INDOOR AIR QUALITY IN SCHOOLS AND CHILDCARE FACILITIES DURING COVID-19

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University of Colorado Boulder
Recommendations

**Short-range airborne transmission**

- **Results in a few cases**
  - Provide 3-ply surgical masks weekly to all staff and students, mandate wearing at all times in building
  - Implement strict social distancing policies
    - e.g. no eating together in lunch room
  - Implement strict quarantine

**Long-range airborne transmission**

- **Results in superspreading**
  - In addition to strategies for short-range...
    - Aggressively increase ventilation rates to at least 5, ideally 6 air changes per hour outside air
      - Windows/doors open
    - Mandate additional air cleaning in every space that is occupied for > 1 hour by > 10 occupants
      - Room size key: 600-1000 ft² with 8-10 ft ceilings utilize stand alone HEPA air cleaners
      - Larger rooms with higher ceilings use upper room germicidal ultraviolet light

Also suggest adding CO₂ monitors indoors
SCHOOL TRANSMISSIONS
What does the data say?

In the UK no evidence of difference in positivity rate between primary and secondary school teachers and their households, other key workers and their households, and other professions and their households.
"There is no consistent pattern. It's not that closing schools leads to a decrease in cases, or that opening schools leads to a surge in cases." – Insights for Education

- Susceptibility for children aged <10y is relatively low; susceptibility in adults aged >60y is higher; mitigation measures should be implemented when opening schools, particularly secondary/high schools (Goldstein)

- In England summer school session 0.51 outbreaks for each infection per 100,000 in community; infections and outbreaks uncommon across all educational settings; staff members had increased risk compared to students, majority of cases linked to outbreaks were in staff. The probable transmission direction for the 30 confirmed outbreaks was: staff-to-staff (15), staff-to-student (7), student-to-staff (6) and student-to-student (2) (Ismail)

- Main factors whether child care worker got sick overall level of community transmission in county where lived and race/ethnicity – Black, Latino, Native American people more likely to test positive or be hospitalized. Both policy and social context affect people’s risks and outcomes (Gilliam)


COVID-19 School Response Dashboard – Brown University (self report)

Student Confirmed Infection Rate

- Percent of Students with Confirmed Case:
  - 0.77% (8/31 - 9/13)
  - 0.141% (9/14 - 9/27)
  - 0.140% (9/28 - 10/11)
  - 0.090% (10/12 - 10/25)

- Daily Case Rate Per 100,000 Students:
  - 5 (8/31 - 9/13)
  - 10 (9/14 - 9/27)
  - 6 (9/28 - 10/11)
  - 14 (10/12 - 10/25)

Staff Confirmed Infection Rate

- Percent of Staff with Confirmed Case:
  - 0.00% (8/31 - 9/13)
  - 0.16% (9/14 - 9/27)
  - 0.24% (9/28 - 10/11)
  - 0.34% (10/12 - 10/25)

- Daily Case Rate Per 100,000 Staff:
  - 10 (8/31 - 9/13)
  - 14 (9/14 - 9/27)
  - 10 (9/28 - 10/11)
  - 14 (10/12 - 10/25)

Schools Reporting

- 1 (8/31 - 9/13)
- 4,272 (9/14 - 9/27)
- 5,727 (9/28 - 10/11)
- 1 (10/12 - 10/25)

Students Represented in Dataset

- 0 (8/31 - 9/13)
- 1,614,747 (9/14 - 9/27)
- 3,125,170 (9/28 - 10/11)
- 421,999 (10/12 - 10/25)

Staff Counts

- 0 (8/31 - 9/13)
- 10,000 (9/14 - 9/27)
- 400,000 (9/28 - 10/11)
- 421,999 (10/12 - 10/25)
SUPERSPREADING
Superspreading

- As few as 10-20% of infected people transmit 80-90% of the infections; many people barely transmit, asymptomatic/pre-symptomatic
- Super-spreader w/ >10 infections occur when infected is shedding very high viral load & has a high concurrent number of exposed contacts


Skagit Valley Chorale Rehearsal Outbreak

Goal 1: estimate average emission rate of infectious airborne dose

Goal 2: explore how changes in ventilation or duration of event would alter infection risk

Indoors never totally safe, can mitigate

- What happens if we could change conditions?
- All are changing only 1 thing, except “do all previous indoors”

Slide courtesy of Prof. Jose Jimenez
MUSICIANS AND PERFORMERS STUDY

“Let’s Save Music”
Study Chairs: NFHS Weaver and Clemson Spede
CU Boulder Research Team: Miller, Vance, Hertzberg, Toohey, Stockman, Patel, Kumar, Bower, Nelson
U of Maryland Team: Srebric, Milton, Zhu
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Bell Cover Efficiency, Sampled at Bell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarinet</td>
<td>87%</td>
</tr>
<tr>
<td>Bassoon</td>
<td>89%</td>
</tr>
<tr>
<td>Saxophone</td>
<td>64%</td>
</tr>
<tr>
<td>Oboe</td>
<td>96%</td>
</tr>
<tr>
<td>Flute</td>
<td>67%</td>
</tr>
<tr>
<td>Trombone</td>
<td>89%</td>
</tr>
<tr>
<td>Trumpet</td>
<td>92%</td>
</tr>
<tr>
<td>French Horn</td>
<td>95%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performer</th>
<th>Mask Efficiency, Sampled in Front of Mouth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theater 1</td>
<td>80%</td>
</tr>
<tr>
<td>Theater 2</td>
<td>88%</td>
</tr>
<tr>
<td>Soprano Singer</td>
<td>98%</td>
</tr>
<tr>
<td>Baritone Singer</td>
<td>79%</td>
</tr>
</tbody>
</table>

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[Graph showing particle concentration over time for different instruments.]

[Soprano Singer image with a caption.]
Music and Performance Specific Recommendations
VENTILATION
CO₂ TOO HIGH!

VENTILATION RATE TOO LOW!

1.7 L/s/person

10

CO₂ concentration (ppm)

3200

2800

2400

2000

1600

1200

800

400

Ventilation Rate and CO₂ in a tuberculosis outbreak

How Air Change Rates Work

measure of the outside air volume added to a space divided by the volume of that space

ASHRAE recommends: 6.7 L/s/person (or 13 cfm/p) outside air

Occupancy is 35 students/1000 ft²
Design Ventilation Rate: (13 cfm/p) x 35 students = 455 cfm

Air Change Rate? 455 cfm ÷ (10,000 ft³) x (60 m/h)
= 3 air changes per hour (ACH)

Time for 60% of the room air to be exchanged with outside air?
= 20 min

Time for all of the room air to be exchanged with outside air?
= 60 min

Varies a lot during the day and from one environment to the next!
Using CO$_2$ as an Analog for Ventilation Rate

Slide from Dr. Zhe Peng
CO₂ Outdoors and in a Car

Outdoors

In car, 2 people + child

Windows, closed, recirculated air

Windows closed, ventilation system w/ outdoor air

Slide from Dr. Jose Jimenez
Classroom Ventilation and Illness Absence

Increasing VR from current mean of 4 to CA std of 7 l/s/p would reduce IA by 3-5%

Increasing to 9.4 l/s/p would reduce IA by 7-10%

Increasing ventilation rate together with household isolation could be as effective as school closure.

- Baseline
- 100% home isolation
- Close all schools 1% symptomatic
- Close targeted schools at 1 case
- Increase school VR to 5 ach
- Increase school + home VR to 5 ach
- 100% isolation & Increase school VR to 5 ach
- 100% isolation & Increase school + home VR to 5 ach
- 100% isolation & close targeted schools at 5 cases & increase school + home VR to 5 ach

**SCHOOL S.M.A.R.T.**

- **S**: Stay home when sick
- **M**: Mask up
- **A**: Air purifier in every room
- **R**: Refresh indoor air
- **T**: Temporary classrooms

**For Health**

**Target is at least 5 total air changes per hour**

- Ideal (6 ACH)
- Excellent (5-6 ACH)
- Good (4-5 ACH)
- Bare minimum (3-4)
- Low (<3 ACH)

**For Health**

www.ForHealth.org

**Mechanical Vent**

- Measured:
  - OA supply: 231 cfm
  - Indoor supply: 800 cfm
  - % OA: 29%
  - ACH: 1.4 ACH

**Windows**

- 3.3 – 4.0

**Doors**

- 5.4 – 6.5

Note: We report a range of ACH values for the rooms in which multiple CO₂ monitors were used. However, only one CO₂ plot is shown.
FILTRATION
Air Cleaning
Quantifying air cleaner performance

What is the airflow rate that represents the effective amount of particle-clean air produced by the device? This is the CLEAN AIR DELIVERY RATE - CADR

![Graph showing particle concentration with and without air cleaner and ventilation.](Image)
Clean air delivery rate for bioaerosols (m³/h)

- Mycobacteria: 1 μm
- Fungi: > 5 μm


Air Cleaner 1
- CADR of 170
- Clean 30 m³ room

Air Cleaner 2
- CADR of 25
- 4 m³
# Simple Tool for Selecting Portable Air Cleaner for Rooms

## Step 1: How Big is the Room?

<table>
<thead>
<tr>
<th>Select units of preference</th>
<th>feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>How big is your room?</td>
<td>500</td>
</tr>
<tr>
<td>How tall are your ceilings?</td>
<td>8</td>
</tr>
</tbody>
</table>

**Input your room size here in square feet**

**Input your room size here in feet**

## Step 2: What is the ‘Clean Air Delivery Rate’ of the Air Purifier? (You get this from the manufacturer)

| What is the clean air delivery rate of the air cleaner? | 300  |

Find the CADR from the manufacturer in units of cubic feet per minute, or cfm; if they report multiple

## Step 3: How Much Outdoor Air Ventilation Do You Have?

<table>
<thead>
<tr>
<th>How is the ventilation in my school?</th>
<th>Low ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good ventilation</td>
<td>3 ACH</td>
</tr>
<tr>
<td>Enhanced ventilation</td>
<td>4 ACH</td>
</tr>
<tr>
<td>Typical school</td>
<td>1.5 ACH</td>
</tr>
<tr>
<td>Low ventilation</td>
<td>1 ACH</td>
</tr>
</tbody>
</table>

Select this only if your school has:

Select this if your school has pc

## Step 4: Combining Air Cleaning and Ventilation, Is Your Room Meeting the Target?

| Air changes from outdoor air ventilation | 1 |
| Air changes from air cleaner            | 4.5 |
| Total air changes in the room per hour  | 5.5 |

**Target is at least 5 total air changes per hour**

- Ideal (8 ACH)
- Excellent (5-6 ACH)
- Good (4-5 ACH)
- Bare minimum (3-4 ACH)
- Low (<3 ACH)

## Step 5: What Size Room Will Work for This Portable Air Cleaner?

<table>
<thead>
<tr>
<th>Cubic feet per minute (cfm) of clean air from cleaner</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic feet per minute (cfm) of outdoor air from ventilation</td>
<td>67</td>
</tr>
<tr>
<td>Total cfm of air cleaning and ventilation</td>
<td>367</td>
</tr>
<tr>
<td>Recommended room size for this air cleaner (in square feet)</td>
<td>550</td>
</tr>
</tbody>
</table>

This is from the manufacturer (see cell ‘c10’)

This is calculated from air changes per hour and volume of room

This is the recommended maximum size of the room for this air cleaner to achieve 5 total ACH
GERMICIDAL ULTRAVIOLET LIGHT
Upper-Room Germicidal UV

Crowded environments where unsuspected infectious persons may be present (e.g. jails, homeless shelters, hospital waiting rooms)

We found that among different engineering control measures, UVGI singly is the optimal strategy combined with effective isolation and vaccination interventions for containing influenza, measles, and chickenpox. 

Liao et al. 2008

Xu, P. et al. 2003; Xu, P., et al. 2005
CONCLUSIONS

Aggressively focus all resources and efforts on opening schools, reducing community spread with strict mask wearing, limiting gathering sizes, increasing ventilation rates in homes and communities...AND...
THREE IMPORTANT IDEAS

1. Devastating consequences to keeping kids remote and out of in-person school – national priority

2. Returning to in-person school should be prioritized over other aspects of economy (last to close; first to reopen)

3. Cannot be ‘schools as usual’; need layered defense risk reduction strategies

The infection fatality rate for kids is very low; overall risk lens has to include #1 above; strategies in #3 are designed to protect both kids AND adults.
Recommendations

Short-range airborne transmission

- Provide 3-ply surgical masks weekly to all staff and students, mandate wearing at all times in building
- Implement strict social distancing policies
  - e.g. no eating together in lunch room
- Implement strict quarantine

Results in a few cases

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- Susceptibility for children aged <10y is relatively low; susceptibility in adults aged >60y is higher; mitigation measures should be implemented when opening schools, particularly secondary/high schools (Goldstein)

- Secondary transmission very low in Rhode Island child care programs allowed to reopen; occurred when community transmission increased; reduced class sizes and use of face masks for adults (Gelles)

- In England summer school session 0.51 outbreaks for each infection per 100,000 in community; infections and outbreaks uncommon across all educational settings; staff members had increased risk compared to students, majority of cases linked to outbreaks were in staff. The probable transmission direction for the 30 confirmed outbreaks was: staff-to-staff (15), staff-to-student (7), student-to-staff (6) and student-to-student (2) (Ismail)

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Increase (clean) outdoor air supply

- building ventilation can be as effective as public health interventions
- existing ventilation rates may be too low to prevent or control airborne infectious diseases in indoors
- and might need to be increased by 10x


**Fig. 2.** The effect of increasing ventilation rate: (a) change of daily incidents, (b) change of overall attack rate.