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Effect of ventilation on perceived air quality in 18 classrooms

Sverre B Holøs[1,*], Aileen Yang[2], Kari Thunshelle[2], Mads Mysen[1]

[1] SINTEF Building and Infrastructure, Oslo, Norway
[2] OsloMet - Oslo Metropolitan University (Formerly Oslo and Akershus University College of Applied Sciences), Oslo, Norway
[*] sverrebholos@sintef.no

Abstract. The aim of this paper is to assess whether reducing the minimum ventilation airflow rate (V_{min}) has any negative impacts on perceived air quality (PAQ) upon entering an unoccupied room. Seventeen healthy young adults were asked to assess PAQ in 18 unoccupied classrooms upon entry. Extra pollution sources were introduced in two classrooms, while three other classrooms were not cleaned. The ventilation rate in each classroom was set in a random order to off, low (0.9/1.1 l/s per m²), medium (1.3 l/s per m²) and high (2.0 l/s per m²). Increasing the ventilation rate resulted in a significant improvement of the PAQ-score, with highest PAQ-score when V_{min} is set to high and lowest when the ventilation is off. However, most of this increase occurred when increasing ventilation to the low rate. Classrooms that were not cleaned for two days of normal use prior to the test only showed a marked reduced PAQ at all ventilation rates.

1. Introduction

Ventilation is provided to ensure good indoor air quality (IAQ) by diluting indoor pollution sources such as emissions from building materials and furniture as well as odors from people. By using demand-controlled ventilation (DCV), it is possible to adjust the ventilation airflow rate between a preset minimum (V_{min}) and maximum (V_{max}) value based on demand, as determined by sensors. A substantial decrease in energy use can be achieved by implementing DCV in buildings with varying occupancy, e.g. schools and offices. In rooms that are unoccupied for extensive periods, the choice of V_{min} will have substantial impact on the energy saving potential. The use of low-polluting building materials has been extensively promoted for reducing ventilation requirements and energy demand [1]. This approach has been implemented as differential requirement for airflow rates due to building emissions level in current standards as well as building regulations [2].

As it is required to use low-emitting building materials in schools in the Oslo municipality, a minimum ventilation airflow of 0.7 l/s per m² should be sufficient. However, the Education Agency in Oslo recommends a minimum ventilation rate of 2.0 l/s per m² in unoccupied classrooms in Oslo [3]. In classrooms and other rooms of high user density, pollutants from building materials will typically be quite rapidly diluted by the highly increased ventilation rates due to occupancy. Thus, the minimum ventilation rate will have a limited effect on exposure of the building users to emissions from building materials. Reducing V_{min} as much as possible may be attractive option to reduce energy demand in such usage situations.

Still, V_{min} should preferably be sufficiently high to ensure acceptable air quality upon entry of room. Several studies link indoor air quality with health, productivity and learning ability, and perceived air quality is a much used indicator of air quality [4]. We are unaware of studies documenting any specific health or learning effects of perceived air quality upon entry as such in a school situation, but several authors highlights olfactory perception as a likely factor in indoor air related health effects [5]. Cognitive effects from olfactory perception is demonstrated in experimental studies [6].

We wanted to examine if reducing V_{min} below the currently used 2.0 l/s per m² had any negative impact on perceived air quality (PAQ) upon entry of unoccupied classrooms in a relatively new school with extensive use of low-emitting materials.

2. Methods

The study was conducted over a period of four days during a school vacation week in 18 unoccupied rooms at a school in Oslo, Norway. The school was first taken into use 14 months prior to the study. Materials used for the interior were low-polluting or very low polluting. Emission rates from furniture was not subjected to specific demands. The fifteen classrooms are distributed over two floors and have an average floor area of 60 m², height of 2.8 m with similar furnishings. Normally, the classrooms are occupied by pupils from 1st to 10th grade. Three additional rooms, smaller in size (floor area of 30 m²), were also included. These supplementary rooms adjacent to the classrooms are more sporadically used for smaller groups. Both classrooms and supplementary rooms have balanced supply and exhaust mechanical ventilation with a capacity of delivering up to 5.6 – 5.8 l/s per m² floor area. There are operable windows in all the rooms, but daily ventilation depends on the mechanical system. During our study period, the windows remained closed.

Extra pollution sources, i.e. uncapped marker pens, laptops in a ventilated charging cupboard and a vacuum bag with dust from vacuuming a floor area of about 120 m² in the school, were placed outside of view from the test panel in two of the classrooms, and two classrooms had 4 shelves moved from one classroom to the other. One classroom was emptied of all furniture on two of the test days (at ventilation off and low). The classrooms are usually cleaned daily, however, three of the classrooms were specifically left uncleaned after the last day of ordinary school prior to the experiments.

Ventilation flow was set daily for the four experimental days. The ventilation airflow rate in the classrooms for each day was set in a random order to off, low (0.9 l/s per m² for regular classrooms and 1.1 l/s per m² for the smaller sized rooms), medium (1.3 l/s per m²) and high (2.0 l/s per m²). Temperature and relative humidity were measured using Tinytag Plus 2 (Gemini Data loggers, UK), and specific enthalpy calculated.

An untrained sensory panel consisting of 17 young adults (7 females and 10 males) assessed PAQ upon entering the classrooms, with no knowledge of ventilation rate or presence of additional pollutant sources. The participants each received a tablet, entered the classrooms one by one, and assessed PAQ using a digital slider. PAQ was scored on a continuous scale divided in two parts [7]. The PAQ-acceptability scale ranged from -1 ("Very unacceptable") to 1 ("Very acceptable"), with the value of 0.01 representing "Just unacceptable/Just acceptable". It was not possible to score at the midpoint.

Data analyses were performed using SPSS version 24 (SPSS Inc, Chicago, USA). and R with packages tidyverse and lme4 [8–10]. For all tests, the results were considered statistically significant when $P<0.05$. The PAQ-scores were used to calculate the percentage dissatisfied with air quality, where a score > 0.01 indicates acceptable PAQ. This was transformed into an air pollutant load using the formula developed by Fanger [11]:

$$Q = V \left(\frac{\ln(PD/395)}{1.83} \right)^4 \qquad (1)$$

where

Q = specific pollution load, olf/m²;

V = specific ventilation rate, l/s·m²;

PD = percent dissatisfied, %.

Using the non-parametric Friedman's two-way ANOVA by ranks and pairwise comparisons, we investigated whether ventilation rate had a significant effect on PAQ. The factors that significantly affected PAQ in an introductory linear regression were further examined in a linear mixed model to determine the relationships of PAQ with ventilation, pollutant sources and enthalpy (as fixed effect), adjusting for differences between the members of the sensory panel (participant ID as random effect).

3. Results

The measured room temperatures ranged from 20.72 – 24.05 °C and the enthalpy from 33.6 to 44.4 kJ/kg during the four measuring days, see table 1.

Table 1. Overview of measured temperature and calculated enthalpy under different ventilation rates. (Data missing from 2 rooms)

Ventilation	Temperature (°C)			Enthalpy (kJ/kg)		
	Mean± sd	Median	Min; max	Mean± sd	Median	Min; max
Off	22.2±0.91	21.87	21.01; 24.05	40.48±1.94	40.85	35.98; 44.36
Low	21.89±0.76	21.83	20.81; 23.76	36.79±2.20	35.98	33.59; 40.98
Medium	21.86±0.83	21.67	20.72; 23.67	37.46±2.63	36.13	34.37; 41.63
High	21.79±0.72	21.83	20.87; 23.47	37.43±2.66	36.52	34.31; 41.17

Figure 1 shows the distribution of the PAQ-scores under different ventilation conditions for each classroom. Large variation of PAQ-score given by the panel participants is obvious from figure 1, as well as the variation in PAQ-scores between different ventilation conditions and across the different classrooms.
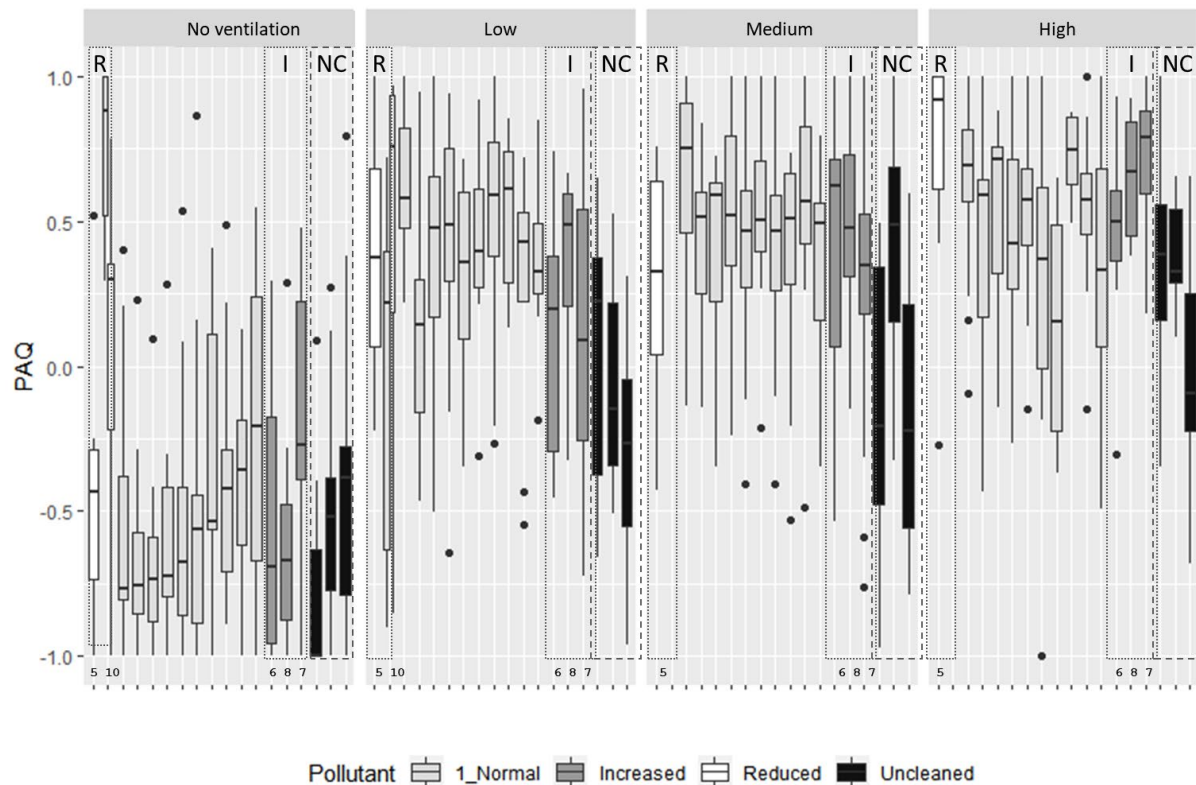
Figure 1. Boxplot of PAQ-scores (for different ventilation rates (V_{min}) in 18 rooms. NC=not cleaned. Details on numbered rooms with reduced (R) and increased (I) pollution are given in table 4.

3.1. Effect of ventilation rate

The lowest PAQ-score (median =-0.53) was observed when the ventilation was off in the classrooms. This resulted in the highest percentage dissatisfied (PD=75 %) with air quality (table 2). Compared to no ventilation, by turning it to low, medium or high led to significant improvements of the PAQ-scores (low: median=0.33), as well as a decrease in the percentage dissatisfied (PD <30 %). However, increasing V_{min} from low to medium (median PAQ-score = 0.47), and from medium to high (median PAQ-score = 0.54), had a much lower effect.

Table 2. PAQ-scores and percent dissatisfied (PD) at different ventilation rates.

Ventilation	PAQ-score			PD (%)		
	Mean± sd	Median	Min; max	Mean	Median	Min; max
Off	-0.39±0.53	-0.53	-1; 1	75	83	15; 92
Low	0.28±0.46	0.33	-0.96; 1	27	23	0; 73
Medium	0.35±0.44	0.47	-0.97; 1	24	20	8; 69
High	0.46±0.4	0.54	-1; 1	16	9	0; 58

3.2. Effect of introduced sources

The introduction of pollution sources had a significant effect on the PAQ-score, of which the PAQ-scores for the classrooms that were not cleaned were significantly lower than for the normal classrooms (figure 2). Adding extra pollution sources, or removing furniture into the classrooms resulted in lower or higher PAQ-scores, respectively, however, these differences were not significant.

The results from the linear mixed model showed that the ventilation rate had a larger effect on the PAQ-score than pollution sources. This effect varied depending on the pollution source. As seen in figure 2, turning on the ventilation to low had a more positive effect on the PAQ-scores in the normal classrooms than for the classrooms that were not cleaned. In comparison, increasing V_{min} from low to medium or high yielded a larger difference in mean PAQ-scores for the classrooms with extra pollution sources or were not cleaned than for the normal classrooms
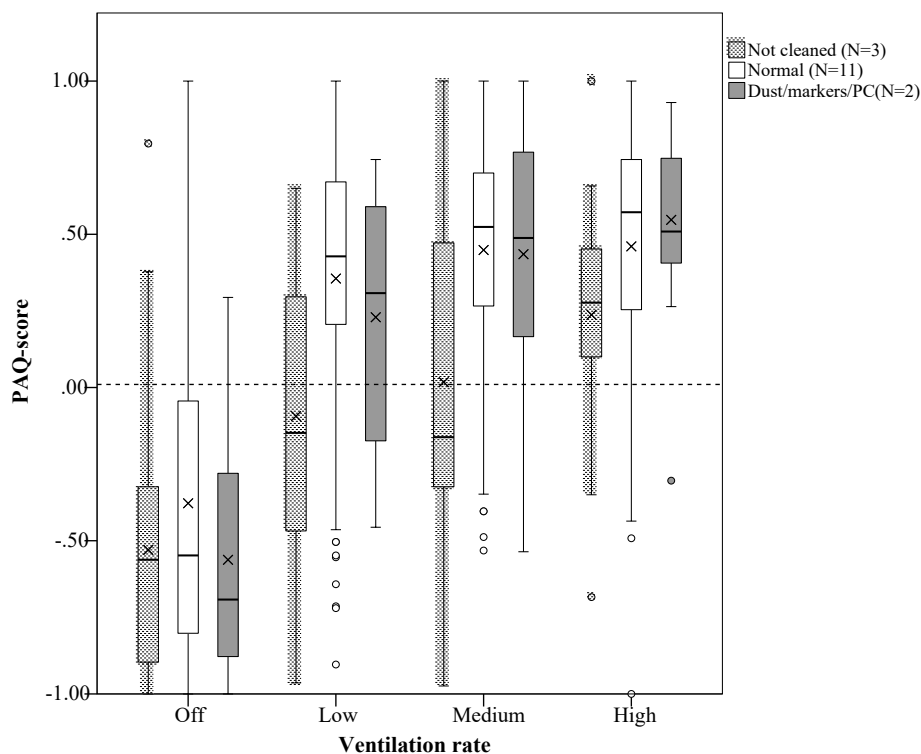

Figure 2. Boxplot of PAQ-scores for classrooms with and without introduced sources for different ventilation rates (V_{min}). Two rooms with reduced sources not included.

3.3. Pollution load

When pollution loads were calculated (table 3) from percentage dissatisfied, the large effect of not cleaning classrooms was visible. Also, it can be seen that an estimate of the pollution load from only one assessment is not very reliable.

Table 3. Pollution load (olf/m² floor area) assuming steady state between emission and ventilation. No calculation is attempted for the classrooms where ventilation is off. b.d..= below detection level (PD=0%).

| Classroom | Airflow | | | Pollution source |
	Low	Medium	High	
3	0.18	0.15	1.05	
4	0.18	0.23	0.09	
5	0.14	0.26	0.11	Less book shelves present (50 %)
6	0.21	0.51	0.11	**Dust bag**
7	0.14	0.83	b.d.	**Added book shelves (50%)**
8	0.09	0.23	b.d.	**Markers, dust bag, laptops**
9	0.05	0.07	0.44	
10 a	0.93			Emptied room
10 b	0.48			Room with furniture
11	0.13	0.62	0.22	
12	0.16	0.07	0.38	
13	0.09	b.d.	b.d.	
14	1.13	1.84	1.67	**Not cleaned**
15	0.06	0.22	0.09	
16	1.04	0.47	0.20	**Not cleaned**
17	0.10	1.02	b.d.	**Not cleaned**
18	0.13	0.21	0.20	
19	0.15	0.15	0.25	
20	0.04	b.d.	0.09	

4. Discussion

The perceived air quality upon entry is the historical basis for several recommendations for ventilation rates [12]. Even if the links of perceived air quality with health and productivity are circumstantial rather than conclusive, it should be aimed to achieve a perception of fresh air upon entry into a room. Our experiments indicate that the use of an untrained sensory panel can be valuable in assessing the indoor air quality, as the results were clearly correlated with ventilation rates and the presence of pollutants. As a consequence of the ventilation rate's effect on room temperature, we were not able to keep constant enthalpy across experiments. It has been shown that perceived air quality is decreased with increasing enthalpy [13]. This adds to the uncertainty of our results, but is not sufficient to explain the differences between classrooms.

However, the variation in estimated pollution loads between classrooms were somewhat inconsistent between ventilation rates, and with substantial differences between classrooms unaccounted for by identified pollution sources. In our experiments, the percentage dissatisfied were not reduced in the classrooms with no extra pollution source when increasing the ventilation rate from 0.9-1.1 to 2 l/s per m² floor area.

5. Conclusion
Even in a building with low-emitting building materials, ventilation prior to entry is necessary to maintain acceptable air quality. Our results indicate that a base ventilation rate of about 1.0 l/s per m² floor area is sufficient for rooms with low-emitting materials, but that higher rates may be recommendable for individual rooms. However, doubling the base ventilation rate to 2.0 l/s per m² is not sufficient to counteract the negative effect of insufficient cleaning or selected other pollution sources, stressing the importance of source reduction over increased ventilation rates.

References
[1] Wargocki P, Knudsen H and Frontczak M 2007 The effect of using low-polluting building materials on ventilation requirements and energy use in buildings *Proceedings - 6th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings: Sustainable Built Environment* IAQVEC 2007 (Sendai, Japan: Tohoku University Press)
[2] CEN 2008 *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acousticsWI_31_Pre-FV_version_prEN_15251_Indoor_Environment.pdf*
[3] Utdanningsetaten 2012 Felles kravspesifikasjon for Oslo kommune, Skoleanlegg 2012 - Del 3 Tekniske Krav
[4] Lewkowska P, Dymerski T, Gębicki J and Namieśnik J 2017 The Use of Sensory Analysis Techniques to Assess the Quality of Indoor Air *Crit. Rev. Anal. Chem.* **47** 37–50
[5] Mayer S 2013 Die gesundheitliche Relevanz von Innenraumbelastungen — Die Bedeutung von Gerüchen *Zentralblatt Für Arbeitsmedizin Arbeitsschutz Ergon.* **63** 312–23
[6] Nordin S, Aldrin L, Claeson A-S and Andersson L 2017 Effects of Negative Affectivity and Odor Valence on Chemosensory and Symptom Perception and Perceived Ability to Focus on a Cognitive Task *Perception* **46** 431–46
[7] Fang L, Clausen G and Fanger P O 1998 Impact of Temperature and Humidity on the Perception of Indoor Air Quality *Indoor Air* **8** 80–90
[8] R Core Team 2018 A language and environment for statistical   computing. R Foundation for Statistical Computing, Vienna, Austria.
[9] Wickham H Easily Install and Load the "Tidyverse"
[10] Bates D, Mächler M, Bolker B and Walker S 2015 Fitting Linear Mixed-Effects Models Using lme4 *J. Stat. Softw.* **67** 1–48
[11] Fanger P O 1988 Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors *Energy Build.* **12** 1–6
[12] Persily A 2015 Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62 *Build. Environ.* **91** 61–9
[13] Fang L, Wyon D P, Clausen G and Fanger P O 2004 Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance *Indoor Air* **14** 74–81