Studying the efficiency of air cleaners at removing various indoor air impurities in classrooms and the relation to pupils’ symptoms

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Abstract. The existing knowledge on the effect of air cleaners in reducing different indoor impurities and health symptoms in real-life applications is still insufficient. PUHHO study aimed to fill this knowledge gap with a blinded intervention study in 18 primary school classrooms. The study was conducted during 8 weeks with 2 weeks without air cleaner, 3 weeks with air cleaner in full operation (filtration) with moderate airflow (200 - 400 m³/h) and 3 weeks sham operation (air cleaner blowing air without filtration). The latter two interventions were conducted in a blinded and mixed setup. Small, but statistically non-significant reductions in particulate matter levels (PM₂.₅, particulate matter less than 2.5 μm and PM₁₀, diameter of particles less than 10 μm) were observed when comparing air cleaner filtration to air recirculation alone (sham operation). The use of air cleaners had no significant effect on the level of total volatile organic compounds (TVOC). Air cleaners did not have significant effect on the microbial levels or on the microbiome of the classrooms. Filtration by air cleaners was found to statistically significantly reduce upper (4.0%) and lower airway (2.5%) and other (4.0%) symptoms, but a nearly equivalent effect was observed with air recirculation alone.

1 Introduction

People spend most of their time in different indoor environments, hence, indoor air quality plays a major role both in human well-being and health. Impurities of indoor air, such as particles, micro-organisms and chemicals, can cause occupant symptoms, and reduce health and well-being of the environment-users [1,2]. Outdoor air, building structures and different indoor sources including occupants are the main origin of indoor air impurities [3-6]. While there are some indications that the use of air cleaners might reduce indoor-air-quality (IAQ)-related symptoms [7], the existing evidence is still insufficient. Furthermore, there are no studies elucidating the effect of air cleaners on indoor microbiome. The objective of PUHHO study was to perform a comprehensive assessment of the effect of air cleaners on particulate matter, volatile chemicals and indoor microbiome in occupied classrooms in Finnish schools, and to explore associations with pupils’ health symptoms.

2 Materials and methods

2.1 Study schools and air cleaners

The study was conducted during one school year in 18 classrooms from third to sixth grades of six elementary schools (three classrooms/school). The monitoring lasted eight weeks in each school, starting with a two-week baseline period, that was followed by two three-week observation periods: one with air cleaner operating with filter and one with air cleaner operating without filter (sham operation; only air circulation). The periods were randomized, i.e. half of the schools started with sham operation, the other half with air cleaner filtration, and pupils and teachers were blinded to the air cleaner operation status. Air cleaners P1 and P3 were equipped

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<td>P1</td>
<td>Pre-filter, activated carbon (4 kg), HEPA (E11)</td>
<td>200 m³/h</td>
<td>Removal of carbon and HEPA filter.</td>
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<tr>
<td>P2</td>
<td>High voltage accumulator, collector electrode, activated carbon (800 g)</td>
<td>230 m³/h</td>
<td>Removal of collector voltage and activated carbon.</td>
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<td>P3</td>
<td>Pre-filter, activated carbon (400g), HEPA (H14)</td>
<td>420 m³/h</td>
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Table 1. Technologies used in different air cleaner models, airflow and how sham operation was performed.

with a coarse pre-filter and HEPA filter, while in the air cleaner model P2, particles were charged with high voltage and then removed by electrostatic precipitator. All air cleaners included an activated-carbon filter (Table 1.)

In each school, all air cleaner models were used, but only one model/room. Two units were placed in different parts of the room. Moderate airflow (200–400 m³/h) were used in all models.

2.2 Measurement of particles, chemical and microbiological impurities

2.2.1 Measurement of the particulate matter

In order to evaluate the variation of PM10 and PM2.5 levels during interventions, their levels were monitored continuously (recorded every 2 min) with DustTrak DRX 8533 in half of the classrooms (9/18; in three schools). Other indoor conditions, such as CO₂, temperature and relative humidity, were determined with VelociCalc 9565-P detector. PM concentrations reported by the optical monitors have not been corrected to a gravimetric sample. Data measured with TEOM at urban background station in Kallio were used as outdoor concentrations.

2.2.2 Microbial measurements

For the determination of microbial concentrations in indoor air, settled dust samples were collected from every classroom on six parallel petri dishes [8] aligning with the two-to-three-week study phases described earlier.

In half of the study classrooms, microbial sampling was complemented with active air sampling using Button Inhalable Aerosol sampler [9] during a five day * six hours collection period (Monday to Friday). Quantitative PCR analyses on those samples was carried out targeting major bacterial and fungal groups based on established qPCR assays: Cladosporium herbarum (Cherb), Penicillium/Aspergillus/P. variotii (Penicillium/Aspergillus spp.); Gram-positive and Gram-negative bacteria, and universal fungal (Unifung) assay targeting total fungal DNA in the samples. The bacterial and fungal communities were sequenced on Illumina MiSeq v3 platform amplicon technique after PCR amplification of the bacterial 16S rRNA [10] and fungal ITS1 [11] regions.

2.2.3 Measurement of volatile organic compounds (VOCs)

VOCs were measured in occupied classroom once a week during 90 min of school day on Tenax TA/Carbobraph 5 TD absorption tubes with the airflow of 100 ml/min from each classroom and from outdoor air on the school yard. Determination of VOCs and their total concentration (TVOC, toluene equivalent) were performed by Finnish Institute for Occupational Health with thermal desorption GC-MS principle.

2.2.4 Symptom reporting

Written consents were requested from the guardians of 294 pupils willing to participate in the study. Directed by a teacher, pupils filled the diary during school days. Information on experienced lower respiratory symptoms including wheezing, coughing during day, coughing during night, phlegm in throat or chest, waking up during night due to problems of breathing, and on upper respiratory symptoms flu or stuffy nose, dry or sore throat, hoarseness of voice, reddening, swollen eyes and on other symptoms was collected. The teacher kept a record of the students' presence in the class during the study.

3. Results

3.1 Particulate matter results

To evaluate how air cleaner affected indoor air particle levels, indoor to outdoor (I/O) ratios were computed for every classroom as a mean of daily (8–15) I/O ratios on baseline. These I/O ratios were then used to calculate expected indoor particle levels without air cleaner by multiplying outdoor levels with the I/O ratio, separately for each classroom. Expected difference was then computed by reducing the calculated expected particle levels from the measured indoor particle levels. Theoretical difference gives indications on how air cleaner operation affected the indoor particle concentration during observation period.
Fig. 1. Difference of real and theoretical levels of PM$_{2.5}$ and PM$_{10}$.

In general, a slightly greater difference between measured and expected PM$_{2.5}$ levels can be observed when air cleaner was operating with filter than without filter (figure 1).

**Microbial results**

We observed small, non-significant decreases in microbial levels in air samples when comparing baseline to air cleaner on with filter (figure 2). For most targeted microbes, also air circulation alone (sham operation) seemed to similarly slightly decrease the levels. For the settled dust samples, we observed no consistent differences in microbial levels in baseline versus full or sham operation of air cleaners. Use of air cleaner did not have considerable effects on the bacterial and fungal classroom microbiota determined by amplicon sequencing of settled dust.

3.3 TVOC results

The concentrations of TVOCs and individual volatile organic compounds (data not shown) were clearly below the action limits specified in the national health regulation for housing, i.e. 400 $\mu$g/m$^3$ and 50 $\mu$g/m$^3$, respectively, throughout the study period. A slight, non-significant, decrease to the baseline (mean: 52.9 $\mu$g/m$^3$) was observed when air cleaner was operating with filter (mean: 39.44 $\mu$g/m$^3$). Levels of TVOCs on baseline and when air cleaner was operating without filter (mean: 55.00 $\mu$g/m$^3$) were very similar.

**Fig. 2.** Violin plots of qPCR measurements from active air samples during three operations: air cleaner off, air cleaner with filter and air cleaner on without filter (sham operation). $n = 18$ ($n = 17$ for Grampos, air cleaner off). CE = cell equivalents.

3.4 The effect of air cleaner operation on health symptom reports

Altogether, 141 of 294 pupils answered to questionnaires at least on 5 days on each intervention phase leading to 1,155 observation days on baseline, 1,702 observation days when air cleaner was operating on with filter and 1,630 observation days when air cleaner was operating on without filter (sham operation). A statistically significant decrease in reports of lower, upper and general symptoms could be observed between baseline and air cleaner operating with filter and between baseline and sham operation (Figure 3). However, comparison between air cleaner operating on with filter and (sham operation) were statistically not significant in each symptom category.

4. Discussion

In this study on air cleaner application in 18 Finnish primary school classrooms we found only small, non-significant effects of air cleaner operation on particle, microbial and volatile chemical levels in indoor air. For PM and microbes, reduction in levels appeared to be similar to some extent during sham (no filtration) and regular (with filtration) operation of the air cleaners. Adequate dimensioning of the air cleaner has a crucial role in removing pollutants from the indoor air. The air cleaner only cleans the air that passes through the filter of the purifier. This study indicates that the Clean Air Delivery Rate used in this study may not be enough in a large classroom.

In an earlier study [12] portable air cleaners were found to significantly reduce particulate matter (PM$_{1}$, PM$_{2.5}$ and PM$_{10}$) in a randomized blind crossover study in long term care facilities. The study also showed that sham-operation was able to reduce particle levels, although the effect was not statistically significant. The additional air circulation produced by the air cleaners probably improves the overall mixing of air in the classrooms and, thereby, enhance the air exchange.
produced by the ventilation systems. As a result, both the full operation of air cleaners with filters and the sham operation can lead to dilution of pollutants.

Pupils reported significantly less symptoms on both intervention phases (filtration or sham operation) compared to baseline, but there was no significant difference between these two air cleaner operations. An earlier study showed that the use of air cleaner improved respiratory rate among children diagnosed with asthma compared to control group in school environment. However, these results were not statistically significant [13]. Either randomized clinical trial with air cleaner did not show a significant decrease in asthma-symptoms among school children, when using air cleaners [14]. This phenomenon needs further study to evaluate if it is due to placebo effect or could only air circulation decrease the experience of reported symptoms. Overall, this kind of blinded interventional study set up in school environment was first of its kind with broad view to understand efficacy of air cleaners in reducing different types of indoor air impurities. In addition, the application of portable air cleaners to tackle indoor microbial levels is of greater interest today than ever before, but studies on the effect on indoor air microbiota in real-life environments are scarce.

In conclusion, our intervention study carried out in real-life, in classroom environments does not show significant impact of air cleaner operation with the used CADR on indoor volatile chemical, particle or microbial levels, though some reduction during both sham and actual filtration operation was observed compared to baseline measurements. The finding that both sham and filtration operation of air cleaners were associated with reduced symptom reports of the pupils needs follow-up investigation.

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References