Should we differentiate ventilation requirements for different user groups?

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Abstract
The aim of our study is to investigate whether it is necessary to adjust the ventilation requirements according to different user groups. This study is focusing especially on teenagers, who might have a higher odour load than children due to increased hormone and sweat production during puberty. The odour intensity (OI) and the perceived air quality (PAQ) were evaluated in four classrooms in Oslo, Norway. Two control classrooms of 9-11 years olds (children) were compared with two case classrooms of 12-15 years olds (teenagers). A sensory panel of 18 untrained people visited the four classrooms three times during a three-hour period and were asked to evaluate PAQ and OI upon entering the classrooms. The classrooms were supplied with a constant ventilation rate of 7 l/s per person, with no additional ventilation for building materials. We found that the classroom with children had a significant better PAQ-score than both classrooms with teenagers. Furthermore, although the ventilation rate per person was reduced, the percentage of panellists dissatisfied with OI and PAQ was lower (<20%) than expected. Our results indicate that children and teenagers have different sensory pollution loads, and therefore might need differentiated ventilation rates if the ventilation rates were to be optimised. However, more research is needed.

Keywords: Perceived air quality, Odour intensity, Percentage of dissatisfied, Ventilation rate, IAQ, Sensory pollution load, Bioeffluents, Untrained panel, school

1 Introduction

The main purpose of ventilation is to reduce and dilute the indoor pollution sources, such as building material emissions and body odour intensity. Especially for children at school, it is important to have good indoor air quality (IAQ) in the classrooms as it can improve their learning and performances. Considering the complex structure of indoor air, with thousands of chemical compounds in the air, using chemical analysis has so far not answered the question of what makes a good indoor climate. Sensory pollution analysis, introduced by Fanger [1], has during the last 40 years been used as the basis for ventilation standard and guidelines [2,3]. The "olf" unit defined as the emission rate of air pollutants (bioeffluents) from a standard person has been used to quantify air pollution sources. Any other pollution source is then expressed by the equivalent source strength, defined as the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source. Table 1 summarizes the pollutant load from different sources used in the European Standard CEN 1752 [2] .

Table 1. Sensory pollution load from humans and buildings [2].

Source	Sensory pollution load (olf)
Sedentary adult (1-1.5 met)	1
Person exercising, low activity (3 met)	4
Person exercising, medium activity (6 met)	10
Children, 3-6 years	1.2
Children, 4-16 years	1.3
Building, low pollution	0.1 per m^2
Building, polluting	0.2 per m^2

Currently, the ventilation standard distinguishes between the emission rates of different building materials, but not for the ventilation rates per person of different user groups [3]. According to ASHRAE, the ventilation rate required for acceptable IAQ can be defined with <20% of people dissatisfied (PD) [3]. For a standard person (1 olf), this is equivalent to a ventilation rate of 7 l/s per person. However, as shown in Table 1, the sensory pollution load for children differs from the standard person, but the recommended ventilation rates does not take this factor into consideration. Seemingly, the resulting sensory pollution load, based on different user groups, hasn't implicated any practical meaning considering the ventilation requirements. For example, using Fanger's [1] equation to calculate the required ventilation rate to remove the sensory pollution from children (1.3 olf) and to achieve maximum 20% of people dissatisfied, the ventilation rate would be approximately 9.1 l/s per person.

During puberty, due to increased hormone and sweat production, teenagers might have an even higher sensory pollution load than children. Based on this, the purpose of this paper was to assess whether it is necessary to adjust the ventilation requirements according to different user groups, focusing on teenagers and children.

2 Methods

2.1 Study design

The study was carried out in four classrooms at a school in Oslo, Norway. Two control classrooms with pupils in the 5^{th} and 6^{th} grade (children aged 9-11) were compared with two case classrooms with pupils in 8^{th} and 10^{th} grade (aged 12-15). The characteristics of the classrooms are summarized in Table 2. The airflow rates in the four classrooms were kept constant during the experiments, even though the school has demanded controlled ventilation. The classrooms were supplied with a constant ventilation rate of 7 l/s per person with no additional ventilation for building materials. The four classrooms had an average floor area of 60 m^2, height of 2.8 m and had similar furnishings.

Table 2. Characteristics of the classrooms, with estimated number of people (N).

Classroom	N	Floor area (m^2)	Airflow rate (m^3/h)	Air change rate (h^{-1})
5. grade	28	60.1	706	4.20
6. grade	24	60.0	605	3.60
8. grade	17	60.9	428	2.54
10. grade	25	60.5	630	3.75

An untrained sensory panel of 18 people evaluated the odour intensity (OI) and perceived air quality (PAQ) in the four classrooms during a school day. The school day consisted of a morning teaching period (8:30 – 11:50), lunch break (11:50 – 12:30) and an afternoon teaching period (12:30 – 15:55). The experiments were carried out on the 13th March 2017 in the morning teaching period; during the first, second and third teaching hour. To ensure that the experiments were performed close to steady state conditions, each visit was done at minimum 30 minutes into the teaching hour. The four classrooms were visited three times in a random order. The untrained sensory panel consisted of six females and 12 males aged 24-41 (mean±standard deviation: 28.3±4.3). Each panellist received assessment forms for each round and the evaluations were done according to the ASHRAE Standard 62 [3]. The panellists entered the classrooms at the same time and gave their scores for PAQ and OI within maximum 30 seconds to counteract sensory adaptation. PAQ was evaluated using a continuous acceptability scale divided in two parts [4]. Odour intensity was measured using a 6-point scale [5]. Figure 1 shows the scales used for subjective assessment of PAQ and OI.

Data on temperature, CO_2 concentrations and outdoor airflow rate were collected for each classroom by the Building Management system (BMS). Relative humidity was measured using Tinytag Plus 2 (Gemini Data Loggers, UK).

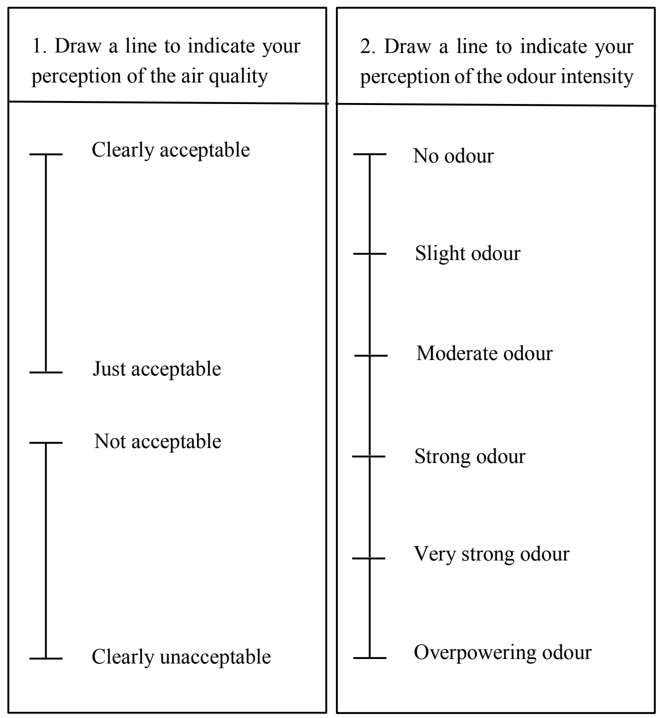

Fig. 1. Scale used for subjective assessment of PAQ (left) and odour intensity (right). The panellists were asked to draw a line. Note that the scale for PAQ is divided into two parts.

2.2 Data analysis

For data analysis, both the PAQ acceptability scale and OI-scale was converted into numbers. The PAQ acceptability scale was divided in two parts and coded as following: 1 = "Clearly acceptable", 0.01= "Just acceptable", -0.01=" Not acceptable", -1= "Clearly unacceptable". The OI-scale was coded as following: 1= "No odour" and -1 = "Overpowering odour". The scores of odour intensity and perceived air quality were used to calculate the percentage dissatisfied (PD) with air quality [1].

The statistical differences between case and control classrooms were analysed using the non-parametric tests Friedman's ANOVA by ranks or Wilcox Signed-Rank test. Statistical analysis was performed with SPSS version 24 (SPSS Inc, Chicago, USA).

3 Results

Table 3 summarizes the measured indoor climate parameters obtained from the BMS loggers. We also calculated the personal ventilation rate and enthalpy. The actual number of occupants in classrooms of 6th and 10th graders deviated the most, resulting in a higher ventilation rate per person. Generally, there were not many variations in the temperature, relative humidity and CO_2-level between the visits across the four classrooms. As seen in Table 3, the difference in temperature is most likely due to the reduced ventilation rates as the enthalpy in each classroom is similar. The first visit, which was made approximately 30 minutes after the school started, resulted in the lowest CO_2-level and highest RH in all four classrooms.

Table 3. Overview of the actual number of occupants/pupils (N), outdoor air supply rate ($\dot{V}_{supply}$), calculated ventilation rate per person ($\dot{V}_{pers}$), room temperature (T), CO_2, relative humidity (RH) and calculated enthalpy during the three visits in the classrooms.

	N	$\dot{V}_{supply}$ (m³/h)	$\dot{V}_{pers}$ (l/s)	T (°C)	CO_2 (ppm)	RH (%)	Enthalpy (kJ/kg)
5th grade							
1.	26	677	7.2	22.5	609	30.4	38.5
2.	26	642	6.9	23.2	1006	27.5	35.8
3.	26	736	7.9	23.7	847	24.9	35.5
6th grade							
1.	18	591	9.1	23.3	588	32.3	38.2
2.	15	547	10.1	23.5	863	26.7	36.0
3.	20	572	7.9	23.3	809	24.8	34.7
8th grade							
1.	16	432	7.5	24.0	531	26.5	36.8
2.	18	397	6.1	24.8	607	24.4	37.1
3.	17	397	6.5	25.4	599	22.7	37.3
10th grade							
1.	25	672	7.5	23.7	593	29.9	37.8
2.	20	582	8.1	24.2	827	25.4	36.6
3.	26	588	6.3	24.2	814	26.1	37.3

3.1 Odour intensity

Figure 2 shows the variation of the scores for odour intensity in the four classrooms. The OI-score of 0.1629, corresponding to "*moderate odour*", was set to indicate acceptable odour intensity. The median OI-scores for the classrooms with teenagers were mostly lower than the median OI-scores for the classrooms with 6th graders. Surprisingly, the classroom of 5th graders received the lowest overall OI- score (median =0.48), which corresponds to moderate to slight odour. The percentage dissatisfied was also highest in this classroom (PD=16.7-22.2%). We were later made aware that people had complained about unpleasant odours occurring in this classroom. Consequently, the classroom with 5th graders was excluded from further analysis since it was not considered a representative classroom.

Generally, we found no significant differences in OI-score between the classroom with children and the two classrooms with teenagers. The classroom with 6th graders, with the highest personal ventilation rate, received the highest overall OI-score (median=0.67) and the lowest percentages of dissatisfied with the IAQ. During the three visits, the panellists were largely more dissatisfied with the odour intensity in the classrooms with teenagers than the classroom with 6th graders (see Table 4).

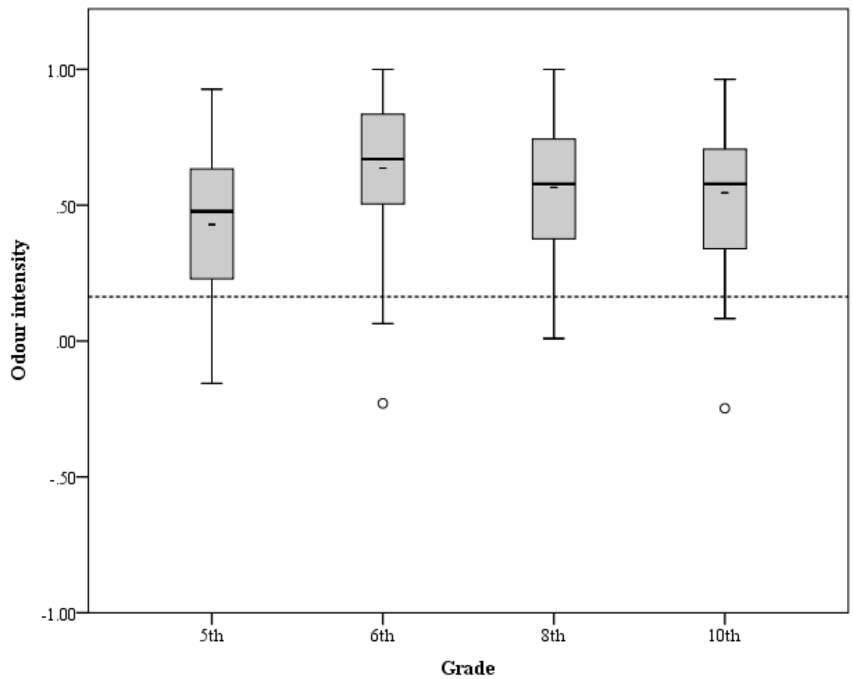

Fig. 2. Boxplot of the scores for odour intensity by grade. The dotted line indicates moderate odour (score=0.1629). The dark line in the middle of the boxes is the median, the short line is the mean. The top and bottom of the box are the 75th and 25th percentiles. Whiskers indicate the 10th and 90th percentiles and individual outliers are shown as points.

3.2 Perceived air quality

An overview of descriptive statistics for each visits is shown in Table 4. Figure 3 shows the variation of PAQ-scores across the four classrooms, with a PAQ-score of 0.01 set to “Just acceptable”. Generally, the classrooms with teenagers received lower PAQ-scores than the classrooms with children. The classroom of 6th graders received the highest overall PAQ-score (median=0.73), and the classroom of the 8th graders the lowest (median=0.39). We also found that the PAQ-score for the classroom of 6th graders differed significantly from the two classrooms with teenagers (Friedman’s ANOVA, p<0.01). We did not find any significant difference in PAQ-score between the classroom of 5th graders and the classrooms with teenagers.

As seen in Table 4, during the three visits, the panellists were generally more dissatisfied with the air quality in the classrooms with teenagers than the classrooms with children.

Table 4. Descriptive statistics of the odour intensity and perceived air quality (PAQ) during the three visits in the four classrooms.

	Odour intensity (OI)				**PAQ**			
	mean±sd	**median**	**min, max**	**%PD**	**mean±sd**	**median**	**min, max**	**%PD**
5th grade								
1.	0.41±0.29	0.43	-0.14, 0.87	22.2	0.55±0.26	0.58	0.10, 0.96	0
2.	0.39±0.31	0.45	-0.12, 0.91	22.2	0.50±0.27	0.51	0.06, 0.98	0
3.	0.49±0.34	0.55	-0.16, 0.93	16.7	0.46±0.28	0.52	0.03, 0.87	0
All	0.43±0.31	0.48			0.50±0.27	0.53		
6th grade								
1.	0.60±0.31	0.64	-0.23, 1.0	5.6	0.51±0.33	0.61	-0.06, 0.98	5.6
2.	0.65±0.28	0.72	0.08, 1.0	5.6	0.70±0.24	0.79	0.21, 1.0	0
3.	0.66±0.29	0.70	0.06, 1.0	11.1	0.68±0.26	0.75	0.12, 1.0	0
All	0.46±0.29	0.67			0.63±0.29	0.73		
8th grade								
1.visit	0.54±0.28	0.55	0.1, 0.98	11.1	0.33±0.34	0.34	-0.17, 0.93	11.1
2.	0.61±0.29	0.64	0.01, 0.98	16.7	0.44±0.36	0.35	-0.06, 1.0	5.6
3.	0.54±0.23	0.55	0.1, 1.0	11.1	0.48±0.31	0.51	0.1, 1.0	0
All	0.57±0.26	0.58			0.41±0.34	0.39		
10th grade								
1.visit	0.51±0.22	0.57	0.1, 0.83	11.1	0.52±0.25	0.54	0.01, 0.93	0
2.	0.53±0.36	0.61	-0.25, 0.96	16.7	0.38±0.39	0.31	-0.51, 0.96	11.1
3.	0.60±0.24	0.59	0.10, 0.94	5.6	0.49±0.30	0.56	-0.08, 0.91	11.1
All	0.55±0.28	0.53			0.46±0.32	0.51		

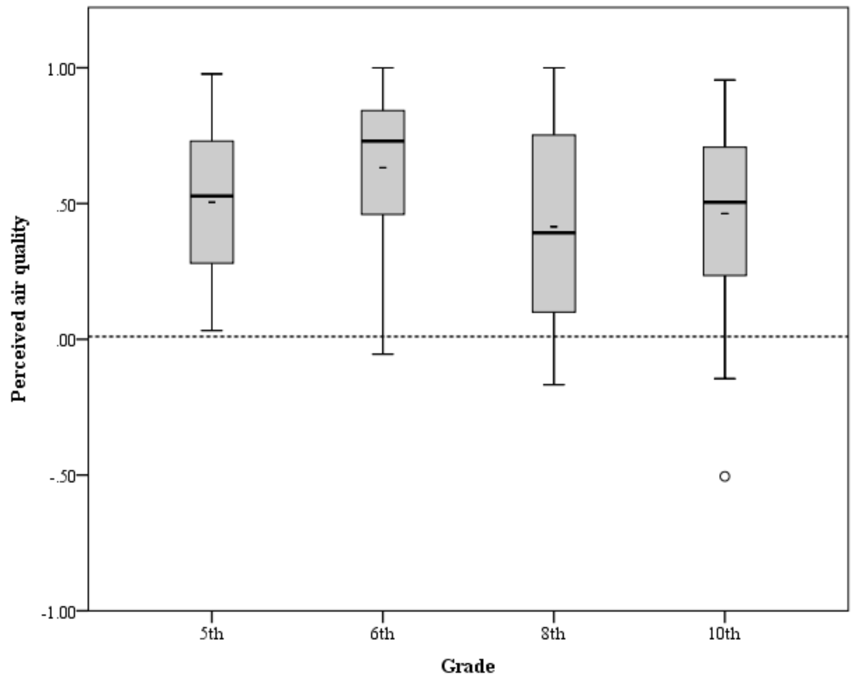

Fig. 3. Boxplot of PAQ-scores by grade. The dotted line indicates acceptable PAQ (score=0.01). The dark line in the middle of the boxes is the median, the short line is the mean. The top and bottom of the box are the 75th and 25th percentiles. Whiskers indicate the 10th and 90th percentiles and individual outliers are shown as points.

4 Discussion

The use of sensory measurements to calculate the necessary ventilation to achieve a certain PAQ is generally accepted [1,5]. The main research question asked in this paper is whether differences in user groups should be considered when estimating the required ventilation rates for optimal indoor air quality. According to the technical report CEN CR 1752 [2], the sensory pollution load from kindergarten children and school children differs from the standard person, this due to children having a higher activity level and possibly poorer hygiene. Subsequently, it is reasonable to assume that this difference influences the indoor air quality, and thus ventilation requirements should be differentiated between different user groups. Our findings do not provide any indications of whether the pollution load from children and teenagers are lower or higher than the standard person. It would be of interest to compare the pollution load of the standard person with children and/or teenagers.

Nevertheless, we did find that the OI-scores was overall lower for the classrooms with teenagers compared to those with children, although this difference in OI-scores was not significant. Furthermore, the PAQ-scores for the classrooms with teenagers were also significantly lower than the classroom with children. This indicates that the panellists were generally more satisfied with the air quality in the classrooms with children. Yaglou et al. [5] recommended higher ventilation rates per person for children to achieve similar acceptable odour intensity as for adults. Similarly, we found that higher personal ventilation rates for children in the 6th grade resulted in the lowest percentage dissatisfied and highest OI-score.

Compared with other studies, we found a lower percentage dissatisfied with OI and PAQ in our study. This could be due to that majority of the studies on sensory measurements and ventilation rates also included pollution load from tobacco smoke and building materials in addition to occupancy [1,6–8]. Fanger [1] also postulated that the sensory unit olf for individual pollution sources can be added if they occur at the same time, but also recommended further research about this. In our study, low-emitting building materials have been used in all classrooms, thus it is reasonable to assume that the pollutant load from the materials is rather low. The focus of our study was mainly on the pollution load from occupants, assessing pollutant loads from building materials is beyond the scope of this study.

During field experiments, it is hard to control every parameter that can influence the results. The sensory panel visited the classrooms during a normal school day. As shown in Table 3, during the three visits, the number of occupants in the classrooms varied. This obviously affected the amount of supplied air per person ($\dot{V}_{pers}$). The school has demand-controlled ventilation with optimizers. Even though the four classrooms were programmed to deliver a constant air volume, the supplied airflow rate might vary due to pressure changes in the main ventilation duct when the ventilation in the classrooms nearby changed during the school day. This factor, and the 15-minute long break before the third visit, might have caused the different CO_2-levels during the day. Nevertheless, none of the pupils left the classrooms during the 30 seconds the untrained panel evaluated the PAQ and the OI.

As seen in Table 3, with a ventilation rate of 6.3 l/s per person and a temperature of 24.4 ºC, we only achieved a PD of 5.6% during the third visit in the classroom with 10th graders. With the exception of the classroom with 5th graders, which was excluded due to known unpleasant odours, the percentage of panellists dissatisfied with PAQ (<12% dissatisfied) and OI (<17% dissatisfied)was considerably lower than expected. With the supplied ventilation rates based on the occupants only, the PD was expected to be higher than 20% if the pollution loads in olf are summarised. Based on this, even with lower ventilation rates, it should be possible to accomplish an expected level of 20% dissatisfied in three of the four classrooms we visited. Even though only four classrooms were assessed, our results indicate that the olf values shown in Table 1 might be outdated. However, further research is needed.

5 Conclusion

Our results indicate that there might be a need to differentiate between user groups in regards to ventilation rates.

6 Acknowledgements

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