Energy & Buildings 297 (2023) 113470

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

Reduced night ventilation did not impair indoor air quality for occupants in a sample of Finnish school and daycare buildings

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A R T I C L E I N F O

Keywords:
IAQ
IEQ
Mixed models
MM questionnaire
Survey
Reduced night ventilation
Schools
Daycare centers
Finland

A B S T R A C T

Ventilation in buildings plays a significant role from the points of view of indoor air quality, health and comfort. In addition, ventilation is one major consumer of heating energy in buildings. In this study, we investigated the effects of shutting down mechanical ventilation at nights on measured and occupant reported indoor air quality as well as health symptoms. Extensive field measurements and standard MM questionnaire surveys among school personnel and children were carried out three months before and three months after changing the ventilation operation mode (from 24 h ventilation to shutting down when unoccupied) in twelve school and daycare buildings. There were small differences in the estimated mean indoor temperature, relative humidity, and particle concentrations results before and after the operation mode change (intervention), which could also be related to seasonal factors. However, the intervention did not associate with any of the studied occupant outcomes, including reported thermal comfort, stuffy 'bad' air, or health symptoms among children or personnel. Therefore, according to the survey responses, shutting down ventilation at night had no noticeable effects on the perceived indoor air quality and health during occupancy.

1. Introduction

Proper control of different indoor air quality (IAQ) and climate factors in educational institutions and childcare facilities is crucial due to the detrimental impact poor IAQ can have on human health and performance e.g., [38]. This importance is further emphasized by the fact that students spend a significant amount of time within these settings [3]. Schools are typically occupied for about 6–8 h during the weekdays, whereas the nights and weekends are usually unoccupied.

The purpose of ventilation is to bring clean air for building occupants, as well as diluting and removing polluted air from the breathing zone. Ventilation impacts indoor temperature (T), especially in the cold climate regions where building envelopes are built airtight to avoid heat loss. In such climates, it is difficult to provide adequate ventilation and thermal comfort by natural means (e.g., by opening windows). It has been estimated that mechanical ventilation is responsible for about 30 % of the total energy consumption of buildings [27], hence turning off ventilation during the unoccupied hours can significantly reduce energy consumption e.g., [11]. However, one can say that in schools and care facilities, energy-saving should be a secondary value to learning, health, and well-being e.g., [49].

Although ventilation is important for temperature and pollutant control, it also affects pressure differences across the building envelope. While it has been argued that turning off ventilation during nights may lead to issues with IAQ, dampness and microbial growth, a commonly used practice has been to keep the exhaust running, either using the primary ventilation system or by employing a secondary system built for this purpose. A prior study, "Comprehensive development of nearly zero-energy municipal service buildings" (COMBI), found that mechanical ventilation can cause high negative pressure across the building envelope in buildings during absence periods [46]. High negative pressure can draw pollutants from outdoor sources or from the ground, whereas high positive pressure may lead to localized point-like condensation of moisture at the air leak sites, thereby increasing the risk of microbial growth [39]. High negative pressure has also been associated with occupants being more unsatisfied with IAQ [18]. On the

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https://doi.org/10.1016/j.enbuild.2023.113470
Received 17 May 2023; Received in revised form 2 August 2023; Accepted 15 August 2023
Available online 16 August 2023
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other hand, without ventilation, the concentrations of indoor air pollutants are expected to increase, and when the ventilation is turned back on, it takes some time before the concentrations reach the target level as expected before the shutdown period e.g., [35].

Lestinen et al. [25] in their study of eleven Finnish educational buildings compared three ventilation strategies of 1) continuous ventilation, 2) intermittent ventilation, and 3) total shutdown during unoccupied period (but ventilation back on two hours before occupancy). They concluded that two hours of ventilation before occupancy is sufficient to ensure acceptable IAQ, while ventilation during unoccupied period is rather unnecessary. However, it is important to note that the study only measured total volatile organic compounds (TVOCs) and microbial concentrations in settled dust over a 2-week period to assess IAQ. The study did not assess occupant perceived IAQ and health, which could be sensitive for changes in IAQ related to ventilation [13].

Several European standards provide guidance for the correct use of ventilation [5,6,7]. National regulations and guidelines define the requirements and recommendations for IAQ and climate. In Finland, these guidelines are provided by various entities, for example the Ministry of Social Affairs and Health [31], the Ministry of the Environment [29], the municipalities' indoor air network [44], and the Finnish Association of Indoor Air Quality and Climate FISIAQ [41]. FISIAQ [15] has also published recommendations regarding the utilization of ventilation in public buildings outside of operating hours. The recommended minimum ventilation rate is 0.15 $dm^3/s,m^2$ outside the occupied period. The recommendations do not include turning off ventilation for the entire unoccupied period, and in case of intermittent ventilation, a 2-hour flushing time before occupancy is recommended. It is noted that the recommendations are focused on buildings and technical systems, while cautioning that occupants' perceived IAQ can depend on many factors including their possibility to control indoor conditions.

Overall, operating time conditions and IAQ are established based on the design criteria. A Finnish elementary school study by Toyinbo and colleagues [43] found that about half of the classrooms with mechanical ventilation met the recommended ventilation rate of 6 l/s-person, as compared to none of the classrooms with natural ventilation. The study also found that an increase in classroom ventilation resulted in a lowered classroom T and vice versa. A prospective study of US schools by Mendell et al. [28] found that classroom ventilation rate below the recommended 7.1 *l/s per student* for California schools resulted in an increase in children' absenteeism due to illness. The importance of pollutant control has become more evident due to the Covid-19 pandemic, during which effective ventilation has been shown to reduce the spread of the coronavirus in classrooms e.g., [16]. Further on, studies have linked ventilation adequacy with academic performance of students e.g., [20,19,47]. These studies are based on conditions assessed during occupied hours, and do not reveal information regarding the possible effects of ventilation operating times on the studied outcomes.

Ventilation also has a role in managing the heat loads generated in classrooms. Too high and too low classroom temperatures can result in thermal discomfort that can be detrimental to health and learning [21,19,24]. Turunen et al. [45] reported a correlation between average indoor T and perceived IAQ, suggesting an increased indoor T can result in higher prevalence of students reporting poor IAQ.

Perceived thermal comfort is related to age of the occupant(s). According to [32,42], children are more sensitive to hot temperatures than adults, and children perceive thermal comfort at approximately 2–4 °C lower T than adults. The optimal operative indoor T for children has been determined to be 22.6 °C, which is lower than for adults under the same climate conditions [9]. Additionally, children's school days often involve a lot of activities, which may affect their perception of warmth [49].

Most school studies are focused on the effects of classroom indoor air quality (IAQ) on children's health and academic outcomes. It is important to note that classroom IAQ can also affect the health and productivity of teachers and other school personnel. A study of 852 teachers from 32 schools in Manitoba, Canada found that thermal comfort and ventilation in the classroom had effects on teachers' physical wellbeing [37]. According to Muscatiello et al. [33], there was an association (OR 1.30, 95 % CI 1.02 – 1.64) between teachers reporting neuro-physiologic symptoms such as lack of concentration, fatigue, and headache per 100 ppm increase of maximum classroom carbon dioxide (CO_2) concentration. Smedje et al. [40] studied the school personnel response to IAQ in 38 Swedish schools and found over half (53 %) of them to perceive IAQ as bad or very bad. The teachers who perceived bad IAQ were mainly those who were unhappy with their work environment and had a disposition to allergies such as hay fever.

Perceived IAQ in school buildings can be affected by multiple environmental, personal, and psychosocial factors and their interactions e.g. [14]. In order to assess possible changes in occupant perception, a strategic, validated approach is needed. Standardized MM-questionnaires were specifically designed to assess perceived indoor climate in buildings [2]. The initial version, designed for workplaces (MM40), was developed and tested in 1986 [1]. Later on the questionnaires were tailored primary schools and daycare centers (MM60 and MM80). The primary goals in creating these questionnaires were to make them short and easy for self-administration, with clear and reproducible questions. However, different versions are based on the same core questions, making them more comparable. Reference values represent the questionnaire outcomes in "healthy" buildings without known indoor climate issues [2]. The MM questionnaires have been translated into many languages and are routinely used in Finland e.g., [23,36].

Considering the limited research previously conducted on this specific topic, our objective was to assess whether shutting down ventilation during unoccupied periods has effects on either measured or perceived IAQ and health during occupied hours in schools and daycares.

2. Material and methods

In this study, data collection was carried out in twelve school and daycare buildings, which did not have any known IAQ issues or complaints. Background information is presented in Table 1. The buildings are district heated and equipped with mechanical ventilation systems. Eight buildings were built <10 years before the study, and four buildings were built between 1904 and 1990. Nine buildings were made of concrete, one of brick/concrete and two of timber frames. Buildings air leakage (q50-rate) varied from 0.5 to 4.3 $m^3/h,m^2$, as shown in Table 1. The measured spaces primarily consisted of classrooms in schools and group/playrooms in daycares. The selection of the spaces was based on the criteria of being able to shut down ventilation during periods of absence.

The measurements were conducted in two phases: 1) normal operation mode between October and December 2021; and 2) changed operation mode with ventilation shut down during unoccupied period between January and March 2022 (see Fig. 1). Average outdoor air T and RH were −2,1 °C, and RH 88 % during Phase 1, whereas they were T −2.5 °C and RH 84 % during Phase 2.

Under normal ventilation conditions (Phase 1), the ventilation systems in the study buildings were typically operated at full air volume between 4 AM to 5 PM. The ventilation operated at reduced airflow throughout the night. In the changed situation (Phase 2), the operating time was changed so that outside the occupied period the ventilation was shut down. The ventilation was started two hours before occupancy at 5 AM and typically run with full air volume until 5 PM. However, in some cases, due to evening use of the building or other demands, the ventilation stayed on later, either at full or partial air flow.

Energy consumption calculations were done according to the EN ISO standard [8,30], using the measured average monthly outside temperatures and the reported ventilation operating times, also accounting for school holidays. The average temperature efficiency of heat recovery

Table 1
Background information about the school and daycare buildings.

Building No./type	Year constructed	Frame material	Air leakage q50-rate (m^3/h,m^2)	Air leakage q50-rate measurement year	Total number of children's	Total number of personnel
1/Daycare	2019	Concrete	0.9	2018	45	10
2/School + daycare	2018	Concrete	0.9	2017	96	15
3/school + daycare	2018	Timber frame	1,8	2018	72	6
4/School + daycare	2014	Concrete	0.9	2014	80	11
5/School	2014	Concrete	1.0	2018	103	9
6/School	2013	Concrete	1.0	2018	105	22
7/School + daycare	2012	Concrete	0.8	2012	84	10
8/Daycare	2012	Concrete	0.5	2011	38	6
9/School	1990	Concrete	4,3	2022	26	2
10/Daycare	1986	Concrete	2,7	2022	59	11
11/School	1952	Brick/ concrete	3,8	2018	111	10
12/School + daycare	1904	Timber frame	2,3	2018	40	7

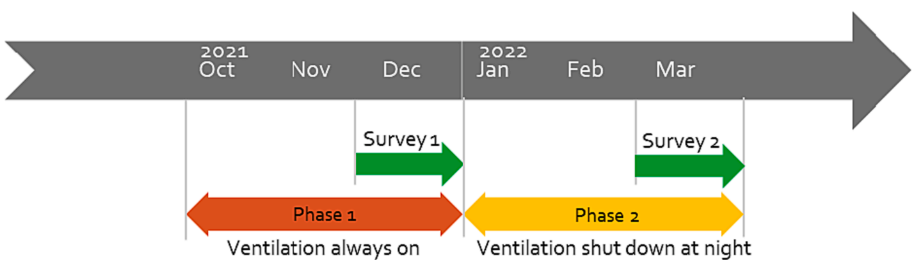


Fig. 1. Timeline of the study.

was assumed to be 65 %, exhaust air T +23 °C and supply air T +18 °C.

The measured IAQ parameters included pressure differences (ΔP), temperature (T), relative humidity (RH), fine particles ($PM_{2.5}$ and PM_{10}), carbon dioxide (CO_2), and volatile organic compounds (VOCs). This study focuses on comparing the differences in measured and perceived IAQ parameters during the two operation modes (Phases 1 and 2).

Differential pressure gauges and measuring devices to monitor T, RH and CO_2 concentrations were installed in March 2021. The air pressure difference was measured at 5-minute intervals across the building envelope. Indoor T and RH were measured and recorded with 55 Rotronic CL11 loggers (accuracy ±3 °C, ±5 %) and 31 Comark N2003/N2013 data loggers (accuracy ±0.5 °C, ±3 %) at 1-hour interval. The measuring tools were calibrated before field use at the Tampere University of Technology (TUT) construction technology laboratory. In May 2021, additional devices for measuring PM and VOCs were installed. The fine particles sensor was the AirWits PM Internet of Things (IoT) sensors (range 0…1000 µg/m^3, accuracy ±10 µg/m^3 between 0 and 100 µg/m^3 and 10 % between 100 and 1000 µg/m^3). The VOC sensor used was the AirWits IAQ R1.1 IoT-sensor (range 0...60 000 ppb, accuracy 15 %). The IoT sensors were set to measure at 10-minute intervals. Both sensors utilized the Sigfox Low-Power Wide-Area (LPWA) network protocol. For differential pressure measurements, custom-built gauges from the COMBI [46] project were employed. These gauges were constructed using Honeywell differential pressure sensors and Raspberry Pi computers Calibration was determined separately for each unit. The external head of the outdoor pressure difference measuring tube was shielded to prevent direct exposure to outdoor climatic conditions.

If possible, the measurement devices were installed in the breathing zone at a height of 1.2 m from the floor level. However, in some of the facilities, the devices had to be installed higher so that the children could not reach them. The devices were visited approximately every four weeks to collect the data on a separate flash drive and to empty their memory. At the same time, their operation was checked. The devices measuring particles and VOC concentrations logged the measurement data directly into the cloud service, from where they were downloaded. More detailed building-level information and measurement results are reported by Ketko [22].

Data on occupant perceived indoor climate and health was collected using the MM40 questionnaire for the personnel. For children (age 0–6 years), the MM80 questionnaire was used, and parents were asked to respond together with their children. All personnel (N = 119) and parents of the children (N = 859) were invited to participate in the online questionnaires utilizing Lime Survey Community Edition Version 5.6.1. The first survey (Phase 1) was carried out in December 2021 and the second survey (Phase 2) in March 2022. The internet connection was secured.

The overall response rates were 42 % (ranging 7 – 83 % per school) for personnel and 19 % (ranging 1–35 % per school) for parents. Among personnel, out of the 50 persons who responded to the first survey, 46 also participated to the second survey. Among the parents, the number of respondents were 139 and 63, respectively.

The questionnaire responses were analyzed using IBM SPSS statistics version 26 using descriptive statistics, Linear Mixed Models (LMM) for continuous IAQ estimates and Generalized Linear Mixed Models (GLMM) for binary occupant responses, where subjects were defined by school and room identification numbers. First, basic model included only intervention (Phase 1 vs. Phase 2). Secondly, the backward elimination method was used to fit a GLMM model by starting with a full model that included all potential predictors for individual target (dependent) variable. Non-significant predictors were removed in an iterative manner, leaving only significant predictors in the final model.

3. Results and discussion

3.1. Measurement results

During the study period, the change in operational mode (Phase 1 to Phase 2) resulted in an average energy saving of 26 % in heating related to ventilation. The energy-saving potential is greater for buildings where the ventilation is operated at full air volume around the clock (four study buildings), as compared to buildings that are operated only at reduced air flow during the unoccupied period (eight study buildings). The energy saving potential also depends on the building characteristics.

Statistically significant differences between periods before and after operation mode change were seen for estimated mean T and RH (Table 2). In theory, stopped ventilation (during the night), without adjusting the heating system, could result in higher indoor T and consequently, lower RH. However, these changes can also be related to different seasons / outdoor conditions. There were also statistically significant differences between PM levels, but the levels were very low with no practical implications.

Table 3 shows LMM analyses results: pairwise comparisons of differences between occupied (Mon-Fri 09 – 15) vs. unoccupied (Mon-Fri 23 – 04) hours, as well as between before (Phase 1) and after (Phase 2) ventilation operation change. As expected, larger differences are seen between occupied vs. unoccupied concentrations of indoor pollutants, including CO_2, and VOCs, where maximum concentrations are most likely related to occupants and their activities.

Table 4 shows the Pearson correlations between the measured IAQ parameters in the classrooms. There is a strong positive correlation between mean $PM_{2.5}$ and PM_{10} ($r = 0.97$, p-value < 0.001), and a strong negative correlation between indoor T and RH ($r = -0.72$, p-value < 0.001). Strong correlations between $PM_{2.5}$ and PM_{10} indicate similar sources of particulates (mainly outdoors), whereas there exists a known relationship between T and RH during the heating season [34]. Maximum CO_2 concentration has a moderate correlation with maximum VOC concentration ($r = 0.40$, p-value $= 0.003$), whereas maximum VOC concentration has weak to moderate correlations with mean $PM_{2.5}$ and PM_{10} ($r = 0.31$, $p = 0.02$, $r = 0.29$ and p-value $= 0.04$ respectively), which could be attributed to occupants and their activities, as well as ventilation characteristics. In addition, there is a weak positive correlation between mean pressure differential and $PM_{2.5}$ concentration ($r = 0.28$, p-value $= 0.045$), i.e., higher ΔP across the building envelope tends to associate with higher $PM_{2.5}$.

(1 = Mean ΔP, 2 = Mean T, 3 = Mean RH, 4 = Max. CO_2, 5 = Max. VOC, 6 = Median VOC, 7 = Mean $PM_{2.5}$, 8 = Mean PM_{10}).

3.2. Questionnaire survey results

Table 5 shows the background characteristics of the responders based on first (Phase 1) and second (Phase 2) surveys. It was noticed that the prevalence of children reporting eczema was significantly lower for the second survey, which could influence the associations between perceived IAQ and health symptoms.

Table 2
Mean estimates for IAQ parameters during occupied hours (9am-3 pm) before (Phase 1) and after (Phase 2) ventilation operation change.

Parameter	Estimated mean Pre (Phase 1)	Post (Phase 2)	p-value
Pressure differential, Pa	−9.3	−8.0	0.301
Mean T, °C	20.9	21.3	0.038
Mean RH, %	21.4	18.2	0.000
Max CO_2, ppm	838.9	917.0	0.107
Max VOC, ppb	2984.6	3004.8	0.753
Median VOC, ppb	188.3	218.1	0.101
Mean $PM_{2.5}$	3.8	4.4	0.000
Mean PM_{10}	5.9	6.5	0.007

Table 3
Pairwise comparisons of differences between occupied (9 am-3 pm) vs. unoccupied (11 pm-4 am) hours and normal (Phase 1) vs. changed (Phase 2) ventilation operation modes.

Parameter	Mean differences Occupied – Unoccupied	p-value	Phase 1 - Phase 2	p-value
Pressure differential, Pa	0.0	0.965	−0.6	0.409
Mean T, °C	0.0	0.954	−0.6	0.005
Mean RH, %	0.5	0.052	3.5	0.000
Max CO_2, ppm	399.3	0.000	−52.4	0.072
Max VOC, ppb	1993.4	0.000	−340.2	0.358
Median VOC, ppd	−57.1	0.003	−49.0	0.010
Mean $PM_{2.5}$, μg/m^3	0.4	0.000	−0.5	0.000
Mean PM_{10}, μg/m^3	0.5	0.001	−0.5	0.000

Figs. 2 and 3 illustrate reporting of environmental and symptom factors among those who responded to both surveys. Children's parents reported indoor environmental factors usually below the reference levels, however, symptoms reporting was higher for hand dryness (both surveys), and for nasal symptoms (only for first the survey). Among personnel, too high temperature (only for the second survey) and reporting of scaling/itching sculp and difficulties concentrating (only for the first survey) exceeded the MM survey reference values.

Table 6 shows the GLMM results related to measured IAQ vs. school children and personnel perceived IAQ / symptoms. Switching ventilation off during unoccupied hours (Phase 2) did not associate with any of the studied outcomes. However, there were statistically significant associations between many outcomes and IAQ parameters. For example, among children perceived IAQ (poor or very poor classroom air quality) was significantly associated with maximum CO_2. However, $OR < 1$ was counterintuitive in this case. Similarly, there were statistically significant associations between reported eye irritation and itchy scalp and maximum CO_2, which could be related to ventilation adequacy. Since higher CO_2 indicates lower ventilation, these results could also be considered counterintuitive and opposite from for example Simphonie study, which reported ventilation rate significantly associated with decreased odds of suffering from eye and skin disorders [4]. One possible explanation could be that higher ventilation in cold climate may result in lower RH, which could explain increased risk for eye and skin symptoms in the absence of indoor air pollutants e.g. [48]. However, this type of mechanism was not evident based on the monitoring results.

Among personnel, higher RH was logically associated with lower odds for reporting dry air, and higher T with lower odds for reporting too cold. In addition, higher T was associated with higher odds for reporting stuffy air, which is also in line with previous studies e.g. [45]. Higher concentration of PM_{10} was associated with higher odds for dry throat, however, the estimated mean PM concentrations were low as compared to WHO guidelines [17]. In addition, there was an association between maximum CO_2 and skin symptoms (dry and itchy hands), which was similarly counterintuitive as the associations between CO_2 and reported symptoms among children.

In general, the MM40 survey does not include questions about respiratory infections, the use of health services, or some less frequent symptoms and diseases related to microbial exposure. Therefore, these outcomes were not included in the study. Airborne transmission, which is one of the dominant transmission routes of pathogens of several contagious respiratory diseases, mainly takes place between occupants when sharing indoor spaces, i.e. during occupied hours e.g. [10]. Other respiratory symptoms and diseases, such as asthma morbidity related to mold exposure e.g. [12], would require longer than a 3-month study period.

For the survey results to be comparable, representative, and statistically sound, both response rate and sample size should be large

Table 4
Pearson correlations between variables.

	1	2	3	4	5	6	7	8
1	1.00	−0.12	−0.21	−0.00	0.03	0.01	0.28(*)	0.26
2	−0.12	1.00	−0.72(**)	−0.11	0.03	0.14	0.22	0.19
3	−0.02	−0.72(**)	1.00	0.19	0.16	0.00	−0.01	0.02
4	−0.00	−0.11	0.19	1.00	0.40(**)	0.13	0.11	0.14
5	0.03	0.03	0.16	0.40(**)	1.00	0.36(**)	0.31(*)	0.29(*)
6	0.01	0.14	0.00	0.13	0.36(**)	1.00	0.20	0.11
7	0.28(*)	0.22	−0.01	0.11	0.31(*)	0.20	1.00	0.97(**)
8	0.26	0.19	0.02	0.14	0.29(*)	0.11	0.97(**)	1.00

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

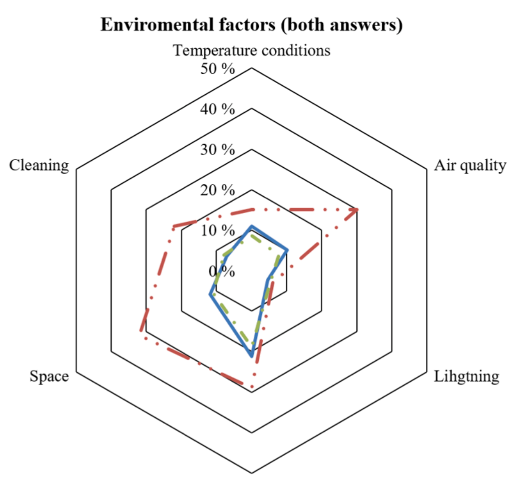
Table 5
Descriptive statistics of the questionnaire responders based on staff self-reporting and parents reporting regarding the children.

	Children Phase 1	Phase 2	p-value	Staff Phase 1	Phase 2	p-value
Gender, female, N(%)	61 (25)	47 (19)	–	45 (90)	38 (95)	–
Allergic predisposition, N (%)						
-Asthmatic problems	13(5)	7(3)	0.674	15 (17)	8(9)	0.187
-Hay fever	34 (14)	28 (11)	0.087	17 (19)	14 (16)	0.843
-Eczema	81 (33)	63 (26)	0.026	26 (30)	17 (19)	0.195
Psychosocial factors, N(%)						
-Work interesting and stimulating (often)	–	–	–	0(0)	32 (36)	0.000
-Too much work to do (often)	–	–	–	0(0)	9(10)	0.000
-Opportunity to influence working conditions (often)	–	–	–	0(0)	7(8)	0.001
-Help from fellow workers (often)	–	–	–	0(0)	23 (26)	0.000

enough. In this study, the response rates were rather low, particularly for the children, and the number of responses from each school was insufficient to draw conclusions on the individual school level. Therefore, further studies with larger samples sizes are warranted to draw more definite conclusions about the observed associations. However, when studying the effects of ventilation operation mode change on survey responses, the responses from twelve school buildings were merged, and the dependency within schools was accounted for by using a multilevel model (school and room IDs), which resulted in a larger sample size for studying the effects.

It should be noted that the measurement data were available on the classroom level: each survey response was matched with the measurement result from the specific classroom, where the child or the teacher spent most of the time during the day. This led to higher level spatial matching than in a typical school research, where IAQ data has been collected from a few measurement points and generalized to the school level. However, whereas the IAQ monitoring data had a high time resolution, utilizing standard surveys with a 3-month recall period did not allow for higher level temporal modeling. Such modeling would require for example, utilizing daily health questionnaires or diaries, or daily illness absence records which are often not readily available [18]. The selection of 3-month periods aimed to use of standard questionnaire protocol as well as similar outdoor temperature conditions between the study periods.

Overall, the results obtained in this study are consistent with the results presented by Lestinen et al. [26], concluding that a 2-hour flushing is long enough to freshen indoor air before occupancy. In



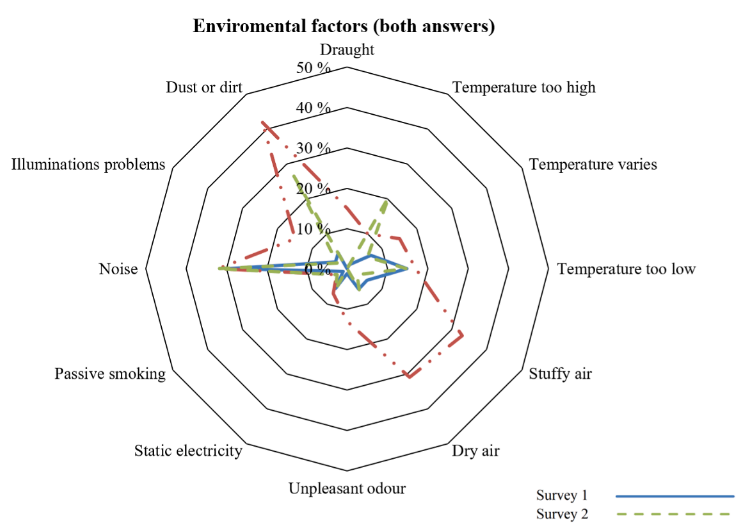


Fig. 2. Perceived IAQ by a) children's' parent reporting and b) staff. Survey 1 corresponds with normal operation mode (Phase 1) and Survey 2 changed operation mode (Phase 2).

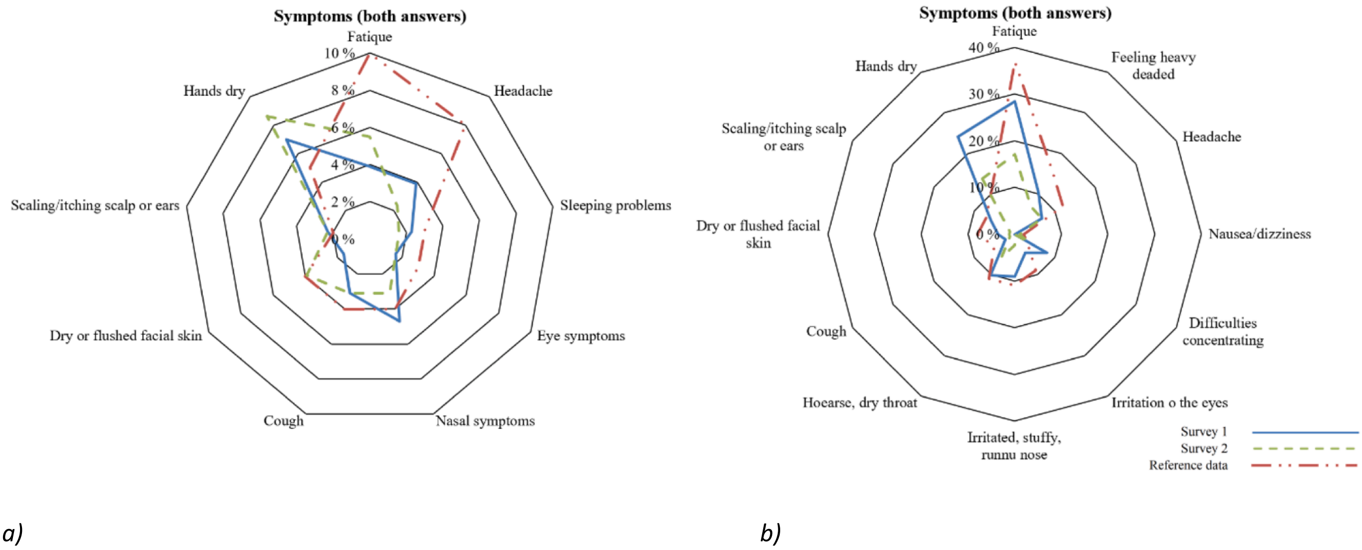


Fig. 3. Reported symptoms by a) parents and b) staff. Survey 1 corresponds with normal operation mode (Phase 1) and Survey 2 changed operation mode (Phase 2).

Table 6
GLMM results for children and school personnel (indoor climate vs. perceived IAQ / symptoms). Statistically significant (p-value < 0.05) associations marked with **bold**.

Children **Outcome** IAQ Parameter, N (%)	Intervention only OR (95 % CI)	Intervention + IAQ parameter(s) OR (95 % CI)
Poor or very poor air quality, 12(4)	0.45 (0.14–1.56) [a]	
Maximum CO_2 [c]		**0.81 (0.68–0.96)** [a]
Eye irritation, 7(2)	1.03 (0.28–3.80) [a]	
Maximum CO_2 [c]		**0.78 (0.64–0.93)** [a]
Itchy Scalp, 10(3)	0.57 (0.14–2.36) [a]	
Maximum CO_2 [c]		**0.73 (0.57–0.94)** [a]
Personnel		
Dry air (often weekly), 8(9)	1.37 (0.30–6.25) [b]	
Mean RH		**0.27 (0.10–0.73)** [b]
Too cold (often weekly), 20 (22)	1.89 (0.66–5.42) [b]	
Mean T		**0.35 (0.15–0.85)** [b]
Stuffy bad air (often weekly), 9(11)	1.30 (0.22–7.64) [b]	
Mean T		**2.31 (1.05–5.10)** [b]
Rough dry throat (often weekly), 14(15)	0.55 (0.17–1.79) [b]	
Median PM_{10}		**2.06 (1.01–4.19)** [b]
Dry and itchy hands (often weekly), 33(36)	0.55 (0.23–1.35)	
Maximum CO_2 [c]		**0.87 (0.76–1.00)**

[a] controlled for age and gender, [b] controlled for gender and years in school, [c] per 100 ppm.

addition to measured IAQ (albeit small differences in the estimated mean indoor T, RH, and PM levels), we did not find significant associations between changing ventilation operation mode and occupant perceived IAQ and health. Both studies included buildings constructed > 1 year ago (i.e., no newly constructed buildings) with no known history of IAQ issues or complaints. In cases where such issues are present, e.g. due to uncontrolled sources of chemical or microbiological pollutants, the need of ventilation and operation times should be considered separately.

4. Conclusions

The study utilized continuous monitoring of IAQ, standardized questionnaires, and multilevel modeling to investigate the effects of nighttime ventilation shutdown on measured and perceived IAQ and health during the operating period in school and daycare buildings. As expected, there were statistically significant associations between some measured and perceived IAQ parameters among school personnel and/or children. However, there were no significant associations related to nighttime ventilation shutdown, i.e. IAQ during occupied hours was not compromised, and there were no perceived IAQ or health related findings that would not support shutting down ventilation at night. With adequate flushing before the occupied hours in the studied school and daycare buildings, ventilation during unoccupied hours did not appear to provide a significant benefit in terms of measured or perceived IAQ, whereas shutdown resulted in an average of 26% reduction in heating energy consumption related to ventilation. The findings indicate potential to develop energy conserving operation of ventilation systems in schools and daycares.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The real data used in this study was obtained through the Future Spaces project. For information on the resources used in this work, please contact the corresponding author.

Acknowledgements

This study was conducted as part of the Future Spaces research project, which aims to improve IAQ in service and commercial buildings. The project was funded by Business Finland, the University of Tampere, VTT Technical Research Centre of Finland, as well as the companies involved. The project is part of the activities of Business Finland's indoor air quality growth engine IAQe (Indoor Air Quality ecosystem). The work conducted by the University of Oulu team was partially funded by the Academy of Finland (decision number 342403).

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