IAQ MONITORING AND ANALYTICS FROM OFFICES TO SCHOOL BUILDINGS

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720 Degrees Oy

ABSTRACT

In 2017, at least four weeks of continuous data were available from six Finnish school buildings, including temperature (T), relative humidity (RH), and concentrations of carbon dioxide (CO_2), volatile organic compounds (VOCs), and particulate matter ($PM_{2.5}$). Parallel to the larger sample of over one hundred office buildings, we report a comparative assessment of the results. Using the same analytical tools than in the offices, estimated mean ventilation rates were significantly lower in the schools, and somewhat higher pollutant levels (e.g. VOCs) were observed. Temperatures tended to be lower in schools, yet the recommended conditions were met. Occupancy patterns are different in schools, which should be taken into account. Time series modeling is a promising technique that could help minimizing the delays in responding to potential IAQ issues.

INTRODUCTION

Previously we have reported results from continuous indoor air quality (IAQ) monitoring in a large sample of over one hundred Finnish office buildings based on newly developed analytical tools. While school buildings could also benefit from continuous monitoring, schools have been less active in utilizing commercially available monitoring and analytical services. Hereby we present results from monitoring of six schools over 2017, and a comparative assessment with a larger sample of over one hundred offices monitored over the same period of time. Some results from time series modelling are also presented. In addition, we will discuss needs to specify analytical processes for schools in terms of occupancy and other pertinent characteristics, and the interpretation of the results accordingly.

MATERIAL AND METHODS

Data on IAQ parameters, including T, RH, CO_2, VOCs, and $PM_{2.5}$, have been continuously collected from a large sample of Finnish offices and also some school buildings. In 2017, at least four weeks of continuous data (15 s interval) were available from six Finnish school buildings along with similar data from over one hundred office buildings.

Whereas the 720 Degrees solution for IEQ analytics is not limited to any specific sensor type (clients own their own sensors, which are connected to the system), all clients are currently using the same type of sensors. The sensors used to collect data for this paper were less than three years old in 2017. Gas sensors are based on solid state or NDIR in option, and according to manufacturer, their life time is >10 years. Lifetime for T is unlimited, whereas the humidity drifts max +/-0.5% RH per year. Accuracy and measuring ranges are as follows:

- Temperature: + / - 0.3° C, resolution 0.1° C, range from 0° to + 50° C.
- Relative Humidity: + / - 3%, measuring range: 10% to 90%, resolution 1%.
- CO_2: + / - 100 ppm & 15% (50ppm & 2% in NDIR) at 25°C and 1013mbar, measuring range: 390 to 3500 ppm (2000ppm in NDIR), 10 ppm resolution.
- VOCs: + / - 0.1 ppm & 15% (Formaldehyde equivalent). Max 300ppm, 0.01 ppm resolution. Above accuracies require the probe to be associated with active air renewal.

VOCs sensors are being converted to a newer model that displays mass concentration (µg/m3) and is ISO 16000-29 TVOC compliant. In the future, also previously collected data can be converted to mass concentration. However, the results in this paper are still based on non-converted data in ppb. The interpretation of the VOCs data is therefore mainly based on relative differences, however, it is also noted that some guideline values exists for TVOCs in ppb. /1/

With respect to each monitored parameters, both 8-hour (corresponding to typically occupied hours) and 24-hour mean, minimum, and maximum values as well as standard deviations were calculated.

Ventilation rates were estimated based on CO_2 concentrations using the peak approach as described in a previous paper /2/. CO_2 generation rates were based on Persily & Jonge (2017) /3/. It should be noted that CO_2 generation rates are lower for children and adolescents than for adults.

Material emissions were detected based on methodology described by della Vecchia et al. using VOCs detected from night time series (weekdays between 4 pm and 8 am) /4/. Both number of days with ME detected and maximum concentrations for ME were included in the analyses. These results will be reported more detailed elsewhere.

Statistical analyses were done with IBM SPSS Statistics version 24, including descriptive statistics and generalized linear mixed modelling (GLMM), where building id and sensor (node) id were used as subjects variables, and the month of the year as a fixed effect.

In addition, times series analyses were conducted. An aim of time series modelling is to be able to use the historical IAQ data to forecast future trends. Thus far, analytical procedures for indoor $PM_{2.5}$ have been developed. Indoor $PM_{2.5}$ is largely dependent on outdoor $PM_{2.5}$, and an example using four latest indoor and outdoor hourly average values is included in this study. The model is based on Random Forest for regression and is used to predict the next hour PM value. The training set consists of data from schools during Jan - Nov 2017 and the test set consists of data from Dec 2017.

With these analyses we seek information that can be used to sustain good indoor climate for building occupants. Ultimately, the large amount of high resolution data collected over long period of time has to be translated into meaningful information, so that the results can be used to improve indoor environments proactively.

RESULTS AND DISCUSSION

Table 1 shows descriptive statistics for offices (combined) and for each school separately. The results are shown as an 8-hour averages during the weekdays, which is more relevant than 24-hour averages for offices and also for schools. It can be seen that T and RH values are comparable and satisfactory both in offices and the sample of schools monitored. However, temperatures tended to be lower in the schools throughout the year.

Table 1. Descriptive statistics for 8h average (SD) throughout 2017 (occupied time).

	Temperature [oC]	Relative Humidity [%]	Ventilation rate [l/s-person]	VOCs [ppb]
Offices (combined)	22.5 (1.7)	27.2 (11.7)	39.2 (22.0)	155.6 (340.8)
School 1	22.1 (1.5)	28.8 (11.1)	19.2 (12.0)	312.6 (441.2)
School 2	21.6 (0.9)	29.4 (11.7)	18.8 (15.4)	273.7 (423.9)
School 3	22.1 (1.1)	26.3 (12.2)	11.0 (5.4)	334.7 (7694.9)
School 4	22.0 (1.3)	31.5 (11.3)	25.8 (12.4)	329.8 (371.0)
School 5	21.4 (1.3)	23.5 (4.7)	25.1 (21.4)	67.9 (76.4)
School 6	21.7 (1.5)	32.2 (13.5)	19.2 (15.0)	45.5 (65.7)

Ventilation rates are exceeding recommended minimum ventilation rates in all buildings. However, estimated mean ventilation rates were significantly lower in the schools. Standard deviation values indicate that the ventilation rates could occasionally fall below the action limit of 6 l/s-person /4/ at least in some classrooms.

As expected, the concentrations of VOCs vary largely and the distribution of the values is skewed with some extreme values. Therefore, a logarithmic transformation was performed before further analyses, resulting in normally distributed data. Somewhat higher pollutant levels were observed in most of the schools as compared to the offices.

School hours in Finland are often less than eight hours long, which could result in some uncertainty with respect to estimating parameters that are influenced by occupancy patterns (such as thermal conditions and indoor sources of pollutants). It is also noted that in addition to night time, limited occupancy and operation of heating and ventilation systems during the weekend and summer time results in conditions that are not representative of normal use.

The following analyses were focused on temporal and spatial (room level) variations. Figure 1 shows results from School 3 that had the lowest ventilation rates. Summer months (from June to August) are not representative of the building use and should be neglected.

It appears that the monthly average values are above 6 l/s-person action limit throughout the year. With respect to daily values, a total of 606 values were estimated (for nodes 1-6, the number of days with estimated ventilation rates were as follows: 45, 154, 103, 113, 37, 154, respectively). The number of days when ventilation rates were below 6 l/s-person was 25 (for nodes 1-6: 1, 3, 3, 3, 14, 1, respectively). Thus revealing one location (zone) where ventilation rates were below the action limit quite frequently, 14 out of 37 days estimated.

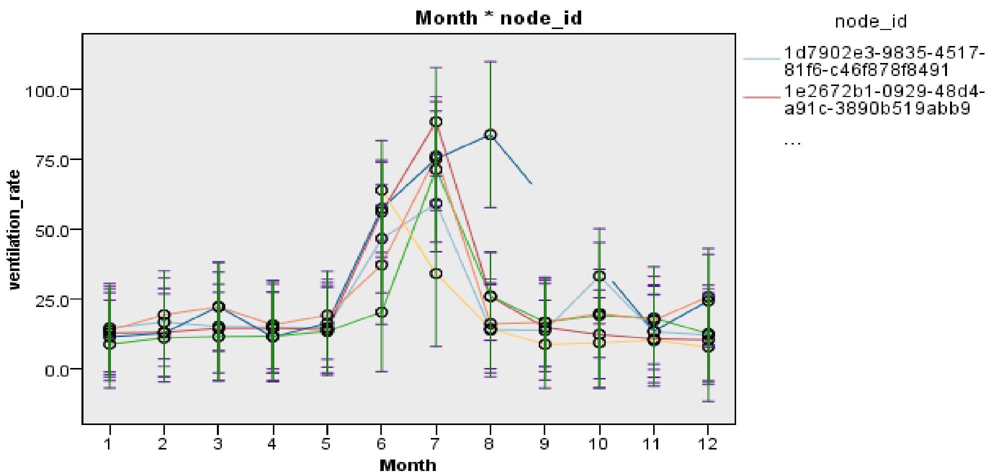

Figure 1. Estimated ventilation rates (l/s-person) by month in School 3.

Figure 2 displays monthly VOCs concentrations using log-transformed data. It seems that School 1 has an increasing trend throughout the year, whereas the opposite (decreasing) trend is seen for School 6. For School 3, first part of the year is decreasing, followed by an increasing trend for second half (could be attributed to refurbishment over the summer). For School 4, the levels remain relatively high throughout the year.

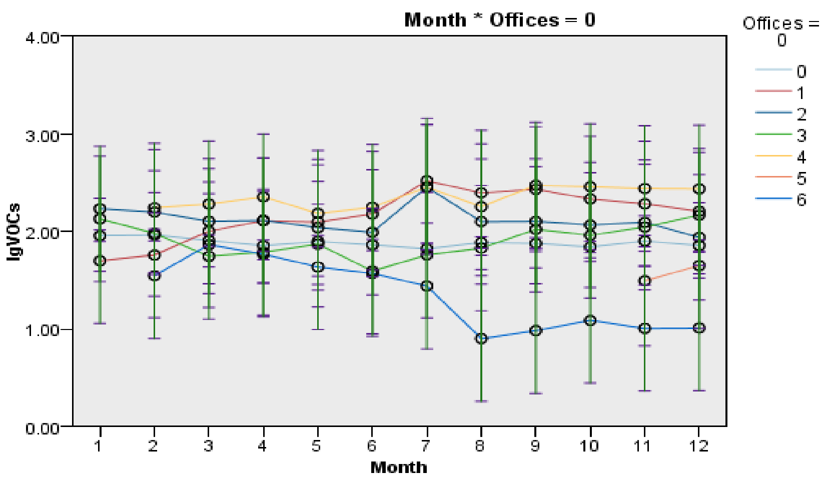

Figure 2. Monthly average VOCs concentrations.

However, there exists some variability within the schools. For example in School 4 (see Figure 3), some classrooms have decreasing trends and some other classrooms increasing trends (higher variability during the first half of the year). There was a weak (r =-(0.2-0.3)), but statistically significant negative correlation between ventilation rates and VOCs concentrations, indicating that lower ventilation rates corresponded with higher VOCs concentrations.

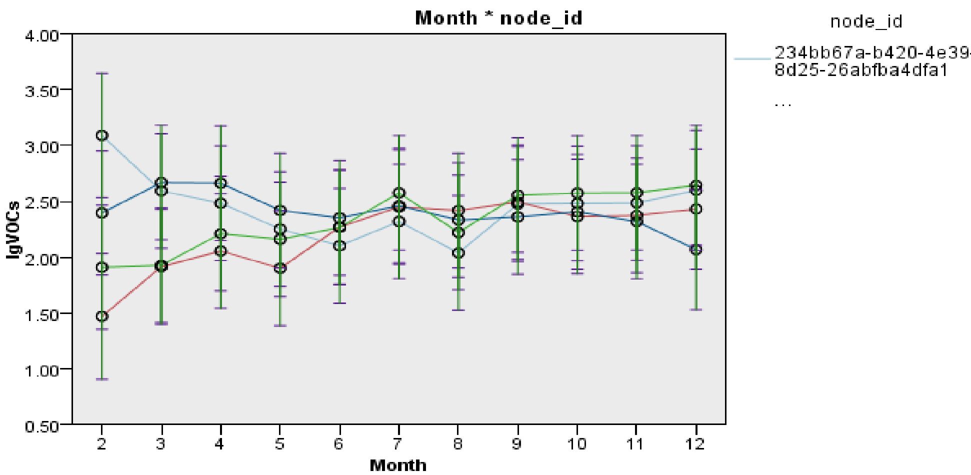

Figure 3. Monthly average VOCs concentrations for individual sensors in School 4.

The results from time series model for the next (future) hour $PM_{2.5}$ in schools data indicate a model fit with R2 .95, Mean absolute error 0.12, and Mean squared error 0.08. Based on these indicator, short term predictions of $PM_{2.5}$ can be made with a relatively good certainty. Future modeling will focus on next 24 hour predictions, which is more challenging and may require incorporation of additional variables, such as building, ventilation and occupancy characteristics. Predicting IAQ parameters could be used for developing more “real time” procedures for building operation, in order to minimize delays from 1) observation to 2) making adjustments to 3) those adjustments making an effect.

CONCLUSIONS

School buildings could benefit from continuous IAQ monitoring. Building characteristics as well as occupancy and time consumption patterns are different from office (work) environments and should be carefully considered when analyzing the monitoring results. Both temporal and spatial differences can be observed, especially in terms of ventilation and indoor air quality (e.g. VOCs concentrations). Predicting future trends could help in minimizing the delays in responding to potential IAQ issues.

REFERENCES

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