What level of air filtration (ACH) is equivalent to an N95 respirator?

Devabhaktuni Srikrishna
Patient Knowhow, Inc.
sri@patientknowhow.com
www.patientknowhow.com

Abstract

N95 respirators are useful for reducing risk from a person infected with COVID-19 at both near-field (e.g. < 6 feet) and far-field exposures (e.g. > 6 feet). Although air filtration is not usually effective at near-field, emulating at least the far-field equivalent of N95 requires 95% relative reduction of particles (20x) from an airborne particulate source in each room. To mitigate COVID infection risk with air filtration, there is a wide range of air change per hour (ACH) recommendations from public health agencies (CDC, CDPH, etc.) ranging from 2 to 12 ACH. Tracking the removal of an inert airborne contaminant (e.g. salt water) as a function of time is often used to measure ACH but is cumbersome and generally not desirable in occupied rooms such as a classroom or home. Instead, we describe a procedure using an optical particle counter to track the decay of ambient aerosols (0.3 µm diameter) and fit it to an exponentially decaying curve to measure ACH from the exponential coefficient. Experiments were conducted both in a room (from surface deposition alone and with air filtration) and in a whole, multi-room house (with air filtration). First, the rate of surface deposition in an unventilated room without HVAC ventilation or air filtration enabled was measured to be 0.6 ACH. Second, ACH was measured (verified) with low-noise generating HEPA purifiers ($299-$999) and Do-It-Yourself (DIY) air purifiers ($55-$160, 1”-5”, MERV 13-16) in each room. The ACH measured with these air purifiers ranged from 4 to 20. Using the measured ACH and volume of the room/house to estimate the clean air delivery rate (CADR) per $100, it varied by a factor of 3x from below 100 cfm for tested HEPA purifiers to above 300 cfm with tested DIY air purifiers. Using 0.6 ACH as a baseline for an unventilated room, at least 12 ACH is required to reduce exposures equivalent to protection of N95 respirators (95%) at far-field, which is verifiable in a room or building with ambient aerosols using either HEPA or DIY air filtration.

Introduction

Emulating N95 protection with air filtration (or ventilation) requires 95% reduction of particles at all distances from the airborne particulate source. However a CDC laboratory experiment [36] confirmed that in-room air filtration does not reduce exhaled breath exposure to simulated participants sitting very close to an infected person (near-field e.g. less than 6 feet) to the same degree as at a larger distance when air is well-mixed within the room (far-field). Respirators remain useful for reducing risk to both near-field and far-field exposures, whereas air filtration can only mitigate far-field exposure in a well-mixed environment, not near-field. Respirators may not always be used by everyone in many non-healthcare settings (e.g. schools, homes, offices). In such settings, both HEPA and lower-cost DIY air filtration can mitigate spread of SARS-Cov-2 and other viruses indoors [30] [40] by reducing far-field exposures in a room or building [42] [43] that may lead to super spreading events [37]. Covid and other viruses/bacteria, carcinogenic wildfire particles, allergens (e.g. pollen, dust), pollution (e.g. diesel soot, wood-burning), etc. can be present in the indoor air we breathe, and air changes per hour (ACH) measures how quickly these harmful particulates are removed by air filtration (or ventilation). Two questions emerge: how much ACH is actually needed to reduce far-field exposures to the same degree as an N95 respirator, and are there simple procedures to measure/check ACH in occupied rooms?

How much ACH is actually needed to reduce far-field exposures to the same degree as an N95 respirator?

ACH is central to ventilation/filtration and is analogous to air pressure (PSI) in a car's tires. It's not good enough to say keep your tires inflated without a minimum PSI (pounds per square inch). In a car's tires, there is a big difference between 10 vs 20 vs 30 PSI. For example, top-heavy SUVs are more likely to roll over at 10 or 20 PSI than at 30 PSI. For hospitals, CDC specifies minimum ACH by type of room (e.g. airborne infection isolation room, surgery, etc.) in Table B.2 of [4]. Whereas CDC doesn't make such specific ACH recommendations in community settings (non-healthcare). For air filtration CDC recommends the so-called "⅔ rule" which is mathematically equivalent to 5 ACH on their main page on ventilation, updated June 2, 2021 [5]. Elsewhere on this page CDC alludes to 6 ACH and higher as having higher airflow rates. A study in Italian classrooms observed a greater reduction in classroom infection rates with increasing ACH from ventilation: 40% at 2.4 ACH, 67% at 4 ACH, 83% at 6 ACH [2] [3].

In general it takes a reduction of aerosol concentrations by 20 times to get the equivalent of 95% filtration as nominally required for N95 respirators. Miller et. al. [37] describes an approximation (Equation 3) for equilibrium viral particle concentration (C) with one or more infected persons emitting virus at rate (E per hour) in a well-mixed room of volume (V) with ACH (λ per hour): $C = E / (\lambda V)$. In an unventilated room (the absence of any indoor ventilation or air filtration), the particle removal still includes surface deposition with a contribution to λ estimated in a wide range of 0.3 to 1.5 [37]. In experiments described below the ACH from surface deposition in a room was measured to be approximately 0.6. Assuming surface deposition contributes 0.6 to λ, 20 times reduction in aerosol concentrations to achieve N95-equivalent filtration requires ACH (λ) from air filtration to be 12.

Retrospective analysis showed that use of KN95/N95 respirators by community members resulted in lower COVID infection rates as compared to cloth and surgical masks [32]. Across a variety of manufacturers the average filtration efficiency of N95 at 0.3 μm particle size was found to be much higher and more consistent at 98% than 81% for KN95 [33]. This 98% is reassuringly higher than the 95% filtration efficiency nominally required for N95, although N95 fit

[34] and filtration efficiency (Figure 2 of [35]) may degrade with reuse over several hours. The N95 average of 98% requires a 50 times reduction in inhaled aerosols (ACH=30) and KN95 average of 80% requires 5 times (ACH=3) in an unventilated room assuming surface deposition contributes 0.6 to ACH (λ).

One study in 2017 found a cross section of recently constructed schools implemented approximately 2 ACH with HVAC on, and 0.2 ACH with HVAC off [38]. Whereas homes, offices, and other structures with temperature-sensitive fan operation to conserve energy may result in ACH closer to the surface deposition approximation.

How can ACH be measured or checked in occupied rooms or buildings?

The amount of filtration (or ventilation) that is required a function of a chosen target ACH in a room is known as the clean air delivery rate (CADR). In case of air purifiers the number needed (predicted) can then be calculated from room volume and ACH in three steps:

Step 1: room vol. = length. x width x height (cf).

Step 2: CADR needed (cfm) = vol. x ACH needed / 60.

Step 3: # of purifiers = (CADR needed) / (CADR per purifier).

For a typical classroom (30'x30'x10') if ACH needed = 6, then CADR needed = 900 cfm. As a rule of thumb, 100 cfm per 1000 cf is needed to meet 6 ACH and double that for 12 ACH.

However, installing and running air filtration based on provisioning sufficient CADR to meet the desired ACH does not guarantee that the desired ACH level will be achieved. Many real-world factors can reduce ACH below the estimated levels including placement and other non-ideal effects such as leaks in the building allowing airborne pollutants to enter from outdoor air. It is therefore useful to check the ACH actually achieved in a room or building by the air filtration system.

As a model, the University of San Diego transparently lists the ACH measured in each classroom [41]. Tracking the removal of an airborne contaminant as a function of time can be used to measure ACH with a standard procedure using aerosols generated from salt water [29], burning incense [31], or extreme aerosol concentrations present during wildfire smoke events [39]. For example, based on the formula provided by CDC, the time it takes to remove 90% of an airborne contaminant is 69 minutes at 2 ACH, 35 minutes at 4 ACH, 23 minutes at 6 ACH, and 12 minutes at 12 ACH [1]. Waiting for extreme events, or generating aerosols is cumbersome and generally not possible in occupied rooms such as a classroom or home.

The technique described in detail below relies on ambient aerosols to measure ACH from surface deposition and with air filtration, as demonstrated in a room and a whole house (multi-room) as summarized in Figure 1 and Figure 2. It may be generalized to any indoor space which does not have very high amounts of outdoor air entering and for which the air filtration is capable of reducing the ambient aerosols inside once windows are closed (such as open windows or an extremely high rate of outside ventilation).

Figure 1: ACH measured for each purifier in single room

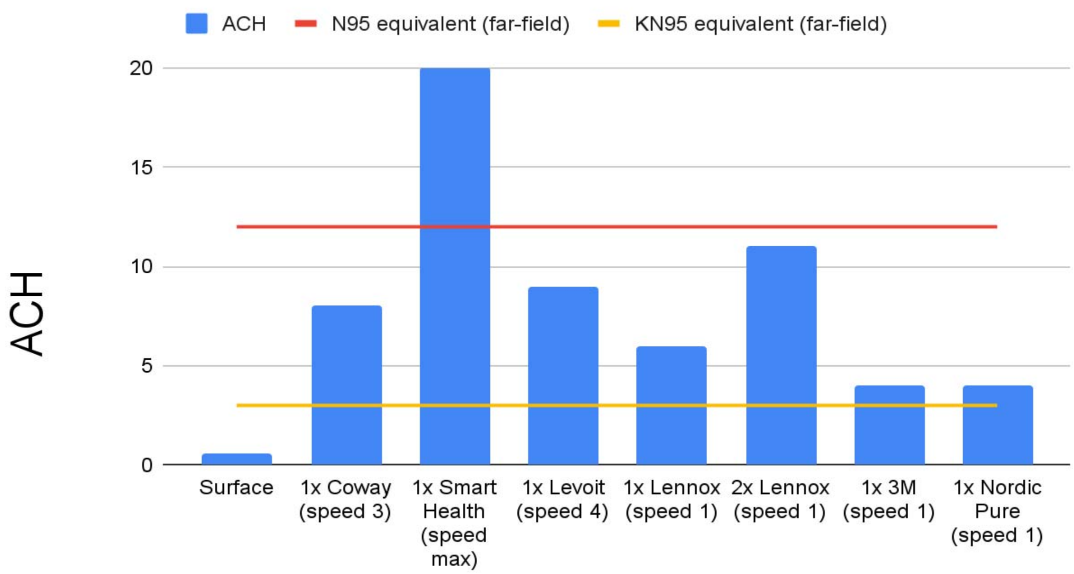
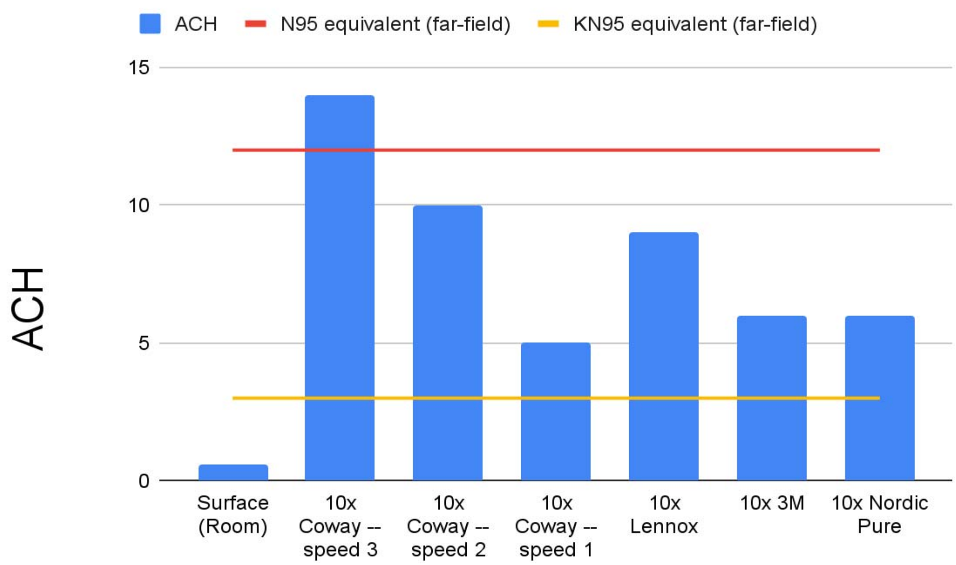


Figure 2: ACH measured for purifiers in whole house



Safety notes

These safety notes are included here from [30]. California Air Resource Board recommends never leaving box-fan air filters unattended while turned on, and to use box fans manufactured after 2012 and are clearly identified with the UL or ETL safety markings because it is likely they have a fused plug to prevent electrical fires e.g. if the device is inadvertently knocked over [45]. Chemical Insights, a subsidiary of Underwriters Laboratories, recently tested five different electric box fan models (approximately 20″ × 20″ in size) with attached air filters and concluded that all measured temperatures fell below the maximum acceptable thresholds defined by the market safety standard for electric fans [46]. In detail, in addition to assessing DIY fans with clean MERV 13 filters, DIYs were tested with filters loaded with two types of particles (ASHRAE dust and smoke from biomass burning to represent a loaded filter due to a wildfire), and test scenarios also included fully sealing the box fans in plastic and running fans for over 7 hours face-down on the floor. Even under those scenarios, the fans' surface components did not reach temperatures that would cause minor burn/injury, and all fan models were able to operate continuously throughout all test scenarios without reaching UL 507 thresholds. The resources and information in this article (the “Content”) are for informational purposes only and should not be construed as professional advice. The Content is intended to complement, not substitute, the advice of your doctor. You should seek independent professional advice from a person who is licensed and/or qualified in the applicable area. No action should be taken based upon any information contained in this article. Use of the article is at your own risk. Patient Knowhow, Inc. takes no responsibility and assumes no liability for any Content made available in this article.

Methods

Procedure

To measure the ACH of air filtration (HEPA or DIY) in an indoor space such as a room or a whole house, first ambient aerosols from outdoors are allowed to enter the indoor space by opening windows and doors. Then the windows are closed, and then finally the air filtration is turned on to track the decay of indoor aerosol concentrations with an optical particle counter. The shape of the decay curve and asymptote reveal the ACH and leaks of outdoor aerosols into the room or whole house.

Measurement of ambient aerosol concentration

At each point in time, the aerosol concentrations (count per liter) for 0.3 µm particle size were tested using an ISO-certified, particle counter (Temtop Particle Counter PMD 331). Each measurement was conducted in the center of the house for 30 seconds.

Measurement of noise generated by air purifiers

Noise was measured for each air purifier/filter using an iPhone app [44] maintained by The National Institute for Occupational Safety and Health (NIOSH) at a 9″ distance perpendicular to the direction of the output airflow.

Air purifiers and their placement

Air purifiers of different types were placed inside a single room or entire house for each test of ACH. The purifiers were DIY (box fan and filter) and commercial HEPA as described in detail in [30]. Step by step instructions to make the DIY air purifiers are in [40] which includes an aluminum screen for child safety that reduces CADR slightly. DIY air purifiers were run on lowest speed #1 and HEPA were run on three speeds #3 (maximum), #2, and #1. Estimated costs and noise generated are shown in brackets.

The room is estimated to be 2600 cubic feet with different air purifiers placed in the same locations, doors closed, windows closed, HVAC turned off.

- **Surface ($0, 38 dBA, 0 lbs):** No air filtration (to measure surface deposition)
- **Coway ($494, 63 dBA, 25 lbs):** One HEPA Coway Airmega 400 at speed #3
- **Smart Health ($999, 53 dBA, 69 lbs):** One HEPA Smart Health Blast at maximum speed
- **Levoit ($299, 66 dBA, 14 lbs):** One HEPA Levoit Core 600s at maximum speed (4)
- **One Lennox ($160, 58 dBA, 10 lbs):** One DIY 5” Lennox MERV 16
- **Two Lennox ($320, 61 dBA, 20 lbs):** Two DIY 5” Lennox MERV 16
- **3M ($70, 58 dBA, 8 lbs):** One DIY 1” 3M Filtrete MERV 14
- **Nordic Pure ($55, 58 dBA, 8 lbs):** One DIY 2” Nordic Pure MERV 13

The three story house is estimated to be 17,800 cubic feet. For comparison purposes, the different air purifiers were placed in the same locations in different interconnected rooms, inside doors open, windows and outside doors closed, HVAC turned off.

- **Coway ($4644) at speed 3 (63 dBA), 2 (55 dBA), 1 ($39 dBA):** Nine HEPA Coway Airmega 400 and one Coway AP-1512 where fan speed is varied 3 to 2 to 1
- **Lennox ($1600):** Ten DIY 5” Lennox MERV 16
- **3M ($700):** Ten DIY 1” 3M Filtrete MERV 14

Model for ambient aerosol decay with air filtration in enclosed indoor space

The mathematical model for aerosol concentration from an infected person in a room that was described in [37] can be adapted to measure ACH in a whole house or room after an ambient (or generated) aerosol has been introduced. The differential equation (Equation 2) is same, but ambient aerosol concentration at time t can be expressed as an alternate (decaying) solution to the same differential equation:

$$C(t) = (E/\lambda V) + [C(0) - E/\lambda V] \times \exp(-\lambda t).$$

where

C(t) = ambient aerosol concentration at time t
C(0) = initial concentration
E = rate of aerosols leaking into room or house from outside (per hour)
V = volume of room or house
λ = ACH
exp = exponential function.

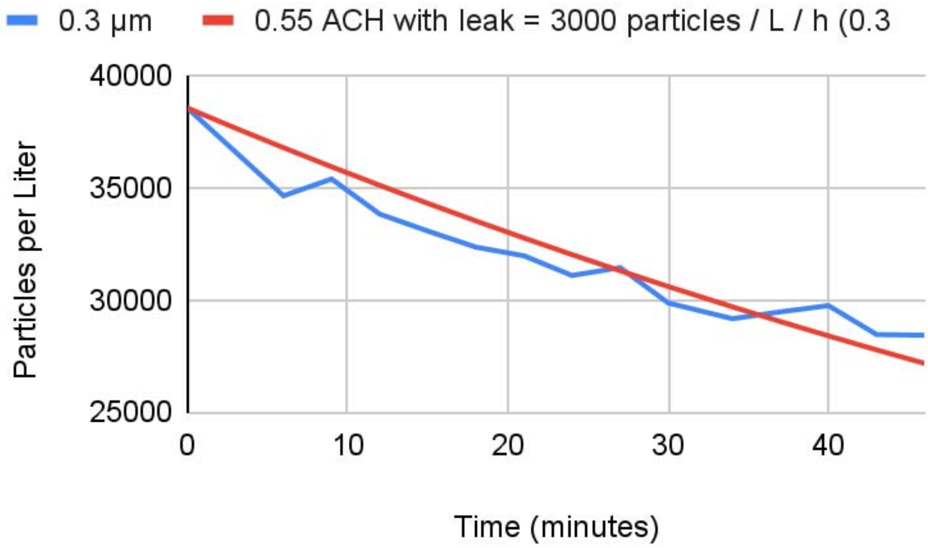
Estimation of ACH and rate of indoor leakage

All measurements (counts) were input into Google Sheets and compared to the model for ambient aerosol decay with different values of ACH and indoor aerosol leak rate. The aerosol concentration measurements representing C(t) are used to select the best approximation for ACH (λ) and the rate of indoor leak (E/V) at 0.3 μm particle size by minimizing the percent error (sum across each measurement).

Results

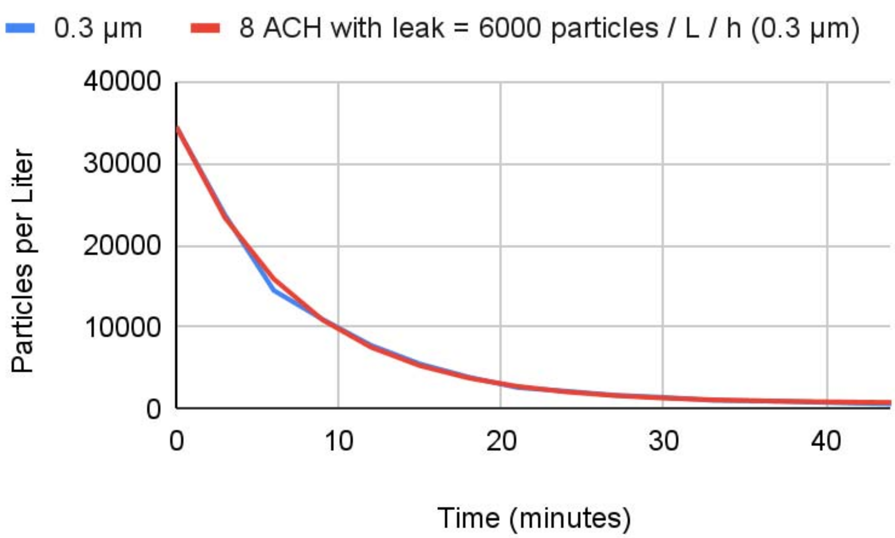
Single Room (Surface)

The rate of surface deposition is estimated to be 0.55 ACH in the room, with percentage error averaging 3% across 16 data points.



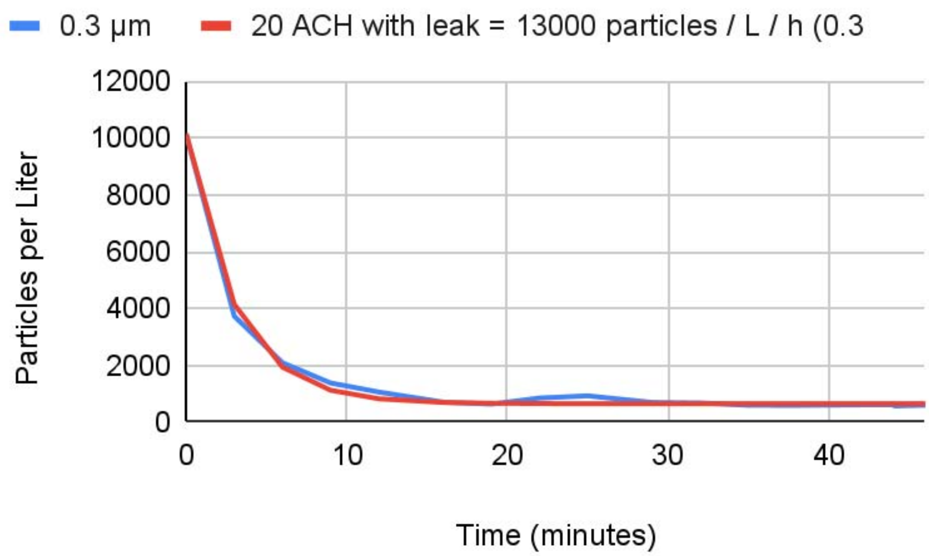
Single Room (Coway)

With the Coway Airmega 400 turned to maximum speed (3), ACH is estimated to be 8 with the percentage error averaging 6% across 16 data points.



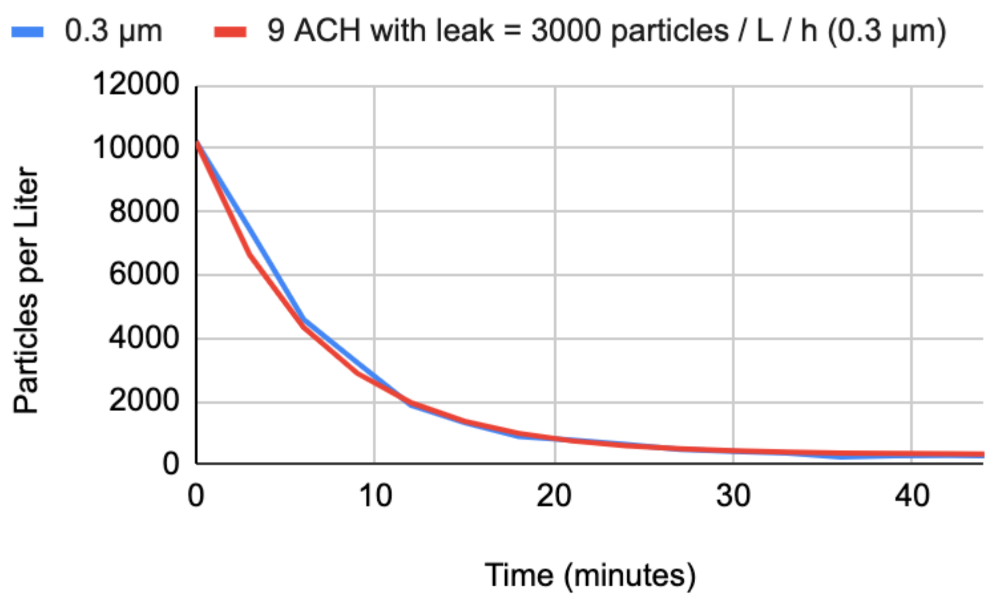
Single Room (Smart Health)

With the Smart Health Blast turned to maximum speed, ACH is estimated to be 20 with the percentage error averaging 11% across 16 data points.



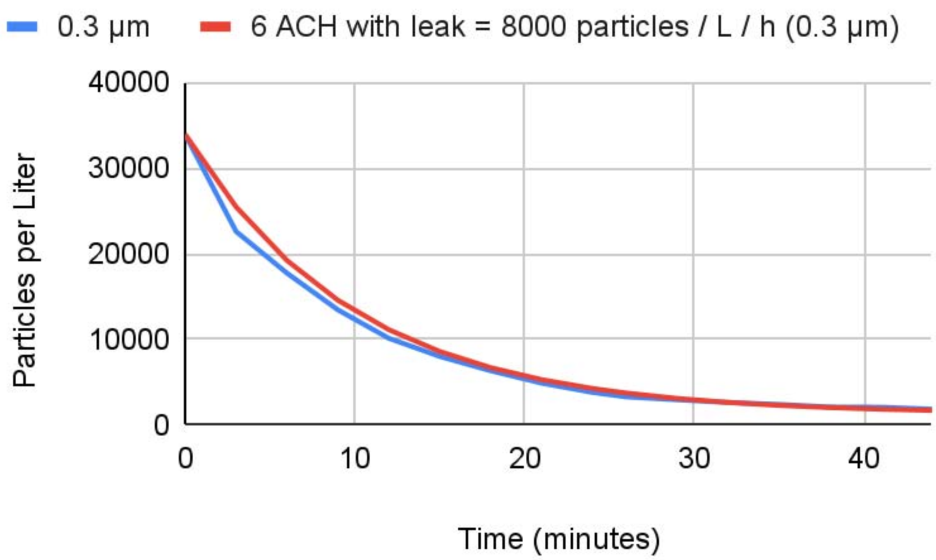
Single Room (Levoit)

With the Levoit Core 600s turned to maximum speed, ACH is estimated to be 9 with the percentage error averaging 11% across 16 data points.



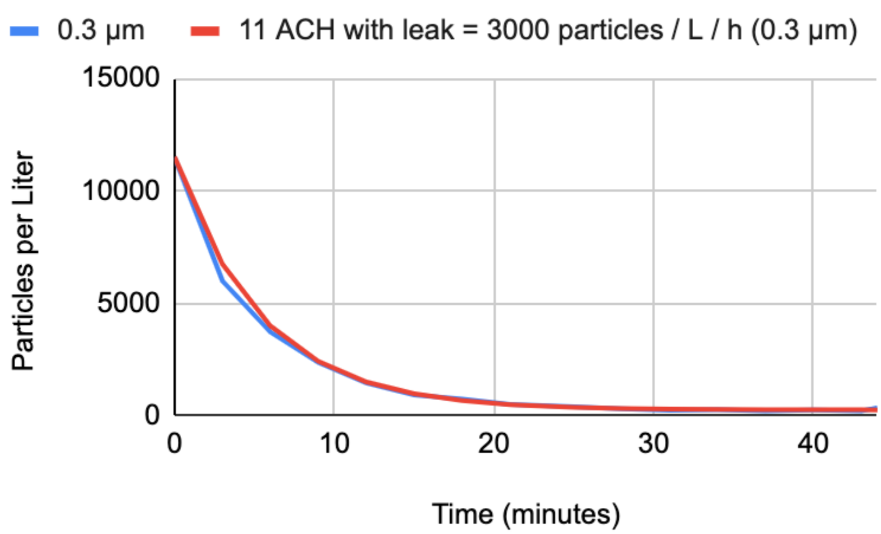
Single Room (1x Lennox)

With one Lennox DIY purifier turned to the lowest speed (1), ACH is estimated to be 6 with the percent error averaging 7% across 16 data points.



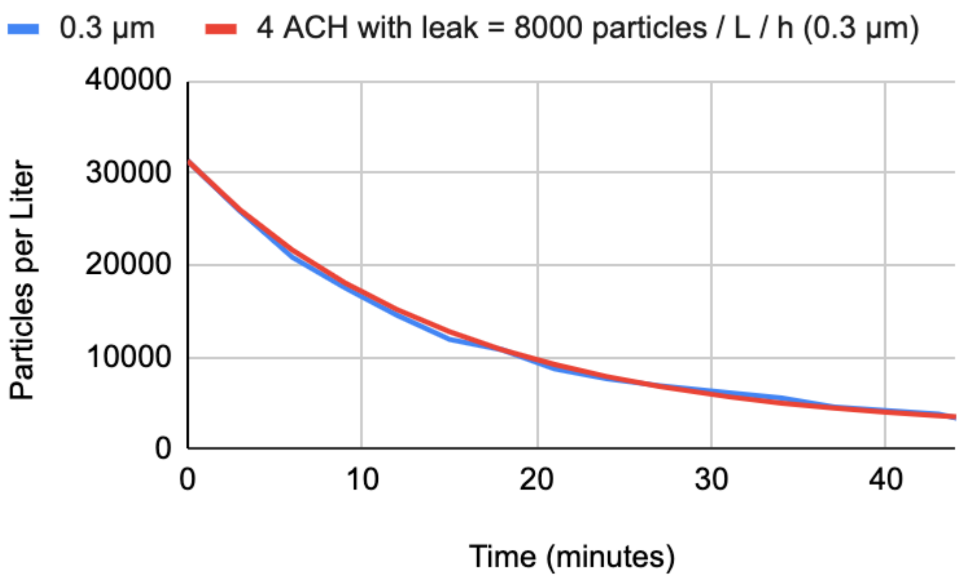
Single Room (2x Lennox)

With two Lennox DIY purifiers turned to the lowest speed (1), ACH is estimated to be 11 with the percent error averaging 9% across 16 data points.



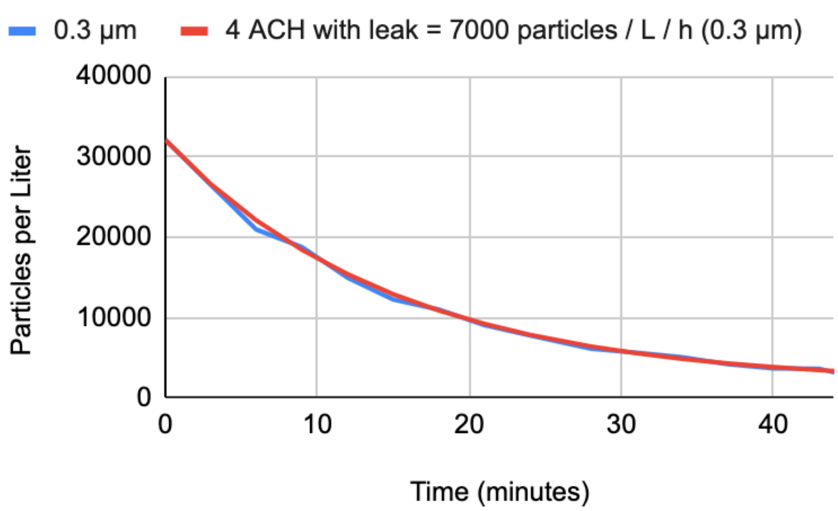
Single Room (3M)

With one 3M DIY purifier turned to the lowest speed (1), ACH is estimated to be 4 with the percent error averaging 4% across 16 data points.



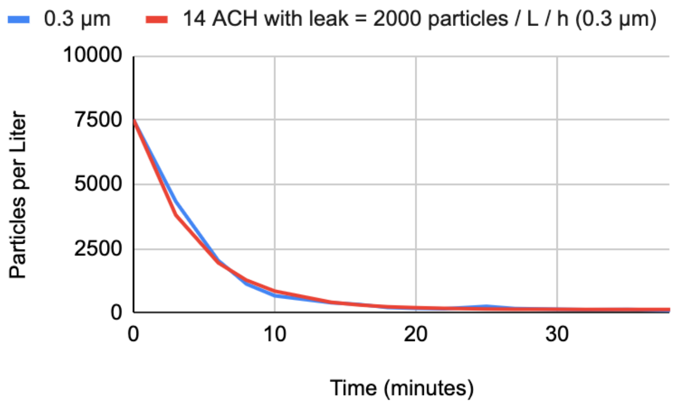
Single Room (Nordic Pure)

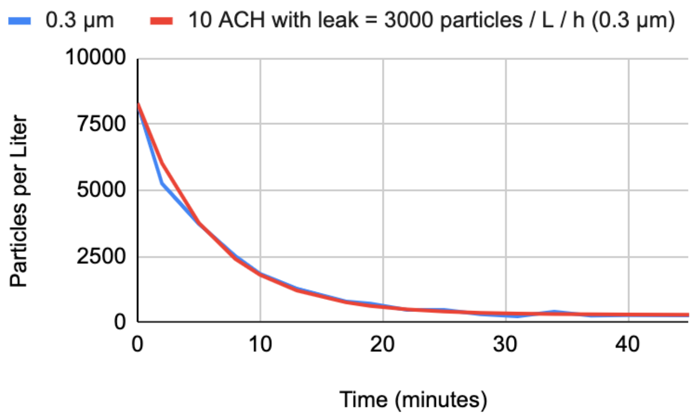
With one Nordic Pure DIY purifier turned to the lowest speed (1), ACH is estimated to be 4 with the percent error averaging 3% across 16 data points.

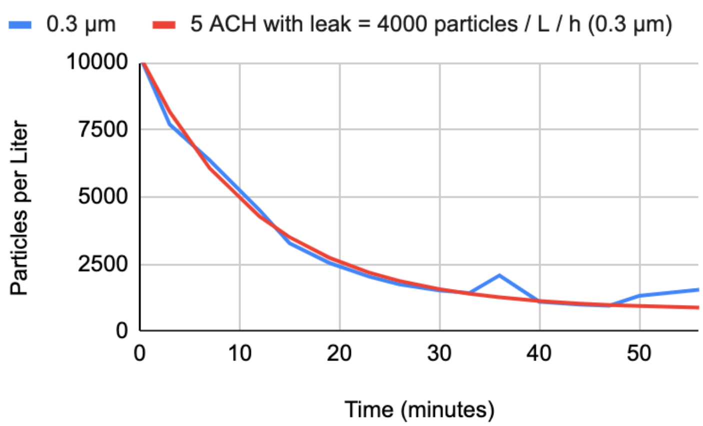


Whole House (10x Coway)

With 10 Coway air purifiers turned to the speed 3, 2, and 1, the ACH is estimated to be 14, 10, and 5 with the percent error averaging 12%, 11%, and 11% across 16 data points respectively.

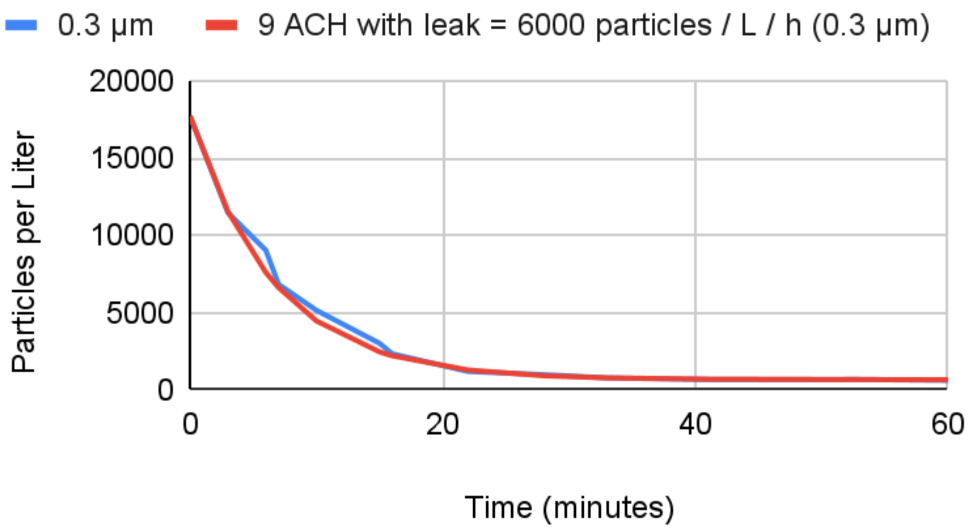






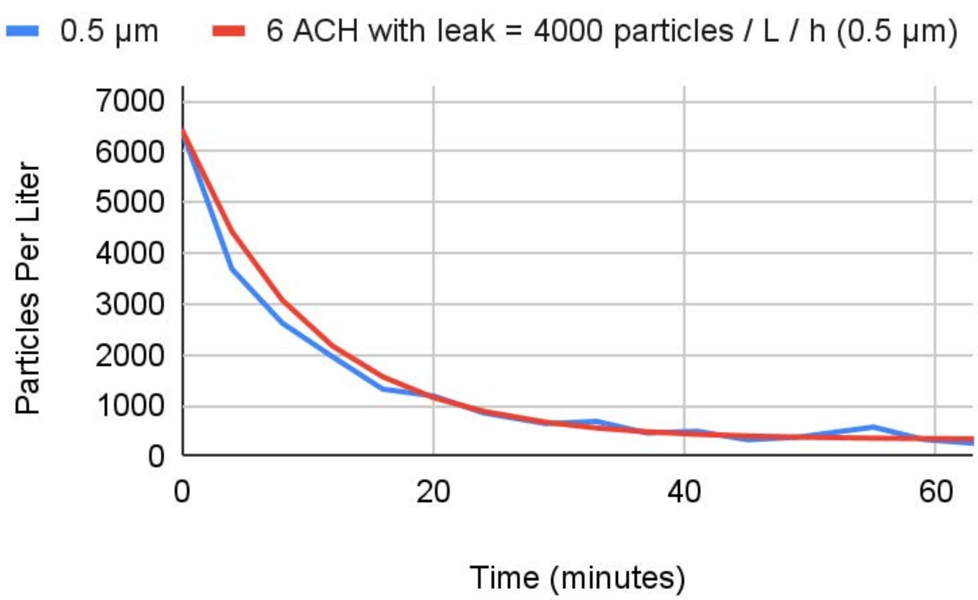
Whole House (10x Lennox)

With ten Lennox DIY purifiers turned to the lowest speed (1), ACH is estimated to be 9 with the percent error averaging 5% across 16 data points.



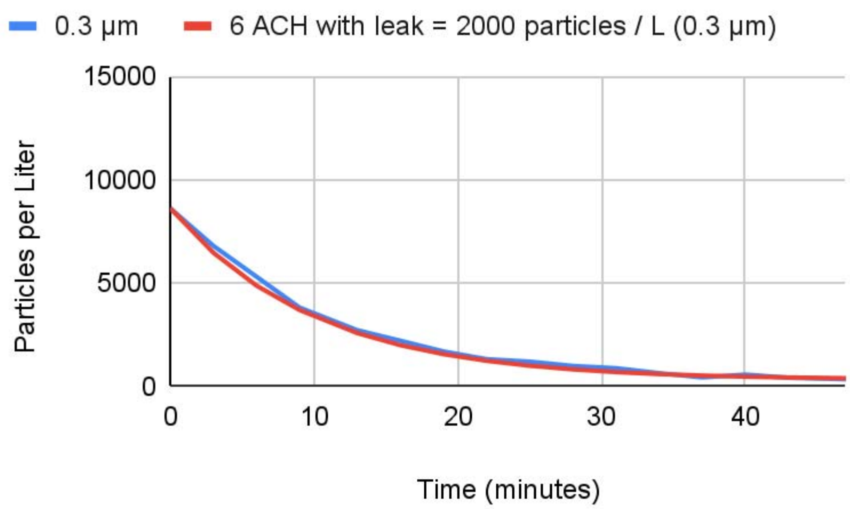
Whole House (10x 3M)

With ten 3M DIY purifiers turned to the lowest speed (1), ACH is estimated to be 6 with the percent error averaging 11% across 16 data points.



Whole House (10x Nordic Pure)

With ten Nordic Pure DIY purifiers turned to the lowest speed (1), ACH is estimated to be 6 with the percent error averaging 10% across 16 data points.



Limitations

These are included here from [30]. Although SARS-Cov-2 is extremely small (approximately 100 nm in diameter [47], it may be exhaled in respiratory aerosols and droplets that are much larger (several hundreds of nanometers to several microns). The research on which are the most common COVID transmission modes (aerosol, droplet, or surfaces), and what is the most common aerosol particle sizes by which it is transmitted continues to evolve as new variants emerge. One potential limitation is in extrapolating results from the ambient test aerosols used in this study to real-world applications for removal aerosols relevant to SARS-Cov-2.

Filtration efficiency and CADR results from DIY air cleaners highlight potential performance differences between filters made by different manufacturers of comparably rated MERV 13, 14, and 16 filters. Hence filter selection is critical to achieving the results desired. There may also be variability in filter performance due to manufacturing defects or variations among fans and filters from the same manufacturer. The long-term durability of filtration efficiency and airflow of these filters after extended use with box fans is also uncharacterized unlike HEPA-purifiers which have well-understood operational history.

Discussion

The experimental results summarized in Figure 1 demonstrate that ACH with or without air filtration can be measured (checked) in both a single room and a whole building by tracking the rate of decay of ambient aerosols present inside. As shown in Figure 3, the effective CADR and cost for each purifier can also be estimated based on measured ACH and estimates of the volume of the room and house (CADR = Volume x ACH / 60 / # of purifiers), which agree to within 20% of each other. The same ACH-derived CADR is shown alongside the weight of each purifier in Figure 4. The differences in effective CADR for the same purifiers between room and whole house may reflect differences in placement and orientation of the purifiers within each room of the house. Based on these CADR estimates, Figure 5 compares the CADR (cfm) per $100 and noise generated for each of the purifiers which varies by a factor of over 3x.

Figure 3: Estimate of CADR for each purifier based on measured ACH versus cost

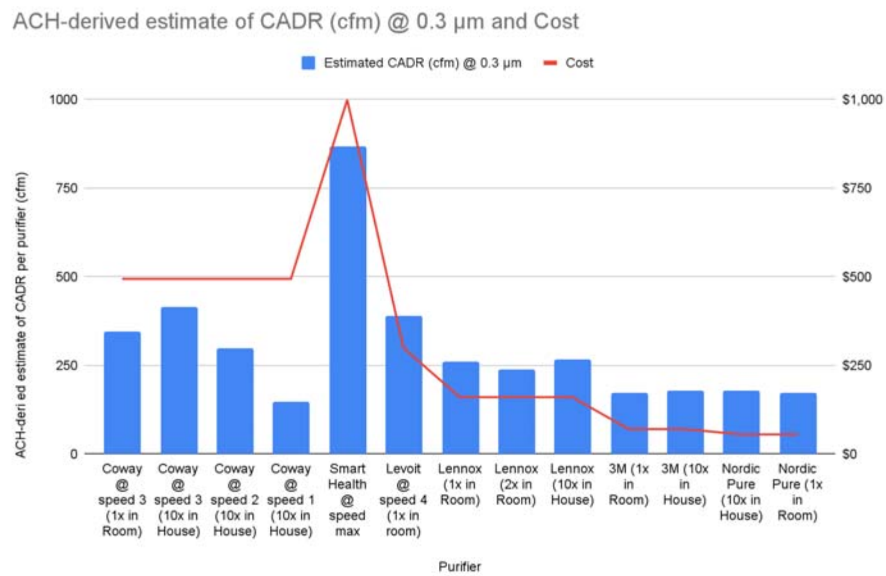


Figure 4: ACH-derived estimate of CADR for each purifier based versus weight

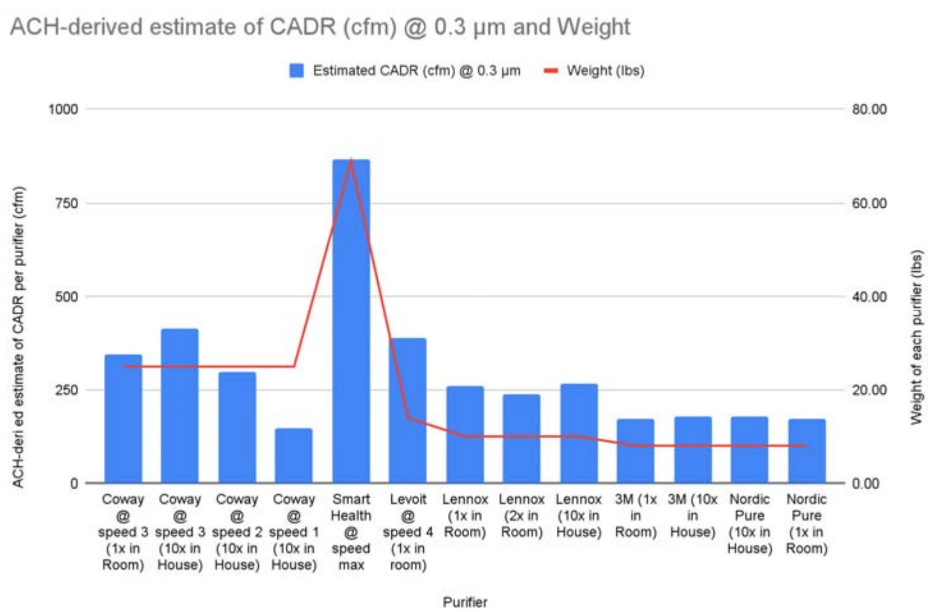
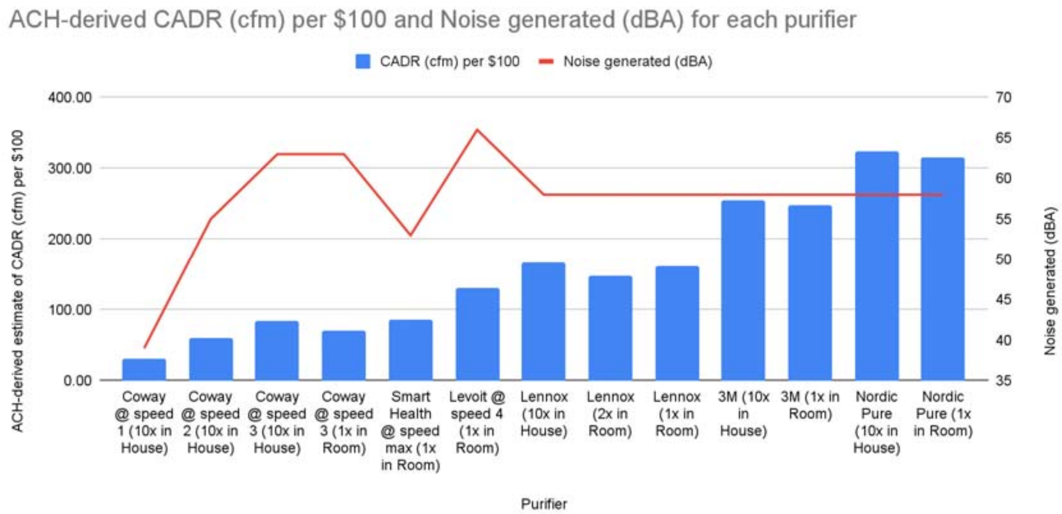
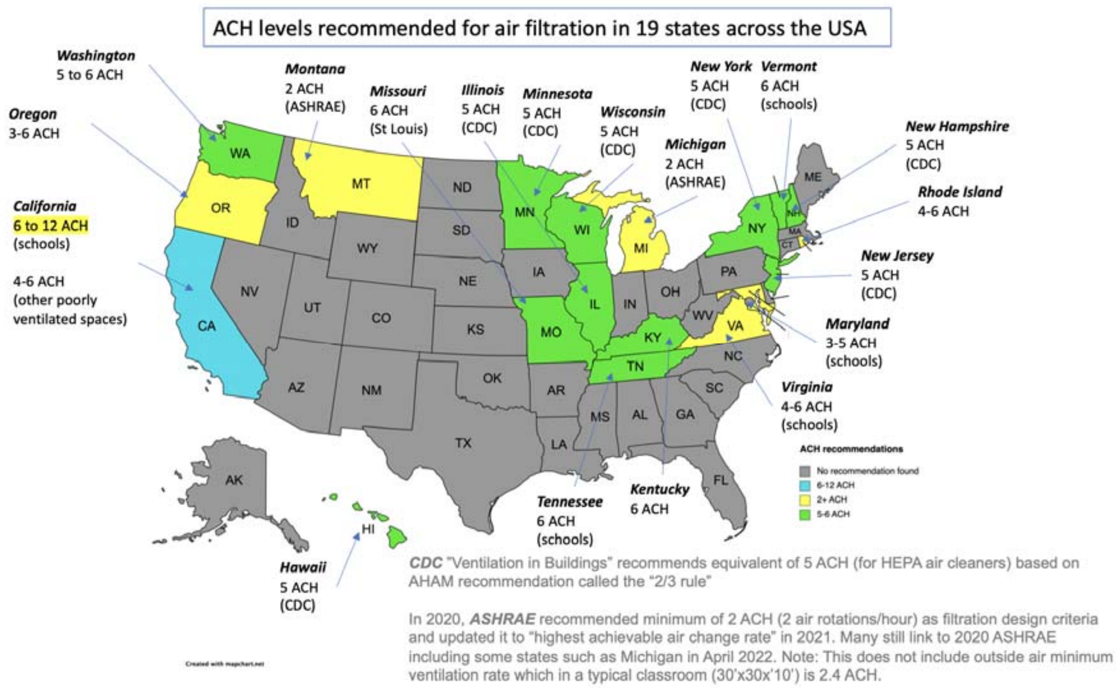


Figure 5: CADR (cfm) per $100 and noise generated for each purifier



ASHRAE minimum outdoor air rates set forth in 62.1-2019 for non-healthcare facilities are meant for removal of common indoor contaminants but may not be sufficient to achieve a desired level of infection risk reduction [6]. For a typical classroom (30'x30'x10'), 62.1-2019 says add per-person minimum (25 x 10 = 250 cfm) to per-area minimum (900 sf x 0.12 = 108 cfm) which equals 358 cfm or 2.4 ACH. To achieve suitable risk reduction for infection control, the ASHRAE Epidemics Task force suggests additional steps most likely needed but ASHRAE does not appear to make minimum recommendations for these steps [7]. Although a 2020 version of this same document recommended a 2 ACH minimum ("2 rotations/hour") which was linked to in April, 2022 by Michigan.

As shown in the map below, at least 19 states across the US have independently issued their own ACH guidelines or linked to recommendations from CDC or ASHRAE noted above. Although the laws of physics/chemistry/biology are the same in 50 states, there a wide range of ACH recommendations ranging from 2 to 12.



- California recommends 6-12 ACH for schools [10], and only recommends 4-6 ACH for other poorly ventilated indoor spaces [11]
- Hawaii refers to CDC (5 ACH) [12]
- Illinois refers to CDC (5 ACH) [13]
- Kentucky recommended 6 ACH for schools, "All day: Program system to run terminal unit fans (classroom unit fans) continuously (don't cycle them on and off) to provide more than six air changes per hour of MERV-13 filtered air." [14]
- Maryland recommended "~3-5 per hour" or 3-5 ACH for schools [15]
- Michigan refers to ASHRAE (2020) for schools (2 ACH based on 2020 guidance) [9]
- Minnesota refers to CDC (5 ACH) [16]
- Missouri (St. Louis) recommended 6 ACH [17]
- Montana refers to ASHRAE for schools (2 ACH based on 2020 guidance) [18]
- New Jersey refers to CDC (5 ACH) [19]
- New Hampshire refers to CDC (5 ACH) [20]
- New York refers to CDC (5 ACH) for schools [21]
- Oregon recommends 3-6 ACH [22]
- Rhode Island recommends 4-6 ACH [23]
- Tennessee recommends 6 ACH [24]
- Virginia recommends 4-6 ACH for schools [25]
- Vermont recommends 6 ACH for schools [26]
- Washington recommends 5-6 ACH [27]
- Wisconsin refers to CDC (5 ACH) [28]

In conclusion, the results demonstrate that 5 to 12 ACH as recommended by federal and state public health agencies (CDC, CDPH, etc.) is readily achievable with one or more HEPA / DIY air purifiers in each room, and can also be checked using ambient aerosols (Figure 1). Based on the measurement of 0.6 ACH for surface deposition, at least 12 ACH would be required to reduce far-field exposures and emulate protection of N95 respirators (95%) with higher ACH for greater margins of safety. Whereas at least 3 ACH would be needed to emulate the protection from a typical KN95.

Declaration of interests

I am not associated with any of the manufacturers mentioned in this research.

References

[1] https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html

[2] https://www.fondazionehume.it/data-analysis/controlled-mechanical-ventilation-cmv-works/

[3] https://arxiv.org/abs/2207.02678

[4] https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html

[5] https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html

[6] https://www.ashrae.org/file%20library/technical%20resources/covid-19/may2021_18-21_ieq_bahnfleth.pdf

[7] https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools-and-universities-c19-guidance.pdf

[8] https://images.magnetmail.net/images/clients/ASHRAE/attach/ashrae_reopening_schools_and_universities_c19_guidance.pdf

[9] https://www.michigan.gov/coronavirus/-/media/Project/Websites/coronavirus/k12-Schools/COVID-19-Guidance-for-Operating-Schools-Safely---April-2022.pdf

[10] https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/EHLB/IAQ/CDPH%20Document%20Library/School_ventilation_and_filtration_ADA.pdf

[11] https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/COVID-19/Interim-Guidance-for-Ventilation-Filtration-and-Air-Quality-in-Indoor-Environments.aspx

[12] https://health.hawaii.gov/coronavirusdisease2019/files/2021/08/COVID-19-Guidance-for-Schools.pdf

[13] https://dph.illinois.gov/covid19/community-guidance/ventilation-filtration-air-cleaning.html

[14] https://education.ky.gov/comm/Documents/Ventilation%20Final.pdf

[15] https://health.maryland.gov/phpa/Documents/COVID-19%20TA%20for%20Schools_8.19.21%20v2.pdf

[16] https://www.health.state.mn.us/diseases/coronavirus/indoorair.html

[17] https://www.stlouis-mo.gov/government/departments/health/communicable-disease/covid-19/guidance/upload/Ventilation-Guidance-1-7-2022.pdf

[18] https://dphhs.mt.gov/assets/publichealth/Asthma/COVID-19/HEPAAirPurifiersSchoolsCOVID19.pdf

[19] https://www.state.nj.us/health/ceohs/documents/ceohs%20content/NJDOH_Ventilation_Indoor_Spaces.pdf

[20] https://www.covid19.nh.gov/sites/g/files/ehbemt481/files/inline-images/universal-best-practices.pdf

[21] http://www.nysed.gov/common/nysed/files/programs/back-school/nysed-health-and-safety-guide-for-the-2021-2022-school-year.pdf

[22] https://sharedsystems.dhsoha.state.or.us/DHSForms/Served/le3725_R.pdf

[23] https://covid.ri.gov/covid-19-prevention/indoor-air-circulation

[24] https://www.tn.gov/content/dam/tn/health/documents/healthy-places/healthy-schools/HSW_School_IAQ_Fact_Sheets_Compiled.pdf

[25] https://www.apsva.us/maintenance/return-to-school-classroom-capacity/

[26] https://education.vermont.gov/sites/aoe/files/documents/edu-health-and-safety-faq-8-hvac.pdf

[27] https://doh.wa.gov/sites/default/files/legacy/Documents/1600/coronavirus/VentilationGuidance.pdf

[28] https://www.dhs.wisconsin.gov/covid-19/employers.htm

[29] https://www.sciencedirect.com/science/article/pii/S2590088921000597

[30] https://www.sciencedirect.com/science/article/pii/S0048969722029813

[31] https://www.nytimes.com/wirecutter/reviews/best-air-purifier/

[32] https://www.cdc.gov/mmwr/volumes/71/wr/mm7106e1.htm

[33] https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-021-06008-8/tables/2

[34] https://www.bjanaesthesia.org/article/S0007-0912(20)30480-3/fulltext

[35] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9301359/

[36] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8707272/

[37] https://onlinelibrary.wiley.com/doi/10.1111/ina.12751

[38] https://pubmed.ncbi.nlm.nih.gov/28370427/

[39] https://aaqr.org/articles/aaqr-21-03-tn-0046

[40] https://www.patientknowhow.com/safe.html

[41] https://www.sandiego.edu/onward/classroom-air-quality.php

[42] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8798678/

[43] https://wwwnc.cdc.gov/eid/article/26/7/20-0764_article

[44] https://www.cdc.gov/niosh/topics/noise/app.html

[45] https://ww2.arb.ca.gov/protecting-yourself-wildfire-smoke

[46] https://chemicalinsights.org/wp-content/uploads/DIY-Box-Fan-Report-2021.pdf

[47] https://elifesciences.org/articles/57309