CLIMA 2022
Eye on 2030 | Towards digitalized, healthy, circular and energy efficient HVAC
REHVA 14th HVAC World Congress
22nd – 25th May, Rotterdam, The Netherlands

Impact of night-time ventilation on indoor air quality in kindergartens and schools

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Abstract. In Finland, the public sector employs about 30% of the total employment and the building users include just under a million children and students. Therefore, a good indoor climate in public buildings and the proper use of ventilation systems are important. Night ventilation is commonly used to improve indoor air quality in educational buildings before the premises are used. A typical use has been to turn off the ventilation after using the facilities and restart it about 2 hours before reusing those facilities. Another option is to keep night ventilation running at minimum ventilation. The third option is to use night ventilation intermittently. Although current technology allows ventilation systems to be monitored and controlled using air temperature, carbon dioxide, and presence sensors, it is very common to keep ventilation units running continuously, even if it significantly increases the energy consumption of ventilation. In this study, the pre-started, continuous, and intermittent ventilation strategies were compared by assessing indoor air quality in field measurements during different seasons in 2019 and 2020. The daytime ventilation was kept as usual. Each test period lasted for 2 weeks. Indoor air quality was assessed by measuring TVOC with the metal oxide semiconductor method and microbes by using the quantitative PCR method. Also, CO2, pressure over building envelope, and thermal conditions were measured. The results indicate that the average TVOC concentrations were similar during mornings with all the ventilation strategies. TVOC concentrations were higher during the day than at night. This indicates that the use of the facilities had the greatest effect on TVOC concentrations. The microbial concentration was usually only a few percent of the corresponding outdoor air concentration. The used strategy of night ventilation did not have a systematic effect on indoor microbial concentrations.
In general, the natural variation of the measured physical quantities was greater during the test periods than could be observed with different night ventilation operating strategies. The working conditions at the measured buildings were at normal levels. The results show that 2 hours of ventilation before the premises are used is sufficient, and thus continuous ventilation at night is not necessary.

Keywords. Night ventilation, pollutant sources, indoor air quality, kindergarten, school
DOI: https://doi.org/10.34641/clima.2022.288

1. Introduction

Poor indoor air quality in schools and kindergartens has been widely reported in research literature [1-4], and it is often connected to difficulties in learning [5-7]. To improve the situation, ventilation use patterns have been altered in public buildings. The European standard 16798-1:2019 recommends that the ventilation system is pre-started before space usage or is run continuously at a minimum power during unoccupied times to ensure that there are no contaminants present when the space usage begins.

In Nordic countries, this recommendation has been applied in three ways. One method has been to stop the ventilation when the building is not in use and pre-start it two hours before the occupied periods. Another common method has been to run the fans at partial power during unoccupied periods to ensure the removal of contaminants. Finally, a third strategy has been to intermittently ventilate the spaces during unoccupied periods by running the fans for an hour or two.

While it is well-known that insufficient ventilation during unoccupied time can lead to accumulation of contaminants originating from building materials and furniture [8-9], the effects of different night-time ventilation strategies have not been studied. There have been concerns from the public that if the fans are not run continuously, contaminant concentrations and humidity in the spaces could reach alarming levels during occupied hours. Continuous operation of ventilation systems, however, considerably increases the building energy consumption and thus is not a preferable strategy unless ensuring sufficient indoor air quality demands it.

The purpose of this study was to fill the knowledge gap on how different night-time ventilation

strategies affect the indoor air quality. To assess this, field measurements were conducted in educational buildings. Interventions applying the three common night-time ventilation strategies were conducted in the buildings, and total volatile organic compound (TVOC) and microbial concentrations were measured. None of the case buildings had reported indoor air quality or thermal problems and all were in normal use during the study. The objective was to find out the optimal ventilation strategy which ensures good indoor air quality during occupied hours without unnecessarily increasing energy consumption. The comprehensive results of the study have been published in [10] and this paper rep the main findings.

2. Research methods

2.1 Case buildings

The measurements were conducted in 11 educational buildings in southern Finland during different seasons in 2019 and 2020. Five of the buildings were kindergartens, five schools and one a university building. Six buildings had a constant air volume (CAV) and five a variable air volume (VAV) ventilation system. The building use and ventilation were normal during the occupied hours, and during unoccupied hours three different ventilation strategies were applied: pre-started, continuous, and intermittent.

2.2 Measurements

The main measured quantities were TVOC and microbial concentrations. TVOC was continuously monitored whereas biological samples were gathered throughout each two-week intervention and collected at the end. In addition, CO_2 concentrations, thermal conditions, and pressure differences over the building envelope (where applicable) were measured.

TVOC concentration was measured with a Nuvap N1 IEQ monitor. The N1 deploys a metal oxide semiconductor (MOS) sensor to measure the organic compounds and the sampling is done three to four times per hour. Thermal conditions were monitored with TinyTag plus 2 TGP-4500 loggers and another type of TinyTag (TGE-0011) was used to capture the CO_2 concentrations. A cloud-based solution equipped with Sensirion SDP816 differential pressure probes was used to monitor the pressure differences over building envelope. An overview of the instruments is shown in Table 1.

Sensor	Measured Quantity	Accuracy
Sensirion SDP816	diff. pressure	±3% / ±0.08 Pa
TinyTag TGP-4500	T / RH	±0.5°C / ±3% RH
TinyTag TGE-0011	CO_2	±3% / ±50 ppm
Nuvap N1	TVOC	±15%

Tab. 1 – Sensors used in the measurements.

To study the biological contaminants, settled dust samples were collected from indoors and outdoors on eight petri dishes adjacent to each other. The dishes inside were placed on shelves at a height of 2-2.5 m, and the outside ones were put in an open plastic box sheltered from rain and wind. The quantitative polymerase chain reaction (qPCR) technique was used to determine the micro-organisms present in the samples. The collection period for each sample was two weeks after which they were sent to the Finnish Institute for Health and Welfare (THL) laboratory in Kuopio, Finland for storage and analysis.

As the analysis for all the biological samples was done in one batch, the samples had to be stored prior to it. The samples were prepared for seven days following the arrival in the laboratory. The dust in each collector was swiped into a cotton swab moistened with a dilution solution (sterilized water + 0.05% Tween 20). After this, the swabs were put into tubes containing glass beads to prepare for DNA isolation. Blanks were inserted every 20 samples as a control measure. All the samples were then stored at -80°C.

The DNA isolation was done with a DNA Chemagic DNA plant kit (Perkin Elmer, Germany) according to manufacturer instructions with a KingFisher insulation robot (ThermoFisher, Finland). Salmon sperm DNA (Sigma-Aldrich, USA) was added to the samples as an internal standard prior to isolation. The samples and the glass beads were milled in a bead mill to disrupt the microbial cell walls before the DNA extraction. The extracted DNA was then stored at -20°C before the qPCR analysis was performed.

The actual analysis was done with the qPCR method using assays for three different groups: unifung [11], *Penicillium, Aspergillus* and *Paecilomyces* group [12], and Gram-positive/Gram-negative bacteria [13]. For sample pipetting a Piro pipetting robot (Dornier, Germany) was used, and the analysis was done on a Stratagene Mx3005P qPCR system (Agilent, USA). The salmon sperm DNA along with positive and negative controls for both bacterial and fungal assays were used to ensure the quality of the analysis. The results were calculated according to [12] and reported as cell equivalent per square meter per day (CE/m^2·d).

3. Results

3.1 TVOC

Figure 1 shows the TVOC concentration during morning hours in two of the case buildings (one school, one kindergarten). As can be seen from the figure, there were clear differences in TVOC concentrations between the three night-time

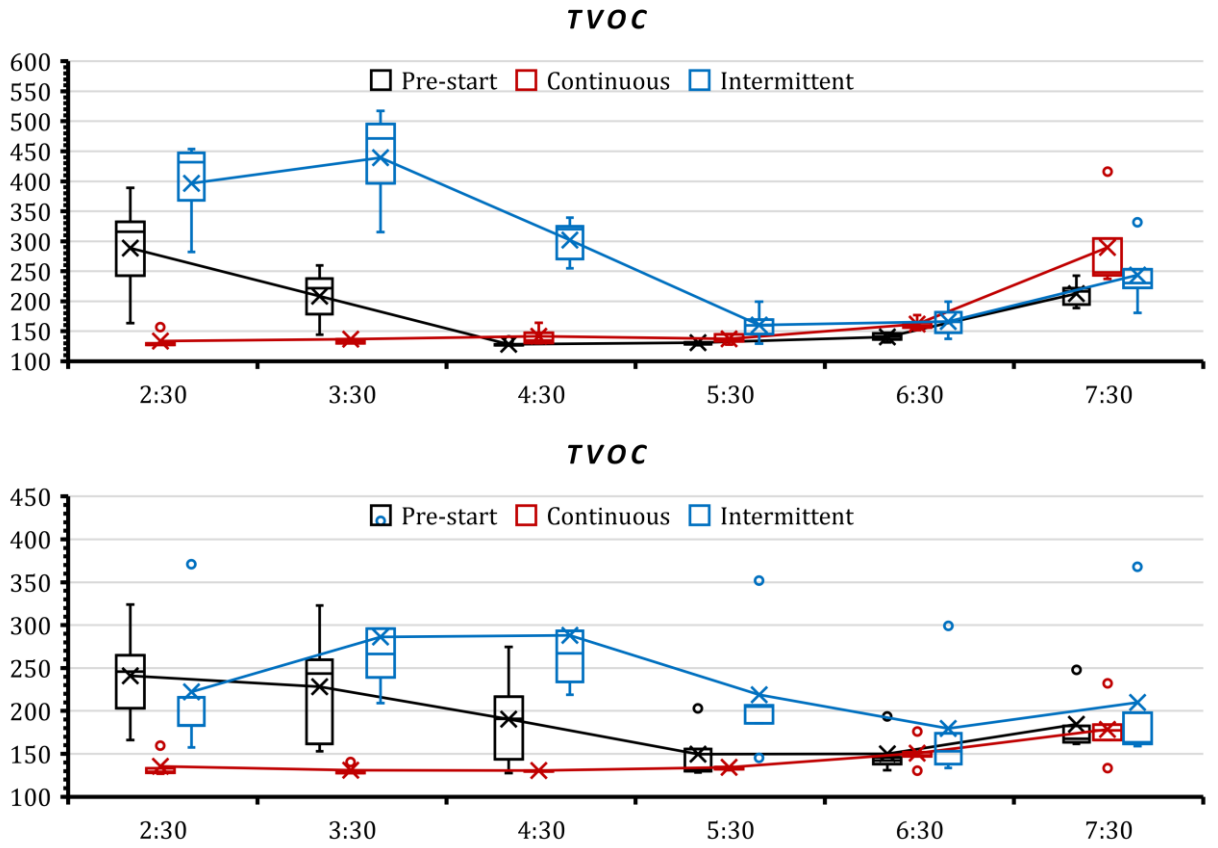


Fig. 1 – TVOC concentration [ppb] during weekday mornings in one of the kindergartens (a) and schools (b). The lines follow the average concentration. [10]

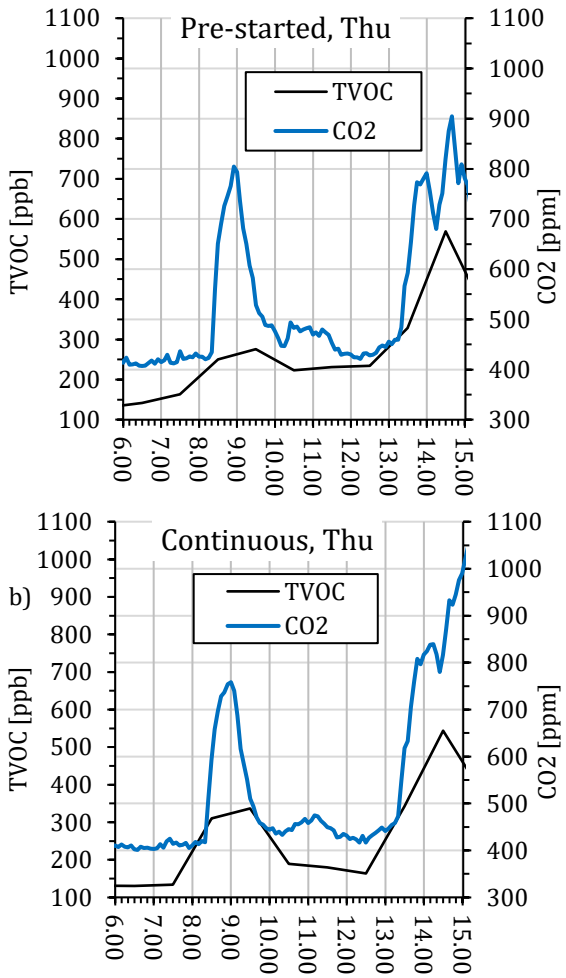
ventilation strategies during the night. As expected, the levels were lowest with continuous ventilation.

T[illegible] ghest levels were found with intermittent v[illegible] tion. This is most likely due to internal pressure differences between ventilation system service areas as the interventions were only applied to one area and the others were operating normally. In the morning when the occupied time began, the TVOC levels were very similar with all three strategies, leading to the conclusion that night-time ventilation does not have a large role in TVOC concentrations during mornings, if the ventilation is started two hours before space use begins. Similar results were obtained from the other case buildings not shown here.

The occupied time TVOC concentrations for one c[illegible]uilding (a school) are depicted in Figure 2 along with the CO_2 concentration which is used to assess occupancy. Similar trends were visible with the other case buildings as well. The peaks in TVOC coincide with those of CO_2, showing that most VOCs originate from the space use. It is also worth noting that the TVOC levels during daytime are similar regardless of the night-time ventilation strategies so night-time ventilation does not have a major role in daytime TVOC concentrations either.

3.2 Microbes

The indoor/outdoor ratios for three of the



a)

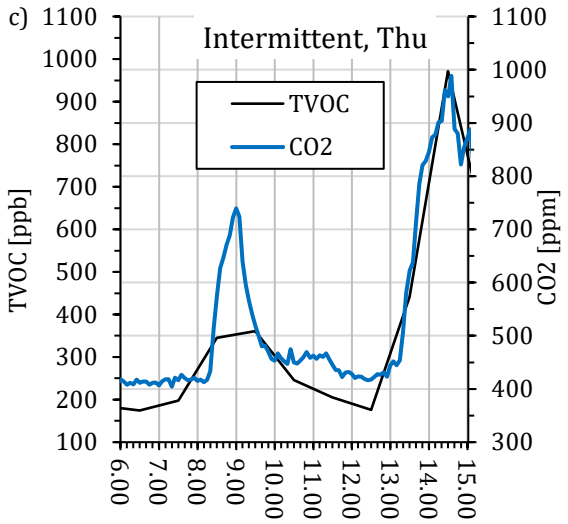


Fig. 2 – TVOC and CO_2 concentrations during a Thursday morning in a school for (a) pre-started, (b) continuous, and (c) intermittent night-time ventilation operation modes.

measured groups (Unifung, Pen./Asp., and Gramneg,) are shown in Figure 3 for one school and one kindergarten. Grampositive bacteria were omitted from this analysis due to outdoor samples having issues, most likely due to inhibiting organic material such as pollen. The ratios were generally very small for most of the groups regardless of the night-time ventilation strategy, and rarely exceeded 10%. This is normal and can be explained by filtration of the supply air. From the data it can be deduced that none of the applied night-time ventilation strategies had a systematic effect on the indoor/outdoor ratios of any of the analyzed groups.

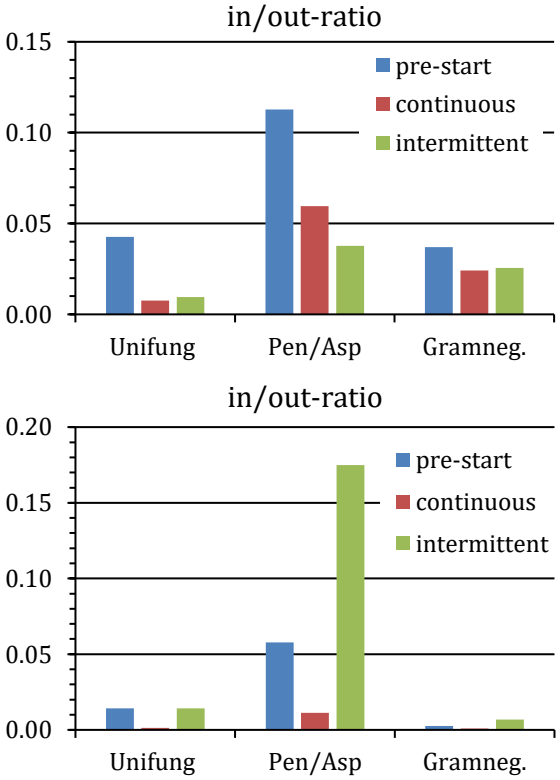


Fig. 3 – Indoor/outdoor ratios of the microbial content in the collected dust samples for one kindergarten (a) and one school (b).

Overall microbial content for indoor samples divided by groups can be found in Figure 4. This data is a combination from two schools, three kindergartens and the university building. The unifung fungal group and both bacterial groups (grampus., gramneg.) behaved similarly with the contents being highest with pre-started ventilation and lowest with intermittent. The mold group (Pen./Asp.) expressed different behavior and with that the intermittent night-time ventilation was giving the highest values and pre-started the lowest.

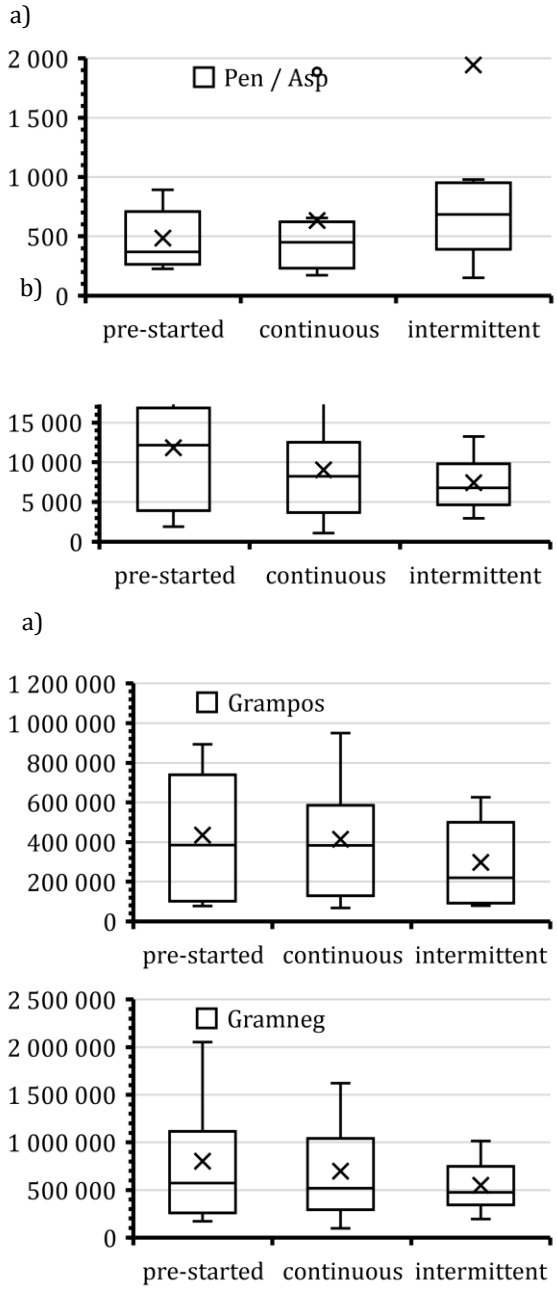


Fig. 4 – Microbial content [CE/m²·d] of indoor dust samples by group: Unifung (a), Pen / Asp (b), Grampos (c), and Gramneg (d). The sample includes three kindergartens, two schools and a university building.

4. Conclusions

In this study, three different night-time ventilation strategies (pre-started, continuous, and intermittent) were compared by making interventions at field sites and assessing the indoor air quality. The main motivation of the study was to assess how different night-time ventilation strategies affect the indoor air quality during occupied times and especially in the mornings. The measurements were conducted in different seasons in 2019 and 2020. The results showed that most pollutants originate from daytime activities in the buildings, and the effect of night-time ventilation on TVOC and microbial concentrations was minimal if the ventilation was pre-started two hours prior to occupied time. Hence, the hypothesis of having to run the ventilation continuously throughout the night to ensure good indoor air quality was proven wrong. The differences seen in the measured quantities between the three night-time ventilation strategies were smaller than that of normal variation produced by differences in space use and seasonal weather conditions.

5. Acknowledgements

This study was a part of the "Effect of ventilation schedules on working conditions and indoor air quality in public buildings" project funded by the Finnish Work Environment Fund. The authors acknowledge the Finnish Work Environment Fund, Aalto University Campus & Real Estate (ACRE), the Senate Properties, and the cities of Helsinki, Espoo, and Vantaa for the financial support. The authors would like to thank Research Analyst Heli Martikainen from the Finnish Institute for Health and Welfare for the laboratory analyses of microbiological samples.

6. Data access

The datasets generated during and/or analysed during the current study were not made publicly available because the data are very case-specific and their applicability in other studies is limited. However, the data are available from the authors upon request.

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