shows a significantly better IAQ in case of room 3. The reasons for this phenomenon was further investigated.

On figure 3, winter season CO₂ levels can be seen in room 4. Both occupancy and floor area is lower than in case of room 1-3. It can be seen that CO₂ levels reach 3000 ppm many times and ventilation patterns are very similar to rooms 1 and 2.

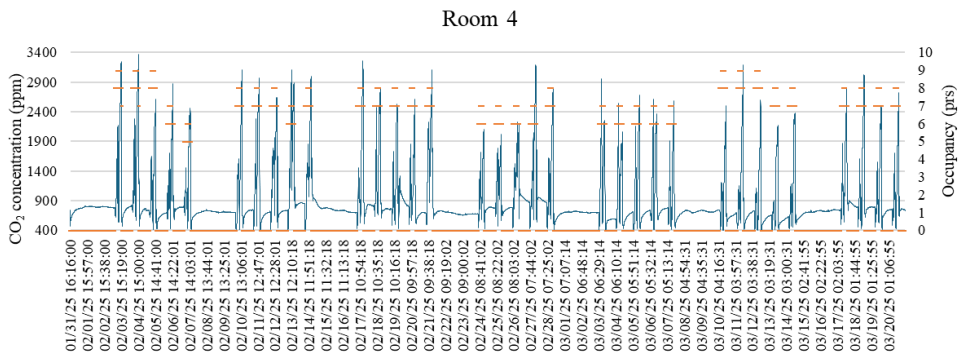


Fig. 3. Winter season CO₂ levels in room 4.

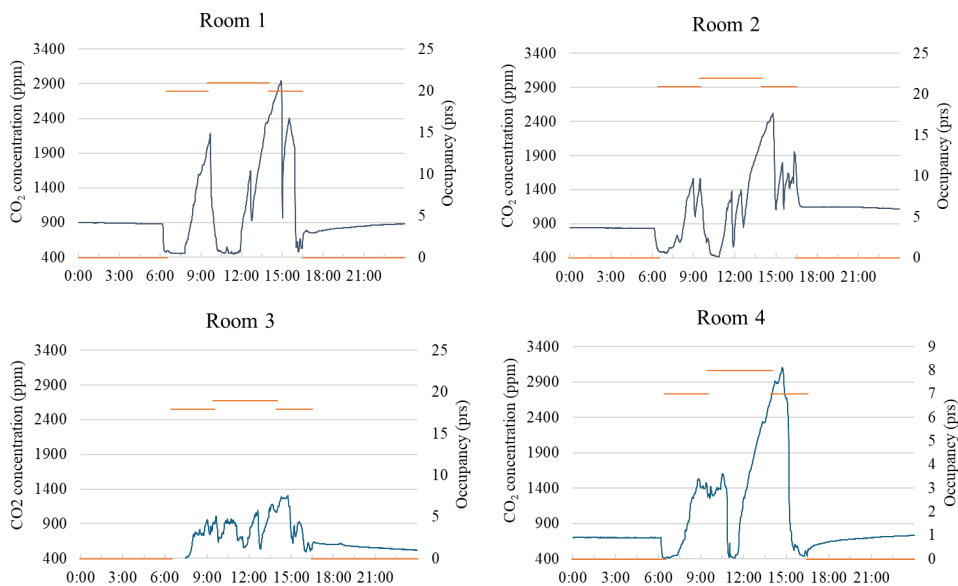


Fig. 4. One day (10. February) winter season CO₂ levels in rooms 1-4.

Daily CO₂ levels in the dataset and also on figure 4 show a more frequent set of drops in case of room 3 which indicates more frequent window opening behaviour.



Fig. 5. One week (10-16. February) winter season indoor temperature levels in rooms 1-4.

It was also investigated, whether more frequent window openings cause thermal discomfort in case of room 3, where CO₂ data showed significantly better IAQ due to frequent window openings. It can be seen on figure 5 that indoor temperature levels are very similar in room 3 to room 2. Significant thermal discomfort cannot be identified in case of room 3 due to more frequent window openings.

3.2 CO₂ frequency distribution

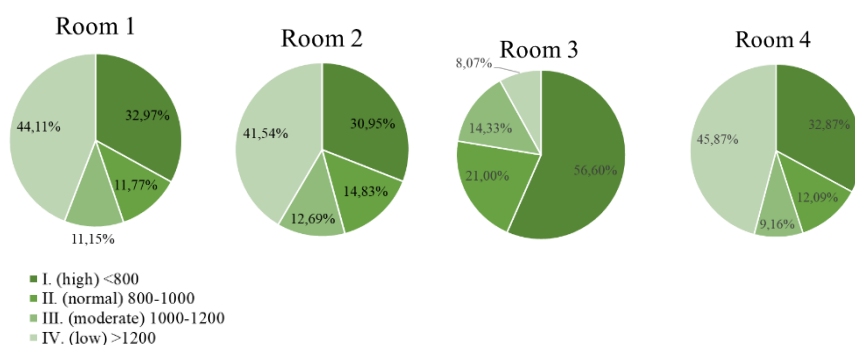


Fig. 6. CO₂ frequency distribution for winter season (10.02-20.03.) according to IAQ categories of standard EN 13779.

On Figure 6, an analysis is presented about the CO₂ level frequency distribution of each room in each season according to comfort categories of standard EN 13779. It can be seen that rooms 1,2 and 4 have very similar distribution with 41-46% of the time falling into low indoor air quality category.

In the appendix, table 3 and figures 6 and 7 present spring and summer season measurements. It can be seen, that lower IAQ is experienced in rooms 1, 2 and 4 in these seasons as well. Room 3 maintain higher IAQ with more frequent, often always open window opening behaviour.

3.3 Teacher interviews: occupant behaviour and IAQ

After analysing IAQ levels throughout the duration of the measurement, a clear picture could be depicted about the usual IAQ of each classroom. CO₂ levels were significantly higher for longer durations in case of classrooms 1, 2 and 4 and many times poor ventilation was detected with CO₂ levels of >1800 ppm falling into category IV (low-level expectation)

according to EN 16798-1 [9]. These values were registered for long (1-3 hours) periods of time.

Teacher interviews showed that teachers are content with the quality of air and reported no problems, symptoms.

Table 2 summarizes the window opening habits of each group room teachers (one interview sheet/group, answers were provided based on a consensus among teachers).

Table 2. Teacher interview results on window opening habits.

Group nr.	Winter	Spring	Summer
1	Turned door for 5-10 mins early morning, before and after meals and during outdoor time.	Same as winter + turned door during outdoor time.	Always turned door + all windows tilted.
2	Turned door during outdoor time and after every meal for 5-10 mins.	Same as winter + tilted windows if weather permits.	Turned door and turned windows for 1 hr in the morning for cooling, otherwise everything closed.
3	Turned door for 10-15 mins before meals and sleep time + additional 2-3 mins in every 30-40 mins.	Same as winter + during outdoor time: turned door and 2-3 tilted window.	Always turned door + all windows tilted.
4	Tilted window, 2-3 times per day for 30 mins + additional short periods every hour.	Tilted window, 2-3 times per day for 30-40 mins + additional short periods every hour.	Turned door + tilted window, always open in case of good weather.

Additional comments:

Group 2 finds everything adequate in terms of air quality, except for times with bad weather when they can't open windows, but no symptoms are reported.

Group 3 added that they always try to tilt windows during winter where currently there are no children playing close by.

Group 4 indicated window opening for restoring comfort as well.

None of the groups expressed that there would be any difference in the behaviour of teachers.

4 Discussion and Conclusions

The traditional ventilation design calculations include standardized, static design parameters which may not represent appropriately the most extreme design condition. This might be caused by the change of usage (more children in one room with demographic booms, daily schedule changes, e.g. all children in one room for a puppet show, etc.), or change in airtightness (e.g.: window change). Ultimately, this might cause poorer IAQ as it could be seen in the case of this child-care facility.

As rooms 1-3 have the same dimensions and also operable windows facing the same direction, variation in IAQ can be caused by different occupancy and the window opening behaviour of kindergarten teachers.

Rooms 1,2 and 4 shows very similar ventilation patterns: windows are open for shorter periods compared to room 3, night time and weekend CO₂ levels are much higher compared to outdoor levels which is caused by the high air tightness of the windows and also by a

habitual behaviour: not to open the windows before leaving work by the teachers. Teacher interviews showed some differences in case of teachers of room 3, but IAQ data shows an even greater difference than expected. Children of room 3 spend their time in a healthier environment with better IAQ solely due to the different window opening behaviour of their teachers.

Daily CO₂ levels in the dataset indicate more frequent window opening in case of room 3. As window opening sensors were not used in case of this study, further investigation is needed on the exact relationship between the drops in CO₂ levels and window openings. However, it can be seen at this stage as well, that teachers in room 3 pay special attention to IAQ and ventilation in general.

Interestingly, teacher interviews showed that respondents are content with the quality of air and reported no problems, symptoms in any rooms. This can be explained by a potential alleged or real influence or fear of the higher authority of the institution (head of the kindergarten). Another line of thought is the questionability of current IAQ and human health related standards and their general applicability. The studies providing a basis for these standards were most of the time conducted in laboratories occupied by young adults [11]. There is a possibility that children do not sense the stuffy air which might be unhealthy for them and also maybe kindergarten teachers are better used to “smelly” and stuffy air than an average IAQ lab participant. Either case, further investigations are required.

Based on these preliminary findings of the study, a CO₂-based automatic ventilation system was proposed to the head master of the facility and also continuous monitoring of IAQ and feedback to the teachers was suggested. Possibly recommendations on behaviour (e.g.: window opening) could be given as well.

Future work includes the correlation analysis of IAQ parameters, time spent outdoor per group with the number of missing children per group. Also, dynamic simulations are being conducted to model indoor conditions, CO₂ levels and also air change rate of group rooms. With this part of the investigations, potential efficiency of the proposed ventilation improvement measures can be evaluated.

5 Acknowledgement

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7 Appendix

Table 3. Statistics of each room per season.

		CO ₂ (ppm)				T (°C)				RH (%)			
		mean	st. dev.	mode	median	mean	st. dev.	mode	median	mean	st. dev.	mode	median
winter	Room 1	1161,9	577,6	456,8	1092,3	24,1	1,3	24,3	24,3	39,9	5,6	39,9	39,8
	Room 2	1136,7	547,1	424,7	1064,7	23,5	1,1	24,0	23,7	41,3	5,3	40,6	40,6
	Room 3	760,4	281,3	369,5	740,5	22,8	1,0	23,0	22,9	39,9	6,3	38,6	39,3
	Room 4	1250,1	696,9	411,0	1106,0	24,0	1,0	24,0	24,2	41,0	5,8	42,8	41,4
spring	Room 1	999,1	471,9	696,8	869,8	24,0	1,0	24,3	24,1	49,0	6,2	52,5	50,2
	Room 2	987,5	470,4	707,7	924,7	23,6	0,8	23,9	23,7	50,4	5,8	54,2	52,0
	Room 3	630,8	257,0	381,5	562,5	23,1	0,8	23,5	23,2	49,8	7,3	51,2	50,9
	Room 4	1063,5	639,7	634,0	852,0	23,8	0,7	24,0	23,9	50,3	6,5	55,5	51,4
summer	Room 1	770,9	390,3	643,8	641,8	25,4	0,7	25,8	25,4	55,5	6,1	61,4	56,0
	Room 2	706,8	297,3	662,7	660,7	25,6	0,7	26,2	25,5	55,4	6,0	59,1	55,7
	Room 3	569,5	247,0	358,5	478,5	25,3	0,7	25,3	25,3	56,8	6,1	58,8	58,8
	Room 4	823,0	480,8	555,0	582,0	25,4	0,8	25,4	25,4	57,8	6,6	59,3	59,0

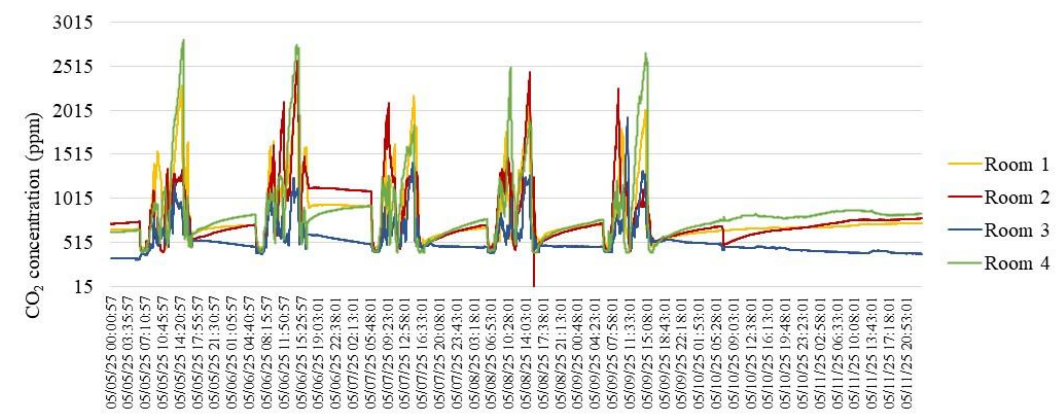


Fig. 6. One week (5-11. May) spring season indoor CO₂ levels in rooms 1-4.

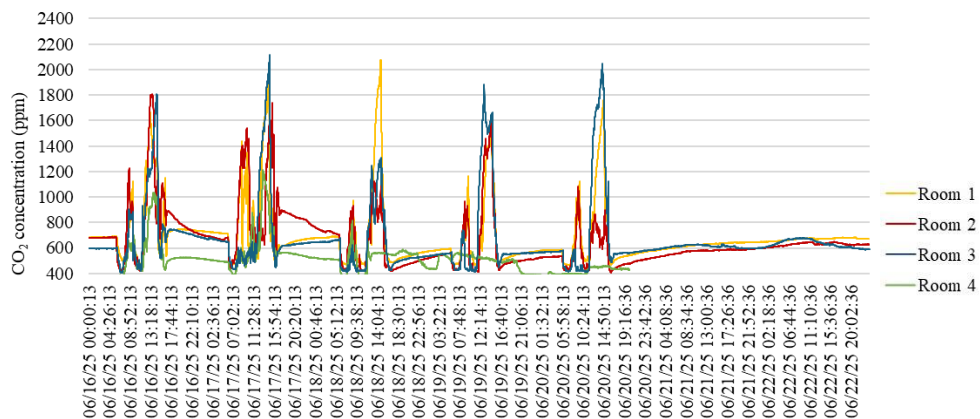


Fig. 7. One week (16-22. June) summer season indoor CO₂ levels in rooms 1-4.