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The effect of room air cleaners on infection control in day care centres

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A R T I C L E I N F O

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A B S T R A C T

The aim of this study was to assess the effectiveness of air cleaning in reducing the risk of respiratory infection in two day care centres using a simple and robust calculation model. Additionally, we aimed to identify potential hotspots for infections in indoor setting and focus countermeasures accordingly. Initial results from an interventional clinical study are provided as proof-of-concept for the model. We constructed a mathematical model to assess the number of persons at risk for airborne infection transmission in day care. Utilizing the model, we used portable air cleaners in two day care units (A and B, number of children participating in the study n = 43) and compared infection incidents between the two intervention units to the rest of the units in city of Helsinki (n = 607). The intervention buildings had mechanical supply and exhaust air ventilation. The risk modelling suggests that the use of air cleaners reduced the expected number of persons at infection transmission risk significantly. At day care centre A the average reduction was 60% (range 52% - 88%) and at day care centre B 53% (range 14% - 59%). During the approximately six month study period, we observed a significant difference in the days absent from day care due to infections between the intervention and reference day care units. On average, the parents were absent from work due to child's illness in reference day care centers for 5.53 days and 3.77 days in intervention day care centers during the study period (p = 0.009). In relative terms the reduction was approximately 32%. Our study offers compelling evidence to support increasing non-infectious air flow rates in daycare centers during periods requiring infection risk management. This can be implemented with portable air cleaners as an effective and cost-efficient strategy for mitigating the spread of respiratory infections among children. The clinical results support the findings suggested by the theoretical model.

Implications and impacts:

– Air cleaning seems to be an effective way to reduce infection risk in day cares

– Identification of infection risk hotspot will help in desgining the preventive methods

– Portable air cleaners offer an affordable and versatile solution also in buildings where existing ventilation is insufficient for infection risk management"

1. Introduction

Respiratory and enteric infections are common among children attending early childhood education, with many episodes occurring in a single winter [1]. These infections cause discomfort and distress to the infected children, increase healthcare expenses and can lead to outbreaks that affect not only the children attending the center but also their families and the wider community.

In addition to the direct effects these infections also result in increased absenteeism among parents. Parents need to take time off work to care for their sick children, leading to substantial costs in terms of lost productivity [2]. Taking care of sick children also affects parents' routines, social life, and experiences of well-being [3]. The extensive use of temporary care leave increases the risk of parental stress and overload [1,4].

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1.1. Paradigm shift from droplets to aerosol

The current paradigm of hygiene has been concentrating on prevention of spread by droplets and direct contact. COVID-19 began a change in the paradigm and recently many studies regarding increased air ventilation and air cleaning have been conducted. Previous research has shown that air cleaners can be effective in reducing concentration of airborne particles and bioaerosol in various settings, including hospitals, schools, and day care centers [5–12]. This has also been used as an evidence of their capability to reduce the spread of respiratory infections although, the relation between bioaerosol and risk for infection transmission is not yet clear [10].

1.2. Recommendations for ventilation

If meaningful reduction of viral particles in the indoor environment should be achieved with room air cleaners, the non-infectious air flow rate of the air cleaners should be high enough compared to existing ventilation of the room. The non-infectious air flow rate of the air cleaner is obtained by measuring the CADR (Clean Air Delivery Rate) value. The CADR is determined by examining the reduction in the concentration of the target pollutant in the test chamber caused by the air cleaner [13]. At least four recommendations for sizing the room air cleaner for specific room exist. 1) Association of Home Appliance Manufacturers (AHAM) recommends the 2/3 rule [14], ie. the CADR of the air cleaner in cubic feet per minute should be equal to at least two-thirds of the room's area in square feet corresponding to an air change rate (ACH) of 5 h^{-1} in a normal height room. 2) US Centers for Disease Control and Prevention recommends also to aim equivalent air change rate (ACHe) of 5 h^{-1}. This can be achieved through any combination of central ventilation system, natural ventilation, or additional devices [15]. 3) According to REHVA the clean air delivery rate (CADR) of a room air cleaner should be 2 times greater than the outdoor air flow by the ventilation system in rooms with a ventilation rate more than 1 h^{-1}. This provides the theoretical reduction of the concentration of a pollutant by 70% [16]. In rooms with a ventilation rate lower than 1 h^{-1} the CADR must be at least 2 h^{-1}. 4) For residential use the Swedish Asthma and Allergy Association recommends a CADR of four times the ventilation rate [17]. 5) Finnish decree for non-residential buildings requires clean air supply of 6 dm^3s^{-1} per person or 3 dm^3s^{-1} per m^2.

1.3. Recommendations for airborne infection control

There are also several recommendations for ventilation to control airborne infections according to number of persons occupying the space. 1) REHVA recommends a variety of air flow rates depending on the type of the space, but sets a minimum of 4 dm^3/s per person [18]. 2) The Lancet COVID-19 Commission Task Force on Safe School, Safe Work, and Safe Travel proposes a flow rate per person starting from 10 dm^3/s/person to be referred as good ventilation while best ventilation needs more than 14 dm^3/s/person non-infectious air flow rate [19]. The task force also gives recommendations based on volumetric flow rate per volume (air change rate, ACHe) ranging from 4 ACHe to more than 6 ACHe. 3) ASHRAE standard regarding control of infectious aerosols in buildings defines an infection risk management mode (IRMM) [20]. The required equivalent air flow rates depend on the indoor setting and varies between 10 and 45 dm^3/s per person. There are no requirements for day care centres but the closest values are those for classrooms (20 dm^3/s/person) and lecture halls (25 dm^3/s/person).

1.4. Infection risk models

In the aftermath of the current pandemic, modelling of airborne infection transmission probability has received increased attention and several models have been presented. The usual way to model is to first estimate the pathogen emission rate and then calculate the infectious aerosol concentration in the indoor air taking into consideration the dilution due to ventilation and air cleaning, the removal by deposition, and the inactivation by time. Thus, exposure dose obtained through breathing can be calculated and infection transmission probability can be estimated. Many of such estimates use a similar approach to Nicas et al [21]. where the human emission of airborne pathogens is based on size and number distributions of expired droplets and the virus concentration of respiratory fluids. A simplified version of emission is based on infectious quanta, where a quanta is defined as a dose of causing infection to $1\text{-}e^{-1} \approx 63\%$ of exposed population. For SARS-CoV-2, the quanta emission rates have been back calculated from known super spreading events. In the quanta context the pathogens are lumped into particles with size < 5 micrometer. Aganovic et al. presented a virus variant quanta multiplier by which the emission rates are multiplied to take into consideration different variants. [22]

Although the extensive activity in the field of infection transmission modelling there are only few studies which have made air cleaning interventions and compared theoretical calculations with clinical outcomes. Banholzer et al. studied the effect of HEPA air cleaner interventions on infections [23]. Although the aerosol number concentrations were on the average 53% lower with air cleaners compared to no interventions there were not any difference found in the probability of SARS-CoV-2 infection. This could be partly attributed to the relatively short two-week intervention period, during which only a few COVID-19 infections occurred. However, there is ambiguity in the results regarding whether air cleaners can effectively prevent the transmission of airborne infections. Some studies suggest a positive impact while others do not [23–25].

The aim of this study was to assess the effectiveness of increased non-infectious air flow rates obtained with portable air cleaning devices in reducing the risk of respiratory infection in two day care centers using a simple and robust calculation model for estimating the risk of airborne transmission of infectious diseases, including COVID-19. It estimates viral shedding rates using in principle directly measurable basic parameters such viral load of the respiratory fluids and airborne aerosol emission rates based on activity. The prevalence of the disease is also used to calculate the probable number of infectious persons in the room, giving a realistic estimation of the number of pathogen shedders in a given space. One important advantage of the model is that it is universal in the sense that it is applicable to airborne infectious diseases in general, although all the key parameters like viral loads in the respiratory fluids and infectious doses are not known for all diseases.

We also use the model to calculate the number of persons in the risk of virus transmission in each room. With this detailed information we could optimize to the location of the air cleaners to reduce the number of the persons in transmission risk in the whole the building. Additionally, we aimed to identify potential hotspots for infections in indoor setting to implement countermeasures efficiently. Initial results from an interventional clinical study are provided as proof-of-concept to validate the model.

2. Methods

2.1. Day care units

The studied two day-care units where air cleaning intervention was conducted (A and B) are in the same area in the City of Helsinki. In day care unit A there are 110 children (age 1–6 years old) divided to 6 groups of and 19 staff members. The day care unit B is occupied with 123 children in 6 groups and 21 staff members. The floor area of day-care unit A is circa 1000 sq meters and its mechanical ventilation flow rate was 2.4 m^3/s in the areas occupied by children and staff. Room floor areas varied between 14.4 m^2 and 68.0 m^2 with an average of 30.3 m^2 and the air change rates varied between 2.7 1/h and 10.7 1/h being on average of 4.2 1/h. Similarly, the day-care unit B a floor area

Table 1
Air cleaners characteristics and location in the two day care units.

Model	CADR with fan speed setting used in this study m3/h	Air cleaner id and location
Air0 SmAIRt1200	1260	A5
Air0 SmAIRt1200	1010	A2, A15
Air0 SmAIRt600	570	B3, B9
Air0 SmAIRt600	434	A3, A8, A14, A18, B7, B12, B17
Alme Pure	372	A6
Halton MobileAirCleaner VCR	1500*)	A16, B5, B6
IQAir CleanZone SLS	650	A7
IQAir Icleen Health Premium	240	A4, A9, A19, A20
ISEC Kuulas	125	A21, B8
ISEC Vinha	453	B20
ISEC Vinha	302	B15, B23
Lifa Air LA502C	285	A11, A12, A13, B2, B4, B10, B11, B19, B22
ISEC Type 1	195	B1, B13, B14, B16, B18, B21
ISEC Type 2	433	A1, A10, A17, A22

*) Reported by the manufacturer

is circa 900 square meters (room areas 11–68 m^2, average 30.7 m^2) and air flow rate was 2.9 m^3/s producing room air change rates between 2.0 1/h and 7.2 1/h with an average of 3.8 1/h. Both buildings are equipped with constant volume air flow mechanical ventilation for supply and exhaust air and were dimensioned according to Finnish legislation. In both day-care centres the air distribution was mixing type ventilation. The reference group was recruited from all other day care units ran by the city of Helsinki.

2.2. Room air cleaners

Air cleaners used in the study were of various models and sizes with clean air delivery rates for particulate matters ranging from 240 to 2700 m^3/h. However, due to the increased noise level the air cleaners were not operated in full fan speed in some locations and the used CADR varied between 240 – 1500 m^3/h. Most of the air cleaners were tested earlier in laboratory applying ANSI/AHAM AC-1–2020 test standard to determine their clean air delivery rates before installation [26]. Their on-site CADRs during the study are shown in Table 1. The floor plans of the day care units and locations of the air cleaners are displayed in Fig. 1.

2.3. Selecting and locating the room air cleaners

Occupancy, activity and time spent in the different spaces of the day care centre varied during the day. This will influence on the risk of disease transmission within the building. Instead of conventional design criteria such as floor area, space volume, and air change rate, we introduce a more sophisticated airborne infection risk-based approach for optimizing the placement of room air cleaners in different spaces.

In practice, there was a limited number of air cleaners available for the day-care centres. This was due to the cost of air cleaners as well as the limited space for air cleaners in day care rooms. In general, there was place for only one air cleaner in a room. The question is how to use these limited number of air cleaners most efficiently to reduce the risk of virus transmission in the whole building.

One of the goals for this risk-based approach is to estimate more precisely the presence of potential pathogen sources (infectious people). The likelyhood of pathogen emission increases as the number of occupants in the indoor space and their activity increase. For pathogen exposure, the time spent in the room is also important. Our risk-based approach enables designing optimal CADR values by comparing the calculated reduction in the number of persons at risk gained by positioning each room air cleaner virtually in different rooms. The position of the air cleaners was then chosen so that the minimum number of persons at risk at building level was obtained.

This new approach requires more specific information about the use profile of the spaces including the number of occupants at different times of the day in each room. The information on normal hour-to-hour activities was gathered from the personnel via a questionnaire. We utilized the occupancy and activity profiles to place the air cleaners with optimal CADR in spaces where the increased clean air flow rates resulted in the most significant reduction in the number of individuals at risk of pathogen transmission.

When positioning air cleaners in practice, it's essential to consider maintaining the room's flow pattern and prevent any short-circuit air

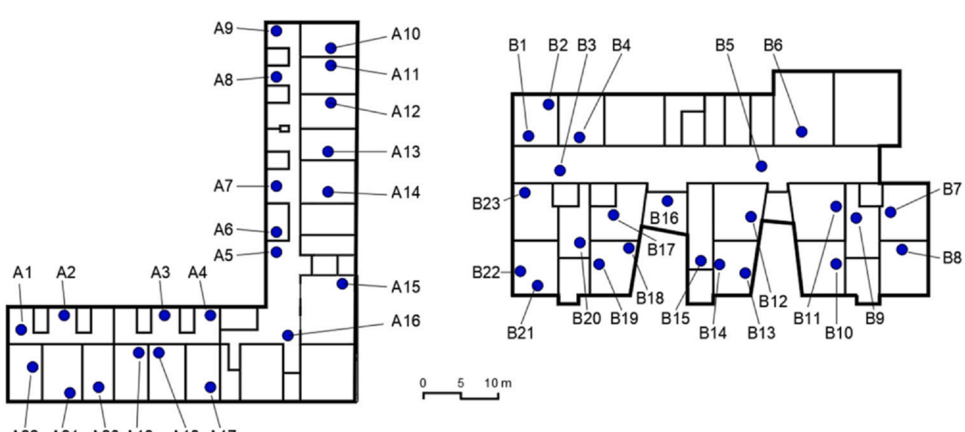

Fig. 1. Floor plans and locations of air cleaners in the day-care centres A (left) and B (right) during the intervention study.

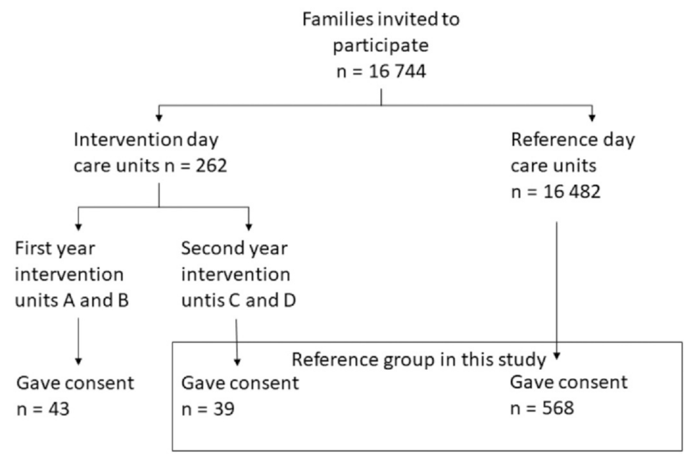

Fig. 2. Recruitment of study participants from children receiving day care in City of Helsinki.

flow disruptions. Proper placement ensures optimal air circulation and effective filtration. Naturally we had to make some compromises due to limited available space when placing the air cleaners in the rooms according to the plan.

2.4. Estimation of infection transmission probability

To assess the potential effect of ventilation systems and the interventional air cleaning systems, a relatively simple mathematical model was constructed. The model calculates pathogen emission rates as a product of viral concentration in respiratory fluids and mass emission rate of droplets which will dry almost instantaneously under normal room air conditions and become airborne aerosols with size < 5 micrometer [27]. The droplet mass emission rate is based on activity of individuals and is estimated from the literature [28,29]. When calculating the indoor exposure, a typical assumption is that the room air is well mixed so that the concentration is uniform within the space to be considered. This is justified in cases where room sizes are not too big and when the air change rates are sufficiently large [30]. Practically this requirement is fulfilled in mechanically ventilated rooms with mixing type of ventilation.

The steady state concentration C_{SS} (viral RNA copies/m^3) then depends on the emission rate G (viral RNA copies/s) and removal terms including ventilation, inactivation in the air and deposition.

$$C_{SS} = \frac{N_I G}{(\lambda + \lambda_{IA} + \lambda_D)V + qE} \tag{1}$$

where λ is the ventilation air exchange rate (1/h), λ_{IA} is the inactivation rate of pathogens in air (1/h), λ_D is deposition rate (1/h), V is the room volume (m^3) and qE is the product of air flow rate of air cleaner and its efficiency (m^3/h), which is practically the same as the CADR. The probable number of infectors N_I is assumed to be proportional to the prevalence of the disease in the community p and number of persons in a room N:

$$N_I = pN \tag{2}$$

In turn, the pathogen emission rate G (viral RNA copies/s) depends on the activity and viral load of respiratory fluid c_V (viral RNA copies/g) as follows:

$$G = q_m c_V \tag{3}$$

where q_m is the mass emission rate of respiratory droplets (g/s) with diameter less than 15 µm. Such droplets dry almost instantaneously in normal indoor air conditions leaving residuals which are about one third of their original diameter The dried aerosols are thus < 5 micrometer in size which can remain airborne for extended periods and may be inhaled by susceptible persons. Both the respiratory emission rates and viral loads of respiratory fluids vary largely between individuals making accurate predictions impossible [28,31]. However, assuming certain reasonable values for the parameters the relative changes in the concentrations can reasonably well be made.

The dose D of inhaled and lung-deposited pathogen-laden particles (viral RNA copies) can be estimated from the average concentration C (viral RNA copies/m^3), breathing rate B (m^3/h) and exposure time t (h):

$$D = CBtf \tag{4}$$

where f is the alveolar deposition factor of the inhaled aerosols in the respiratory system. For simplicity we used single value of 0.3 for inhaled particles < 5 µm [21]. The risk of getting infection P_{INF} is then calculated using the Wells-Riley equation:

$$P_{INF} = 1 - \exp(-0.693\frac{D}{D_{50}}) \tag{5}$$

where D_{50} is the dose (viral RNA copies) causing infection on the average to half of the population. The expected number of the person at risk E is then

$$E = P_{INF} N(1 - p) \tag{6}$$

This figure was calculated for each room in the day-care centres where the air cleaners were installed.

2.5. Work absence questionnaire

For the clinical part of the study, we invited families of all children receiving early childhood education from day care units ran by city of Helsinki to participate. As part of the study, we performed air cleaning intervention in two day care centers located in Helsinki to study effect of particle removal in infectious diseases. The results presented here are first year's initial results from two-year cross over trial of four day care units (NCT05569330). Recruitment process of participants is shown in Fig. 2. As part of the study the participants reported incident infections and parents work absences on weekly basis in a symptom diary. The analyzed questions in the diary were "Has your child been ill during the previous week? (yes/no)" and "Did the child's illness cause work absences to the adults? (yes/no)". A total of 426 children of which 38 were in the day care units with air cleaning systems were enrolled in the study. Response rate was 60–68% across the study period from November 11th 2022 to end of April 2023. Non-parametric Mann-Whitney U test was used to compare parent's absent days due to child's illness ("yes" to both of the questionnaire questions) between the reference and intervention centers. Poisson regression model was constructed separately to control the effects of socioeconomic factors. Age of the child and education level of the parents were added as categorial variables. In this work we present the initial effect on parents' absent

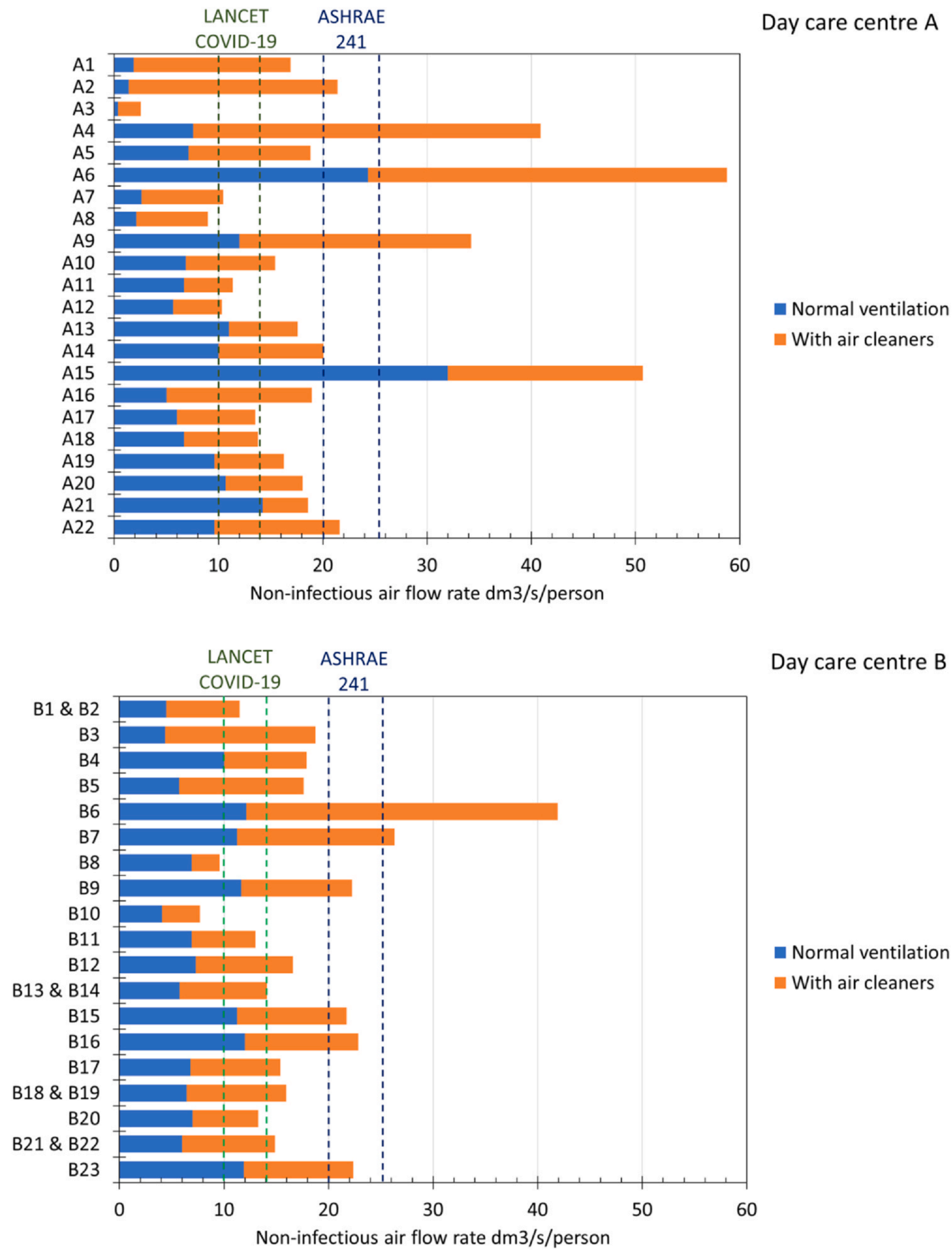

Fig. 3. Non-infectious air flow rate per person (dm^3/s/person) during maximum occupancy without and with room air cleaners in the studied rooms of the day care unit A and B. Lancet COVID commission recommendations 10 dm^3/s/person and 14 dm^3/s/person and ASHRAE requirements 20 dm^3/s/person and 25 dm^3/s/person are shown by green and blue dashed vertical lines, respectively [19,20].

days from work and analyze its effects on society. The study was approved by ethical committee of Helsinki and Uusimaa (HUS/14231/2022) and was conducted according to Declaration of Helsinki.

3. Results

Air cleaners increased the non-infectious air flow rates on average 137% and 126% in day care unit A and B, respectively. Constant volume air flow rates from normal HVAC system and clean air delivery rates (CADR) from room air cleaners in different locations normalized with the maximum number of persons occupying the room are presents in Fig. 3.

In day care unit A (Fig. 3) 68% of the rooms had clean air flow less than 10 dm^3/s/person with the normal ventilation during maximum occupancy whereas the use of air cleaners increased the non-infectious air flow rates so that more than 90% of the rooms exceeded the 10 dm^3/s/person and about one third also exceeded 20 dm^3/s/person. Similar situation was found also in day care unit B (Fig. 4). There the clean air flow rate was lower than 10 dm^3/s/person in 63% of the rooms and the use of air cleaners increased the air flow rate to over 10 dm^3/s/person in 89% of the rooms and 32% had the clean air flow rate over 20 dm^3/s/person.

The modelling of pathogen transmission probability suggested that the addition of air cleaners could lead to a clinically significant reduction in the incidence of respiratory infections among children attending daycare units. The predicted risk varied largely between different spaces depending on the occupancy and activity in the room. The calculated transmission probability in different rooms was over a magnitude higher in the high probability spaces compared to the lowest ones. The air cleaners decreased the calculated airborne concentrations 53% and 37% on average in day-care unit A and B, respectively.

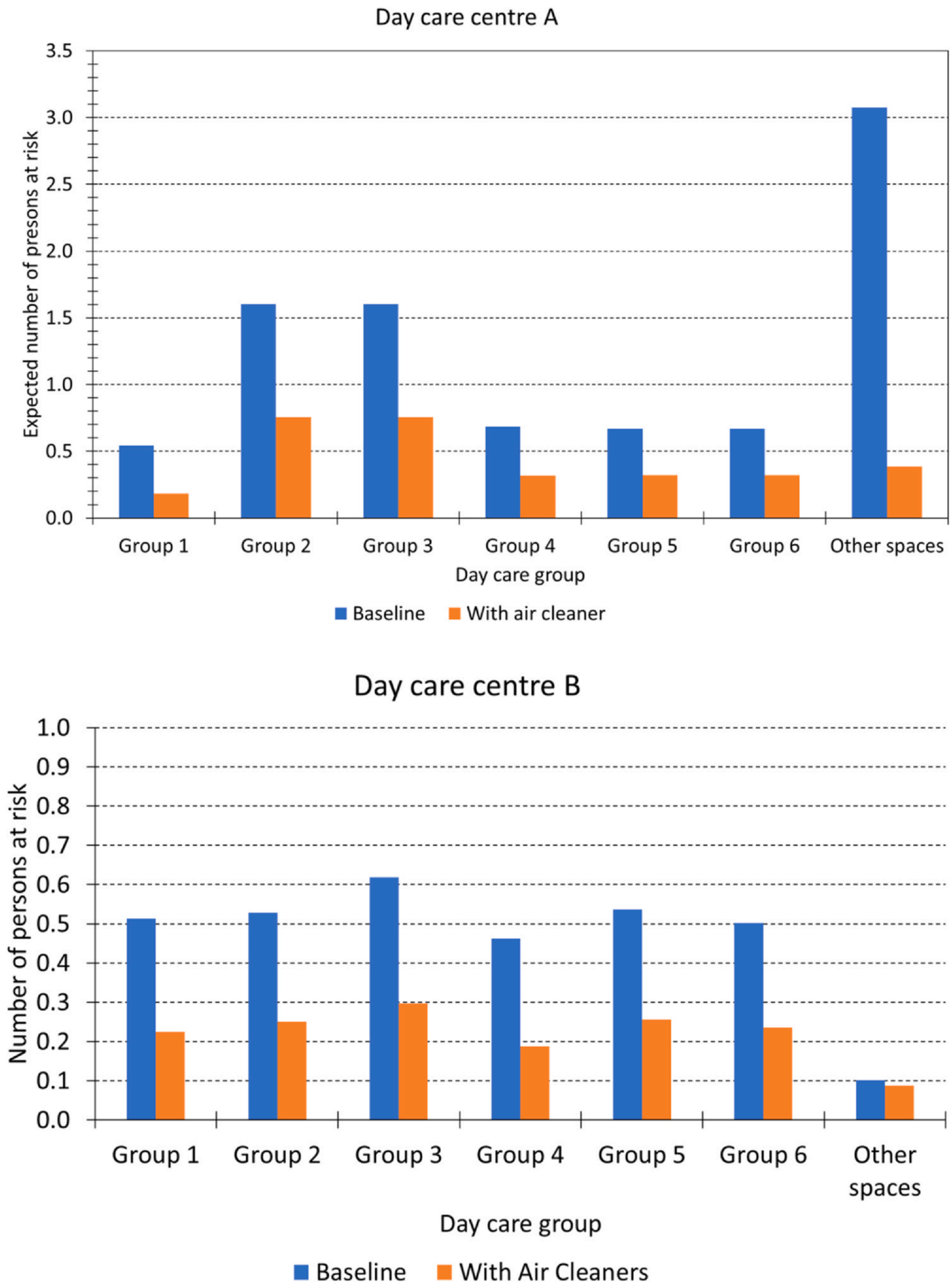

Fig. 4. Expected number of persons at risk in day care unit A and B in different groups of children.

Based on the activity patterns and dedicated rooms for each group in the day care units we estimated the number of persons at risk in each day care unit. The risk modelling suggests that the use of air cleaners reduced the expected number of persons at risk significantly (Fig. 4). At day care centre A the average reduction was 60% (range 52% - 88%) and at day care centre B 53% (range 14% - 59%).

During the study period, we observed a significant difference in the days absent from day care due to infections between the intervention and reference groups. On average, the parents were absent from work due to child's illness in reference day care centers for 5.53 days and 3.77 days in intervention day care centers during the study period ($p = 0.009$). In relative terms the reduction was approximately 32%. In the Poisson regression model increasing level of education protected from absence due to sickness, but there were no statistically significant associations between age or sex of the child and absences. There was no statistically significant difference between the groups in parent's education level or type of employment.

4. Discussion

In this study, we observed a 30% reduction in infections in the intervention group compared to the reference group and the decrease is in line with the estimates given by the model. Although previous studies have shown that properly dimensioned air cleaners can reduce airborne microbe concentrations in schools and healthcare facilities, their effect on infections have not been confirmed before our results [8,9,24].

While being designed according to Finnish regulations, the air flow rates per person in both day care centers were lower than the Lancet COVID commission recommendation [19] of 10 dm^3/s in two thirds of the rooms. The use of air cleaners increased the clean air delivery rate 137% and 126% in day care unit A and B, respectively. After installing the air cleaners, the non-infectious air flow rates were greater than 10 dm^3/s per person in 90% of the rooms and one third exceeded also the ASHRAE [20] recommendation of 20 dm^3/s per person. Such an increase in ventilation air flow rates in existing buildings is often impossible without extensive modifications in the HVAC system. However, with room air cleaners this can be done flexibly in situations where rapid response is needed.

Although the calculated infection probabilities decreased only 53% and 37% the estimated number of persons at risk decreased by 60% and 53% after interventions. This reflects the use of estimated number of persons at risk when selecting and locating the air cleaners to the different spaces of the day care units. The estimation of infection risk alone may not be sufficient to select the optimal control measures in public spaces, but the number of potentially exposed persons should also be considered to mitigate disease transmission efficiently.

In order to achieve subsequently lower pathogen concentrations and consequently a reduced risk of infection, increased non-infectious air flow is required. Therefore, in many cases, it may be beneficial to consider in which spaces the air cleaners reduce the number of people at risk most. Our risk-based approach enables to design optimal CADR by comparing the benefits of placing room air cleaners in different rooms and choosing the final position according to the calculated infection risk level reductions at building level.

The implementation of air cleaners in daycare centers may involve some initial costs. Our results suggest that the benefits of implementing air cleaners in daycare centers outweigh the costs, particularly when considering the potential economic savings associated with reduced absenteeism among parents. Finland's Ministry of Social affairs and health estimated that in 2014 the cost of sick leaves due to direct costs and value from lost working time was 3.5 b€ which was 1.3% of the gross domestic product [2]. This does not include indirect costs such as healthcare, reduced morality, and increased workload for other employees. Confederation of Finnish Industries estimated that the average loss of work input caused by a day of sick leave is 370 euros [26].

While the exact proportion of the cost that is attributable to child illness in daycare centers is unclear, it is likely to be a significant contributor given the high prevalence of infections among children in the daycare. Therefore, reducing the incidence of infections in daycare centers using air cleaners could have a positive impact on both the health and well-being of children and their families, as well as the wider economy and society as a whole.

It is important to acknowledge some limitations of our study. Firstly, the intervention was conducted only in two day care centers. If there are significant differences between the day care centers in Helsinki such factors may confound the effects of air cleaning. Secondly, as the model is designed to be simple and robust and it considers airborne pathway only. In addition, it has numerous assumptions underlying the calculations. Thirdly, no objective measurements of infections were used. The data is based on questionnaires to parents which are susceptible to errors.

5. Conclusion

In conclusion, our study offers compelling evidence to support the implementation of air cleaners in daycare centers as an effective and cost-efficient strategy for mitigating the spread of respiratory infections among children. The approach presented allows the identification of the infection risk hot spots by taking into account the most relevant factors affecting the airborne disease transmission and thereby determining the optimal placement of air cleaners within the building. The optimization parameter is the total number of persons at risk of being infected in the whole building, which should be minimized with the available number of air cleaners. The clinical results support the findings suggested by our theoretical model. The model provides a straightforward but valuable method for assessing the effects of ventilation and air cleaning on the transmission of airborne infections.

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Conflicts of interests

The portable air cleaning equipment were provided by the manufacturers and local commercial agents. The companies lending the air cleaning equipment provided expert advice on the use of the devices, but had no role in planning the study, interpretation of the results or writing of this manuscript.

CRediT authorship contribution statement

Piia Sormunen: Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Ilpo Kulmala:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Arto Säämänen:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Ville Vartiainen:** Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Johanna Hela:** Writing – review & editing, Investigation. **Anni Luoto:** Writing – review & editing, Investigation. **Petra Nikuri:** Writing – review & editing, Investigation. **Enni Sanmark:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Aimo Taipale:** Writing – review & editing, Methodology. **Inga Ehder-Gahm:** Writing – review & editing, Investigation. **Natalia Lastovets:** Writing – review & editing, Methodology.

Data availability

The clinical data is not available due to the Finnish legislation on medical research.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Project reports equipment, drugs, or supplies was provided by Air0, Halton, IQAir, Alme and Lifa Air. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J.P. Collins, A.L. Shane, Infections associated with group childcare, Princ. Pract. Pediatr. Infect. Dis. (2018) 25–32.e3, https://doi.org/10.1016/B978-0-323-40181-4.00003-7.

[2] Rissanen, M. & Kaseva, E. *Cost of lost labour input. sosiaali-ja terveysministeriön työsuojeluosasto toimintapolitiikkayksikkö strateginen suunnittelu-ryhmä* https://stm.fi/documents/1271139/1332445/Cost + of + lost + labour + input_en.pdf/d5790088-8e3e-4d13-a5cd-56c23b67de0c/Cost + of + lost + labour + input_en.pdf?t = 1442323144000 (2014).

[3] M.Y.K. Chow, et al., The impact of influenza-like illness in young children on their parents: a quality of life survey, Qual. Life Res. 23 (2014) 1651–1660.

[4] M. Toivanen, A. Väänänen, J. Pentti, M. Kivimäki, J. Vahtera, Rasittuuko äiti, kun lapsi sairastaa? Seurantatutkimus tilapäisen hoitovapaan vaikutuksesta ylirasittuneisuuteen työssäkäyvillä äideillä, Sos. Laaketiet. Aikak. 47 (2010) 32–44.

[5] Arıkan, _ I. *et al.* Effectiveness of air purifiers in intensive care units: an intervention study. (2021) doi:10.1016/j.jhin.2021.10.011.

[6] Morris, A.C. *et al.* Clinical Infectious Diseases The Removal of Airborne Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and Other Microbial Bioaerosols by Air Filtration on Coronavirus Disease 2019 (COVID-19) Surge Units. doi:10.1093/cid/ciab933.

[7] Gettings, J. *et al.* Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools — Georgia, November 16–December 11, 2020.

[8] M.O.P. Alvarenga, J.M.M. Dias, B.J.L.A. Lima, A.S.L. Gomes, G.Q.M. Monteiro, The implementation of portable air-cleaning technologies in healthcare settings – a scoping review, J. Hosp. Infect. 132 (2023) 93–103.

[9] A. Conway Morris, et al., The removal of airborne severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other microbial bioaerosols by air filtration on coronavirus disease 2019 (COVID-19) surge units, Clin. Infect. Dis. 75 (2022) e97–e101.

[10] J. Curtius, M. Granzin, J. Schrod, Testing mobile air purifiers in a school classroom: Reducing the airborne transmission risk for SARS-CoV-2, Aerosol Sci. Technol. 55 (2021) 586–599.
[11] T. Falkenberg, F. Wasser, N. Zacharias, N. Mutters, T. Kistemann, Effect of portable HEPA filters on COVID-19 period prevalence: an observational quasi-interventional study in German kindergartens, BMJ Open 13 (2023) e072284.
[12] E. Brągoszewska, I. Biedroń, Efficiency of Air Purifiers at Removing Air Pollutants in Educational Facilities: A Preliminary Study, Front Environ. Sci. 9 (2021).
[13] Household and similar electrical air cleaning appliances. Methods for measuring the performance. Part 1: General requirements. EN IEC 63086–1:2020.
[14] Association of Home Appliance Manufacturers. Air Filtration Standards. https://ahamverifide.org/ahams-air-filtration-standards/.
[15] US CDC. COVID-19: Ventilation in buildings. https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html..
[16] REHVA. COVID-19 guidance: Criteria for room air cleaners for particulate matter. https://www.rehva.eu/fileadmin/content/documents/Downloadable_documents/REHVA_COVID-19_Recommendation_Criteria_for_room_air_cleaners_for_particulate_matter.pdf.
[17] Asthma och allergi förbundet. Criteria for recommendation of Air Purifier. Preprint at (2023).
[18] EN 16798-1:2019. *Energy performance of buildings. Ventilation for buildings. Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. vol. Module M1-6.
[19] The Lancet COVID-19 Commission Task Force on Safe Work, S. S. and S. T. Proposed Non-infectious Air Delivery Rates (NADR) for Reducing Exposure to Airborne Respiratory Infectious Diseases. (2022).
[20] ASHRAE Standard 241. Control of Infectious Aerosols.
[21] M. Nicas, W.W. Nazaroff, A. Hubbard, Toward understanding the risk of secondary airborne infection: emission of respirable pathogens, J. Occup. Environ. Hyg. 2 (2005) 143–154.
[22] A. Aganovic, G. Cao, J. Kurnitski, P. Wargocki, New dose-response model and SARS-CoV-2 quanta emission rates for calculating the long-range airborne infection risk, Build. Environ. 228 (2023) 109924.
[23] N. Banholzer, et al., SARS-CoV-2 transmission with and without mask wearing or air cleaners in schools in Switzerland: a modeling study of epidemiological, environmental, and molecular data, PLoS Med 20 (2023) e1004226.
[24] İ. Arıkan, et al., Effectiveness of air purifiers in intensive care units: an intervention study, J. Hosp. Infect. 120 (2022) 14–22.
[25] N.G. Rao, A. Kumar, C. Colon, D.Y. Goswami, Impact of a new portable air purification technology device in the pediatric hospital setting – a pre-post assessment study, Cureus (2020), https://doi.org/10.7759/cureus.7440.
[26] ANSI/AHAM. AC-1–2020. Method for Measuring Performance of Portable Household Electric Room Air Cleaners.
[27] L. Liu, J. Wei, Y. Li, A. Ooi, Evaporation and dispersion of respiratory droplets from coughing, Indoor Air 27 (2017) 179–190.
[28] M. Alsved, et al., Exhaled respiratory particles during singing and talking, Aerosol Sci. Technol. 54 (2020) 1245–1248.
[29] G.R. Johnson, et al., Modality of human expired aerosol size distributions, J. Aerosol Sci. 42 (2011) 839–851.
[30] J. Kurnitski, et al., Post-COVID ventilation design: Infection risk-based target ventilation rates and point source ventilation effectiveness, Energy Build. 296 (2023) 113386.
[31] T.C. Jones, et al., Estimating infectiousness throughout SARS-CoV-2 infection course, Science (1979) 373 (2021).