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λEvaluating Effects of Indoor Air Quality in School Buildings and Students' Health:A Study in Ten Schools of Kuopio, Finland

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Abstract. The quality of indoor air is commonly measured by temperature, humidity and carbon dioxide (CO_2) sensors. Volatile Organic Compounds (VOCs) are usually analyzed using air samples, but also sensors that detect odors and gases are available. In this study, Total Volatile Organic Compounds (TVOC) and Carbon Dioxide (CO_2) concentrations were measured by continuous measurement sensors in schools of Kuopio, Eastern Finland. Results and conclusions, concerning two comparable school buildings' Indoor Air Quality (IAQ) conditions are described by means of carbon dioxide (CO_2) and total volatile organic compounds (TVOC) concentrations; hourly averaged daily curves and distributions. The results indicate that during school days, the CO2 concentrations have been within recommended ranges. In addition, TVOC values stay on relatively low level below 3 ppm. According to recommendations and limit values of many scientific sources, the observed levels should not cause any uncomfortable effects on humans' health and comfort. Occupants' perceptions of IAQ were collected by questionnaire. These responses also support results and conclusion based on measured IAQ data.

Keywords: School, volatile organic compound, indoor, carbon dioxide, building, air quality

1. Introduction

In Western Europe many people may be exposed to indoor air for more than 20 hours per day. The quality of indoor air has considerable impacts on human health and comfort. These two facts explain the growing interest in characterisation of indoor air quality, for example, by means of carbon dioxide (CO_2) and total volatile organic compounds (TVOC). Carbon dioxide is a colourless, odourless, non-flammable gas, and at high levels it is considered to be a potential inhalation toxicant [1]-[3]. In the school classrooms, elevated CO_2 concentrations typically indicate insufficient ventilation. Sufficient ventilation is needed in order to control chemical and biological indoor air pollutant that may cause increased risk for health symptoms [4]. Over the past two decades, a large number of studies in school environments have also evaluated the importance of indoor allergen exposures [5]. Also, indoor environmental quality of low allergen school has been investigated and compared to three standard primary schools [6].

The presence of volatile organic compounds (VOC) in indoor air is associated with adverse health effects such as sensory irritation, odour and the more complex symptoms called the Sick Building Syndrome (SBS). VOCs are chemicals that include carbon and evaporate at room temperature. Many materials commonly used in buildings, paints, thinners, gasoline-powered machinery, building materials and furniture together with cleaning chemicals and cigarette smoke, contain VOCs. The total VOC (TVOC) is used as a measure of the concentration of air pollution and measure of the health risk in non-industrial buildings [7]. The study of uncontrolled public facilities suggests criteria to conduct a risk assessment of VOCs [8]. Influence of the room occupancy on the indoor air quality has been analysed to distinguish relationship between outdoor and

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indoor air quality in French school buildings [9]. Finally, indoor air limit values for VOC emissions in Germany, France and California are compared, and found these limit values urgently need harmonization throughout industrial countries [10].

This study presents results concerning indoor air quality in two schools in Eastern Finland. IAQ conditions are evaluated by means of examination of carbon dioxide (CO_2) and total volatile organic compounds (TVOC), presenting their hourly averaged daily curves and distributions.

2. Materials and Methods

2.1. Data Collection

Utilizing a building monitoring and control system [11], developed by research group of environmental informatics, indoor air quality data was collected from 10 school buildings in Kuopio, Eastern Finland. The collected data consisted of continuous measurements of temperature, relative humidity (RH), CO_2 concentration and TVOC concentration. This study focuses the concentrations of CO_2 and TVOC. Especially, the daily variation of parameters and hourly cumulative concentrations were explored in school buildings presented in Table 1. Daily variations and distributions of CO_2 and TVOC were surveyed in schools number 2 and 3. These two schools were selected because of the same construction year 1968 with renovations in 2006 and 2007, correspondingly.

Table1: Information on study schools and their measurements.

School	Heated	Construction	Renovation	Measurement Period		No. of Measurements		Missing
Number	Vol. (m^3)	Year	Year	Start	End	CO_2	VOC	Values %
1	6700	1997	-	11-Oct-2011	11-Jul-2012	5	1	6
2	**26130**	**1968**	**2006**	**10-Nov-2011**	**12-Jul-2012**	**5**	**1**	**15**
3	**7935**	**1968**	**2007**	**10-Nov-2011**	**12-Jul-2012**	**5**	**2**	**24**
4	19900	1954	2008	10-Nov-2011	12-Jul-2012	5	1	29
5	10350	1953	1992	10-Nov-2011	4-Jun-2012	5	2	24
6	30808	2003	-	10-Nov-2011	12-Jul-2012	7	2	61
7	34235	2011	-	11-Nov-2011	22-May-2012	5	2	43
8	21000	1924	1997	10-Nov-2011	12-Jun-2012	5	1	67
9	7000	1935	2004	14-Nov-2011	12-Jul-2012	5	2	57
10	36965	2011	-	11-Nov-2011	20-Apr-2012	5	2	68

In each school building studied, the continuous measurements of CO_2 were performed in 5 to 7 classrooms and TVOC measurements were performed in 1 to 2 classrooms. Missing values % describes the uncertainties in the measurement events, basically lead by sensor data transfer. Exact measurement arrangements are reported elsewhere [12].

2.2. Data Analysis

The data were analysed under a Matlab-software platform (Mathworks, Natick, MA, USA). First, collected data were pre-processed removing outliers (e.g. measuring errors) and then measured parameters were calculated to hourly averaged values. The original measurement frequency was 10 seconds. In addition, for not to distort the indoor conditions originated by school building users the vacation weeks 42/2011, 52/2011, 10/2012 and 23-28/2012 have been removed from the data.

2.3. Occupant Questionnaire

In the study schools, a computer based test designed to measure attention and cognitive performance was conducted by the University of Eastern Finland School of Applied Educational Science and Teacher Education. The test was taken in the Internet and it included an educational video about the greenhouse effect, followed by questions. Pupils in grades from 5 to 8 participated in the test during a regular school week. Also a questionnaire, developed by the National Institute for Health and Welfare, was embedded to

this performance test. The questionnaire included 17 questions. The questions were mainly about pupils' health and well-being, and also questions regarding to the indoor air quality in the classroom was included.

3. Results and Discussion

3.1. Carbon Dioxide (CO_2) examination

The hourly averaged daily trends of CO_2 concentrations in two comparative schools have been presented in Figure 1. By exploring the hourly mean values, the daily trend curves of schools number 2 and 3, it was seen that school number 2 has higher hourly averages than school number 3. The difference between schools concerning the CO_2 levels may be explained by smaller number of pupils in the class room in the school number 3 (average 18). Respectively, the average size of education group in the school number 2 is 21. Both of the schools have mechanical exhaust and income ventilation system with heat recovery. It appears that during the school days (Monday to Friday) from 8 am to 3 pm CO_2 concentrations are within the recommended ranges in both of the study schools.

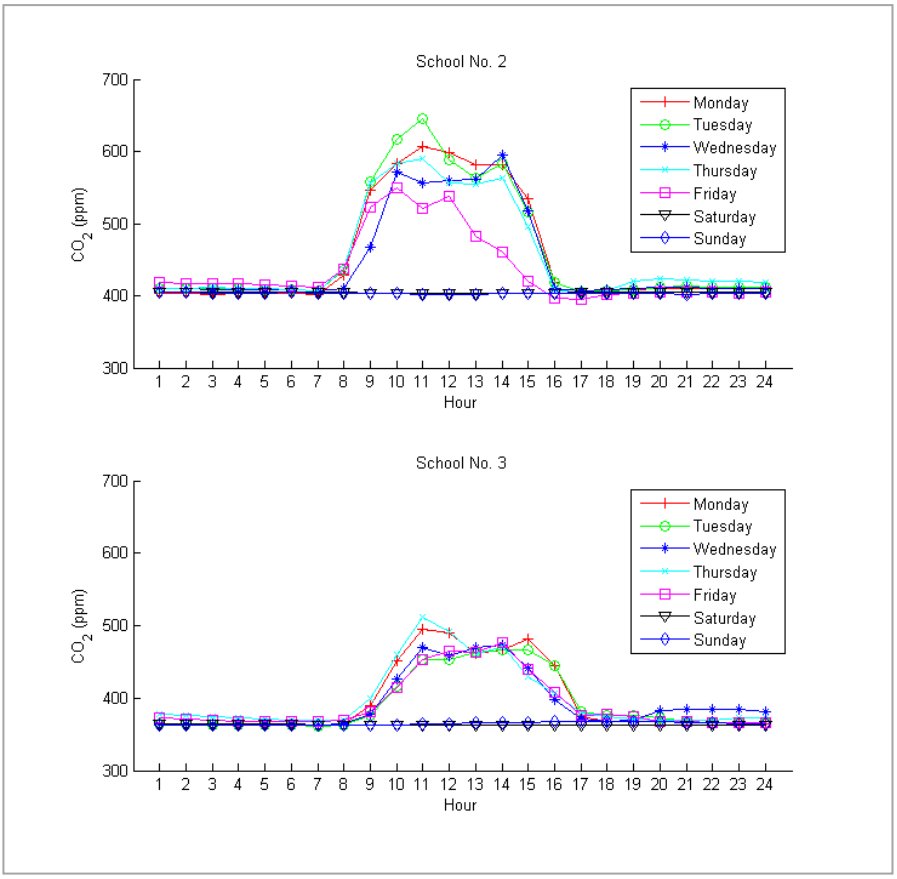

Fig. 1: CO_2 concentrations in schools number 2 and 3.

Distributions of CO_2 concentrations indicating classrooms' IAQ have been presented in Figure 2. The blue colour describes most of the all measurements, representing CO_2 concentrations less than 750 ppm in both study schools. Every measurement is an event consisted of hourly mean value between 8 am to 3 pm on school days. Indoor air quality can be described by means of CO_2 levels according to Finnish Classification of Indoor Climate 2008 based on standard EN 15251 in three categories as follows [13], [14]: S1 (ppm $\leq$ 750) named "individual" and described *very good*, S2 (750 < ppm $\leq$ 900) named "comfortable" and described *good*, S3 (900 < ppm $\leq$ 1200) named "satisfactory" and described *satisfactory*. The publication of Finnish Ministry of Social Affairs and Health [15] defines the indoor CO_2 values below 1500 ppm to be acceptable. However, the range 1200 < ppm $\leq$ 1500 can be described *unsatisfactory*. Values above 1500 ppm can be described *unacceptable* and ventilation should be increased.

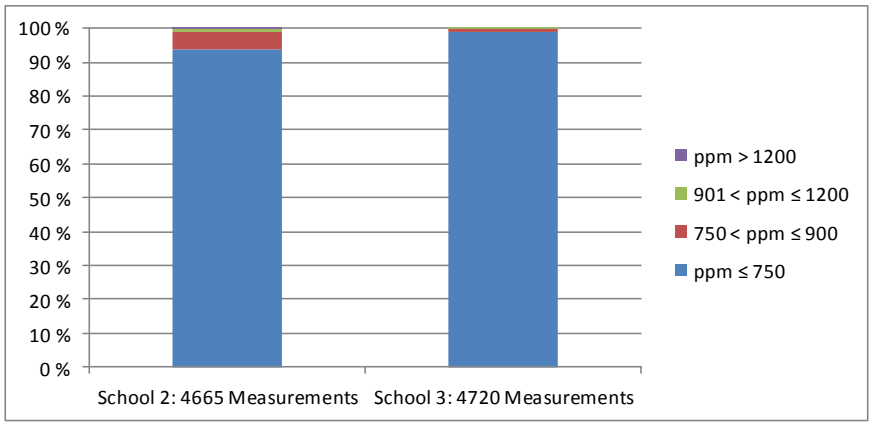

Fig. 2: Distribution of CO_2 concentrations indicating indoor air quality of schools number 2 and 3. In the school number 2 there were total of 4665 events, 4378 events ppm ≤ 750, 231 events 750 < ppm ≤ 900, 52 events 900 < ppm ≤ 1200 and 4 events ppm > 1200. Respectively, in the school number 3 there were altogether 4720 events, 4666 events ppm ≤ 750, 47 events 750 < ppm ≤ 900, only 7 events 900 < ppm ≤ 1200 and none more than 1200 ppm.

From the questionnaire data, Table 2 shows the frequency of pupils' perceived stuffiness or poor indoor air quality, which could be related to insufficient ventilation (and perhaps high CO_2 concentrations). From the respondents, between 12.1 to 26.9 per cent have perceived stuffy air or poor indoor air quality during the day, or within a week prior to the day, when the questionnaire was conducted.

Table 2: Information on occupant questionnaire concerning CO_2 conditions felt in study schools. Question 1: Has stuffiness or poor indoor air quality in the school caused discomfort or inconvenience?

Question 1		School No. 2		School No. 3	
		Frequency	Percent	Frequency	Percent
Response:	No	92	63.4	23	69.7
Missing responses		53	36.6	10	30.3
Total		145	100.0	33	100.0
Response:	Yes, Today	19	13.1	4	12.1
Missing responses		126	86.9	29	87.9
Total		145	100.0	33	100.0
Response:	Yes, During the last week	39	26.9	7	21.2
Missing responses		106	73.1	26	78.8
Total		145	100.0	33	100.0

3.2. Total Volatile Organic Compounds (TVOC) examination

The daily trends in Figure 3 describe the hourly mean values of TVOC concentrations for each weekday. In the school number 2 there has been one TVOC sensor located on the wall of classroom. In the school number 3 there were TVOC sensors mounted on two classrooms. The daily trends of school number 3 are averaged hourly values of these two sensors. When studying the hourly TVOC curves in figure 3 during the school days, we can distinguish some differences between the study schools. In the school number 2, the TVOC values are on the lower level (approximately 3-4 ppm) outside school hours. In addition, in the school number 2 we can find TVOC values decreasing on the level 1 ppm within two hours, when ventilation system is turned on at 7 am in the morning on school days. In the school number 3 the TVOC levels are not decreasing as fast and there is more variation between school days. Presumably, variation in the afternoons' trends between weekdays is due to two TVOC sensors and different utilization of the classrooms. It was found out that on Friday afternoons there is a craft club meeting raising TVOC values. During weekends the

ventilation has been turned off and TVOC levels are stable. Presumably, this constant level is based on emissions of construction materials and furnishing.

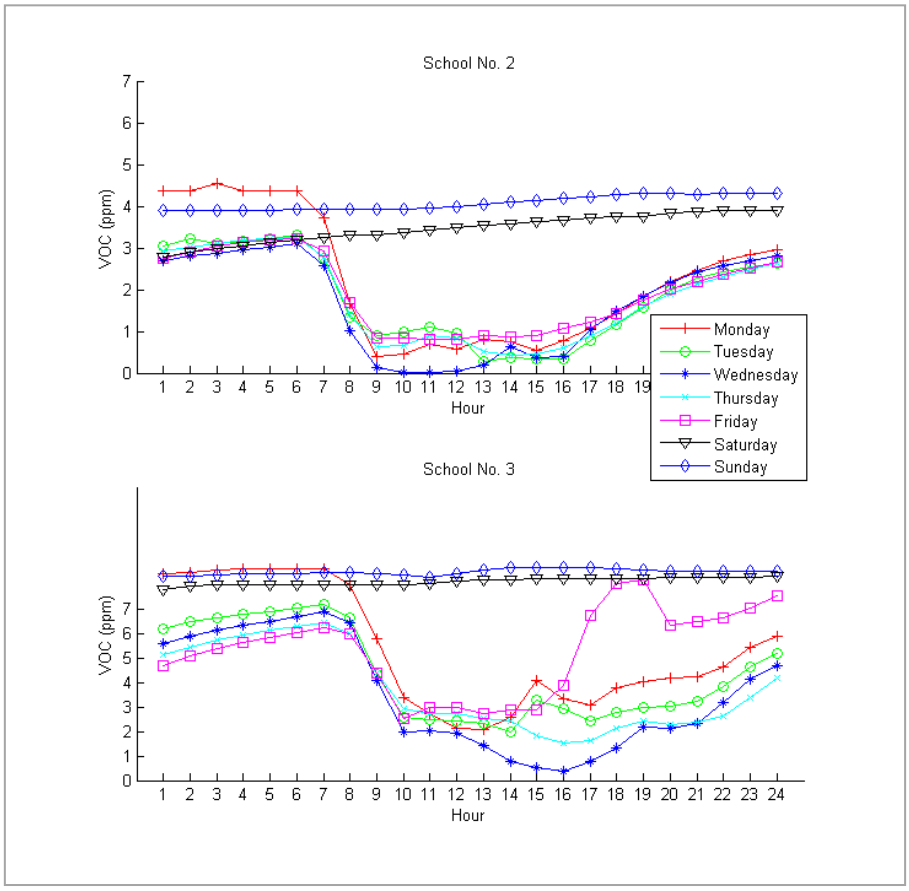

Fig. 3: TVOC concentrations in schools number 2 and 3.

The distributions of TVOC concentrations indicating classrooms' IAQ have been presented in Figure 4. The blue color describes most of the all measurements, representing TVOC concentrations less than 5 ppm in both study schools.

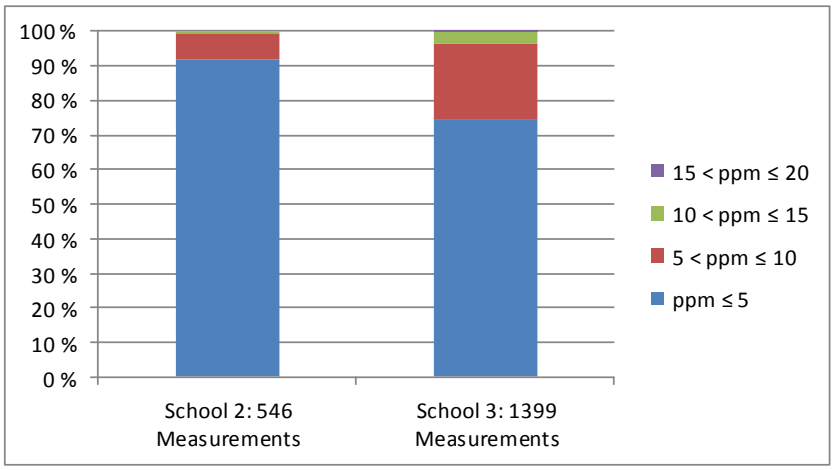

Fig. 4: Distribution of TVOC concentrations indicating indoor air quality of schools number 2 and 3. In the school number 2 there were total of 546 events, 500 events ppm ≤ 5, 44 events 5 < ppm ≤ 10, 2 event 10 < ppm ≤ 15 and none 15 < ppm ≤ 20. Respectively, in the school number 3 there were altogether 1399 events, 1040 events ppm ≤ 5, 310 events 5 < ppm ≤ 10, 46 events 10 < ppm ≤ 15 and 3 events between 15 < ppm ≤ 20.

However, in the school number 3 we can find more variation and more medium or high TVOC values. Every measurement is an event consisted of hourly mean value between 8 am to 3 pm on school days. Indoor air quality can be described by means of TVOC levels according to TVOC sensor manufacture's manual in six categories by indicator leds [16]. The measurement range extends up to maximum 30 ppm. Because of lower than 20 ppm existing in these measuring points, only the four lowest levels are presented. At present, the available data do not allow establishing of thresholds for TVOC [17]. The lower the TVOC concentration in indoor air, the lower is the risk that compounds will adversely effect on occupants' health and comfort [10].

Table 3 presents frequency of reported unpleasant odours. Such odours could be originated by e.g. volatile organic compounds. From 3.0 to 37.9 per cent of respondents reported unpleasant odours during the day, or within a week prior to the day, when the questionnaire was conducted.

Table 3: Information on occupant questionnaire concerning TVOC condition felt in study schools. Question 2: In the school indoor air, have you felt an unpleasant odor that has caused you discomfort or inconvenience?

Question 2		School No. 2		School No. 3	
		Frequency	Percent	Frequency	Percent
Response:	No	75	51.7	22	66.7
Missing responses		70	48.3	11	33.3
Total		145	100.0	33	100.0
Response:	Yes, Today	29	20.0	1	3.0
Missing responses		116	80.0	32	97.0
Total		145	100.0	33	100.0
Response:	Yes, During the last week	55	37.9	10	30.3
Missing responses		90	62.0	23	69.7
Total		145	100.0	33	100.0

4. Conclusion

In this research paper we have shown results of IAQ measurements in school classrooms. In this paper we focused on CO_2 and TVOC hourly averaged daily trends and distributions, evaluating their impacts on school building occupants during school days. The results indicated that during school days CO_2 concentrations were within recommended ranges in both of the study schools. The small difference between these two schools with respect to CO_2 levels can be explained by differences in the number of pupils in the classrooms. In addition, TVOC values stayed on relatively low level (below 3 ppm) during school days, particularly in the school number 2. The levels observed should not cause adverse effects on occupants' health and comfort.

This paper presents multidisciplinary results by combining IAQ measurements and occupants' sensations of perceived indoor IAQ. Data on occupants' perceived IAQ were collected by questionnaires. The questionnaire data give some relevant background information on indoor conditions perceived in the study schools.

The measurements of schools' IAQ will be continued, and the reliability of measurement system could be improved by e.g. developing the data transfer of wireless sensors.

Results and conclusions of this paper can be utilized by the City of Kuopio, Tilakeskus (in Finnish), who owns and maintain the buildings. This type of information can be used make adjustments to the ventilation system setups, if necessary, also considering energy efficiency, as well as occupants' health and comfort.

5. Acknowledgements

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