INTRINSIC
Environment, Health & Safety

RE: Certified Industrial Hygiene Ventilation Assessment for Harmony Union School District

This memo presents the findings of our ventilation assessment and analysis of Harmony Union School District ventilation preparedness for COVID-19 mitigation.

Dear Superintendent/Principal Matthew Morgan,

Wednesday November 18th, 2020 and Monday February 15th, 2021 David M. Moore, MPH, CIH, from Intrinsic Environment, Health & Safety assessed ventilation in a representative sample of classrooms, and communal spaces within the Harmony Union School District (HUSD). The purpose of our visit was to understand the current capabilities of myriad ventilation systems at HUSD, and to determine within the context of all planned mitigation measures, if the ventilation system would provide sufficient airflow to meet Sonoma County, CDPH, ASHRAE, and CDC guidance. Recommendations for further risk reduction with respect to ventilation are included.

BACKGROUND

As part of HUSD's plan for a return to in-person instruction, HUSD requested Intrinsic EH&S review HUSD's ventilation capabilities for risk reduction for COVID-19 transmission. As part of our scope of work, a representative sample of each of the types of classrooms from Buildings B through F, the Gymnasium, the Assembly Room, Library, select restrooms, and staff break room were included in our assessmetn. The overaching goal was to understand the range of ventilation systems, their respective capabilities, identify issues and opportunities for improvement.

Ventilation systems are intended to provide thermal comfort, as well as dilution ventilation (outside fresh air) which removes indoor airborne contaminants, either through natural, or mechanical means. Most all ventilation systems within HUSD schools are capable of providing some degree of filtration. All classrooms have a means to access outside fresh air either through opening HVAC economizers, or through windows and doors. All HUSD classrooms visited have an air intake that provides dilution ventilation. Combined, the filtration from the MERV filters, should they be installed in HUSD classroom HVAC units, and the outside fresh air provide a certain number of air changes per hour (ACH).

METHODOLOGY

Utilzing a calibrated Evergreen Telemetry balometer, and a calibrated TSI VelociCalc and vane anemometer, Intrinsic's Occupational Environmental Health Team measured airflow over two days. Measurements were taken in cubic feet per minute (cfm), unless the vane anemometer was used, in which case linear flow was measured to determine cfm. It was recommended that all systems be at normal operating status prior to the assessment. Additionally, room dimensions were taken, using a Dewalt laser ruler, to calculate air changes per hour (ACH).

This report will include locations and associated measurements (cfm, and cubic volume) along with calculated air exchange values (ACH). Recommendations will be made for addressing any observed deficiencies.

The basis for our assessment, and subsequent recommendations are based on guidance from CDC Guidance for Schools, ASHRAE Journal May 2020, California Department of Public Health ANSI/ASHRAE Standard 62.1-2019 summarized below…

- Increase outside air ventilation
- When weather conditions allow, increase fresh outdoor air...Do not open windows and doors if doing so poses a safety or health risk e.g. triggering asthma symptoms
- Use **fans** to increase the effectiveness of open windows. Position fan so as not to induce potentially contaminated airflow directly from one person to another
- Decrease occupancy in areas where outdoor ventilation cannot be increased
- Ensure ventilation systems operate properly and provide acceptable indoor air quality for the current occupancy level for each space
- Increase total airflow supply to occupied spaces
- Disable demand-controlled ventilation (DCV) controls that reduce air supply based on occupancy or temperature during occupied hours, by setting thermostat to Fan On instead of Fan Auto
- Improve central air filtration:
    - Increase air filtration to as high as possible without significantly reducing design airflow.
    - Inspect filter housing and racks to ensure appropriate filter fit and check for ways to minimize filter bypass.
    - Check filters to ensure they are within their service life and appropriately installed
- Ensure restroom exhaust fans are functional and operating at full capacity when the building is occupied.
- Consider installing portable high-efficiency air cleaners

Assumptions:

MERV 11 is capable of filtering 20% of 0.3-1.0µm (microns) 65% of 1.0-3.0µm and 85% 3.0-10.0µm (ASHRAE). While SARS-CoV-2 virus are submicron, it is found in respiratory aerosol, which is polydisperse from 0.3-1,400µm. However, the geometric mean diameter of droplets measured from coughing and speaking was 13.5µm and 16.0µm respectively (Chao et al, 2008). Meaning that 50% of the mass of respiratory aerosol is well above the size fraction that MERV 11 can comfortably filter. Moreover, predicted risk reductions (Azimi, Stephens, 2013) based on the anticipated distribution of virus ASHRAE suggests an "equivalent outdoor air" value of 73% for MERV 11. ASHRAE acknowedges existing unknowns, with respect to virus distribution in aersosol. Therefore, 50% was assumed as a conservative outside air equivalent value for MERV 11. Such that 1,000cfm of MERV 11 filtration would provide a minimum of 500cfm of outside air equivalent.

For our calculations, it was assumed that the IQ*Air* CleanZone SL HEPAs would be running on their highest setting, providing 820m^3/hr (cubic meters per hour), which equates to approximately 483cfm (cubic feet per minute)of filtered air. HEPAs provide the highest level of filtration; 99.97% of the most penetrating particle size. Because of the physics of aerosols, it is more effective at filtering out particles that are larger and smaller than 0.3µm (NIOSH).

CFM Outside Air + (Total CFM - Outside Air)*0.5 + 483CFM/unit = **TOTAL CFM**

HVAC Outside Air
HVAC MERV 11 Filtration
IQ*Air* CleanZone SL HEPA Filtration

This value was then used to calculate cubic feet per hour (CFH) also abreviated as Q, and using the Classroom Volume (V), the ACH.

Q/V = ACH

CLASSROOM FINDINGS

While most classrooms have more than adequate airflow, much of this is recirculated without any HVAC filtration. The IQ*Air* CleanZone SL's provide 820m^3/hr (cubic meters per hour), which equates to approximately 483cfm (cubic feet per minute) or ~29,000cfh (cubic feet per hour). While this volume of HEPA filtered air, provides substantial air exchange, it doesn't provide enough to meet HUSD's targeted 6 ACH (air changes per hour), without MERV 11 filtration. However, when the economizers are maximized, to allow in maximum outside air, and the return air is filtered with a minimum of MERV 11, along with the IQ*Air*, the combined dilution and filtration ventilation should provide more than adequate air exchange.

Classroom Data:

Room	Combined Estimated ACH with MERV 11	Combined Estimated ACH without MERV 11
Coast Live Oak	7.3	4.2
Red Alder	7.8	4.4
Black Hawthorn	6.7	4.3
Black Oak	8.3	4.9
Maple	8.2	5.0
Madrone	5.7	3.4
Tan Oak	5.5	3.3

Figure 1: Classroom Air Exchange MERV 11 Comparison with one IQAir CleanZone HEPA Filter running at max flowrate (820m^3/hr)

LIBRARY FINDINGS

Given that the space is a much larger space, even with the assumed four IQ*Air* CleanZone SL's providing 820m^3/hr at max flowrate, economizers opened at full (a conservative 20% was assumed), and MERV 11 filters are installed, 6 ACH is likely an unatainable goal. However, ASHRAE recommends 0.12cfm/ft^2 and an additional 5cfm/person for Libraries. Assuming that economizers are open to allow a minimum of 20% OA, this should allow sufficient airflow for ~40 individuals, and still meet ASHRAE guidelines, not including the contribution of the HEPA filters, or natural ventilation from open doors. It is still advisable to prevent cohorts from mixing, and allow sufficient time to permit 3 air changes (~1 hour), prior to the next cohort using the same space.

Library Data:

Room	Combined Estimated ACH with MERV 11	# of People assuming ASHRAE recommended 5 cfm/person
Library	3.7	39

Figure 2: Library Air Exchange with MERV 11 four IQAir CleanZone HEPA Filter running at max flowrate (820m3/hr)

ORACLE OAK ROOM FINDINGS

There was considerable airflow in the Oracle Oak room. However, given IQ*Air* CleanZone HEPA filters for this space were not discussed, it was assumed that they will not be used in this location. Therefore, with respect to air exchanges, only OA, and MERV 11 filtered air was considered. The three columns below indicate the air exchange contribution from an assumed 20% OA rate, the contribution from MERV 11, and the combined ACH of the two.

Oracle Oak Room Data:

Room	ACH OA Assuming 20%	ACH from MERV 11	Combined Estimated ACH from 20%OA and MERV 11
Oracle Oak Main Entrance	3.6	7.2	10.8
Oracle Workroom	1.8	3.7	5.5

RESTROOM FINDINGS

All restrooms measured had more than adequate exhaust ventilation. However, there was one restroom visited, on the outside of the gymnasium which had an exhaust fan that did not appear to be working. ASHRAE 62.1-2019 recommends 70cfm of exhaust per unit for public toilets when heavy periods of use are expected to occur. A unit could mean a stall, or a urinal.

Restroom Data:

Room	ACH	# of People per ASHRAE 70cfm/unit
Oracle Oak Bathroom	8.4	1
Salmon Creek Environmental Center Men's Restroom	7.0	2
Salmon Creek Environmental Center Women's Restroom	7.0	2
Madrone Bathroom	13.2	2

GYMNASIUM FINDINGS

While there are two large units that provide a combined 2300cfm, given the large size of the gym, this is not sufficient to provide more than 1 ACH even assuming a generous 50% OA, and MERV 11 filters. Moreover, even assuming 50% OA, it does not meet ASHRAE 62.1-2019 guidelines for outside air. ASHRAE recommends 0.18cfm/ft^2 and an additional 20cfm/person. For a cohort of 12 students, and 2 instructors, an additional 400cfm would be needed to meet ASHRAE 62.1-2019 guidelines. This could be achieved by opening economizers, adjusting dampers, or increasing fan speed.

Gymnasium Data:

Room	Combined Estimated ACH	Additional cfm OA needed for 12 students and 2 instructors
Gym	0.7	399

KEY

Key	
CFM	cubic feet/minute
CFH	cubic feet/hour
ACH	Air Changes/Hour
HEPA	High Efficiency Particulate Air
MERV	Minimum Efficiency Reporting Values
ACH	Greater than 5 ACH
ACH	Between 4-5 ACH
ACH	Between 3-4 ACH
ACH	Less than 3 ACH

CO_2 NATURAL VENTILATION ASSESSMENT METHODOLOGY

The Assembly Room was a space identified as having only Fan Coil units that provide heating and cooling, without bringing in any outside air.

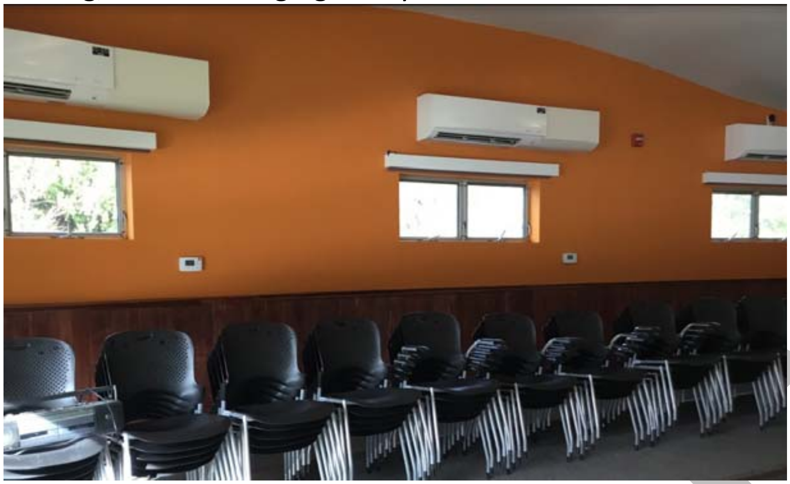


Figure 3: Assembly Room Back Wall Fan Coil Units

In order to characterize air exchanges occuring through natural means, carbon dioxide (CO_2) was used to determine the natural decay rate within the Assembly Room. CO_2 has long been used as an indicator for indoor air quality in schools (Batterman et al. 2006). And more recently, it has been used as an indicator for assessing, and mitigating the potential for COVID transmission (Washington Post). To assess air exchange by outside air at HUSD, a calibrated TSI VelociCalc, along with a calibrated TSI Indoor Air Qualily Probe was used to data log carbon dioxide concentration in parts per million (ppm).

Pure CO_2 was distributed into the Assembly Room by discharging a CO_2 fire extinguisher throughout the room until ~2,500ppm was achieved. Fans were used to facilitate, and expedite even mixing and distribution CO_2 within the room, to further improve the accuracy of the results.

Two conditions were tested: 1. All windows and doors closed 2. Three back windows open, with both doors open. Our goal was to test realistic scenarios that could plausibly increase the amount of fresh air turnover, occuring within the room, using a reasonably likely configuration of windows and doors.

Trials each lasted ~30 minutes each. Each time a condition was tested the time was recorded, as well as at the conclusion of the trial. This was in order to estimate the time at which decay was occuring, to further improve the accuracy of our results. For example, if a Baseline Trial was running, just after the achieving ~2,500ppm, fans were used to distribute CO_2. The TSI VelociCalc, while it was data logging, was walked around to room, to ensure even distribution. Once the levels CO_2 stabalized to within +/- 2% the ventilation assessment team vacated the room. It is expected, that that a rush of CO_2 would have left through the door at the time of exit.

Upon downloading the data using TSI TrakPro, a graph was generated, and analyzed to determine the time at which decay was occuring. Two points (C_1/C_2), were selected during the time decay was occuring, and the time between those two points was inputed into a formula to calculate an empirically derived fresh air exchange rate. The formula below was used to determine the air exchanges per hour (ACH).

ACH = [ln(C_1/C_2)*60minutes]/t

ACH = Air Changes per Hour
ln = Natural Log
C_1 = Concentration at time 1
C_2 = Concentration at time 2
t = time

The formula is a derivation of the function found on the CDC website.

t2 – t1 = – [ln (C2 / C1) / (Q / V)] X 60, with t1 = 0

CO_2 NATURAL VENTILATON ASSESSMENT FINDINGS

The empirically derived ACH from our CO_2 test in the Assembly Room, indicated that windows and doors open, demonstrated an approximately 40 fold increase in air exchange, as compared to no windows open. However, it was discussed that only one person would occupy and work in this space at any given time. In the event additional people would need to be in this space, it would require between 2-5 IQ*Air* CleanZone HEPA filters to achieve 6 ACH, depending on whether or not windows and doors were open.

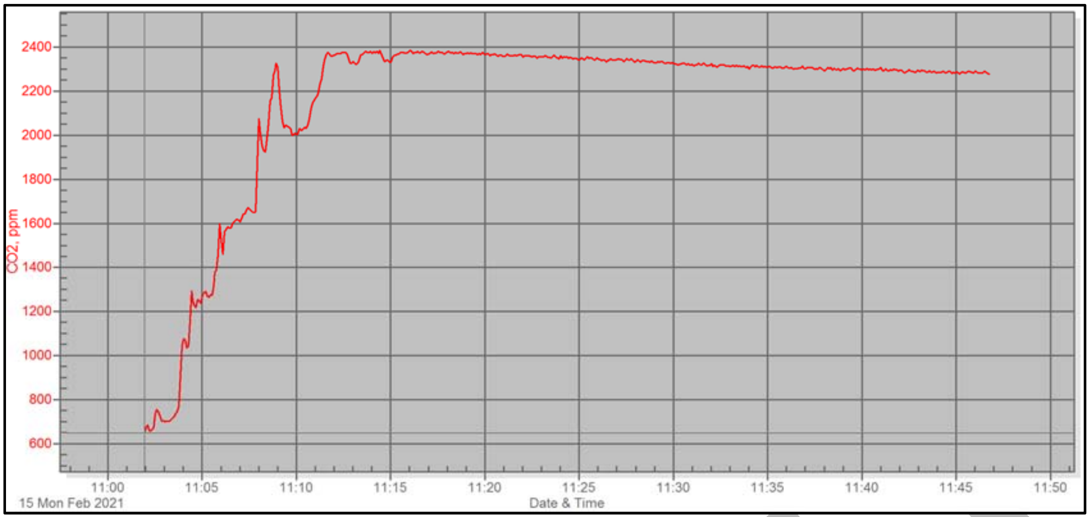


Figure 4: Assembly Room CO2 Trial 1 February 15th, 2021 Air Changes Per Hour 0.08 All Windows and Doors Closed

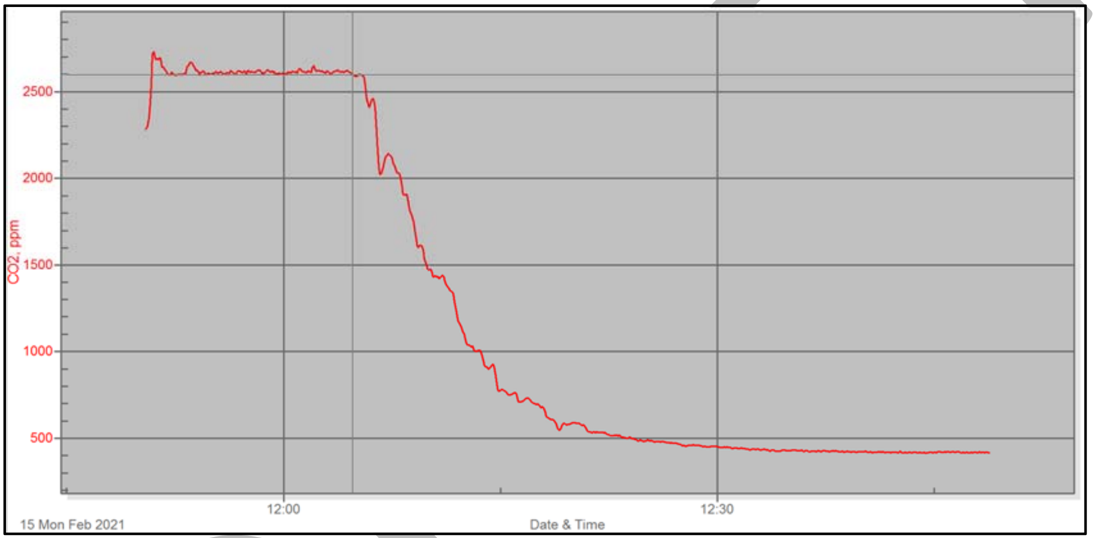


Figure 5: Assembly Room CO2 Trial 2 February 15th, 2021 Air Changes Per Hour 3.9 Three Windows Open, and Both Doors Open

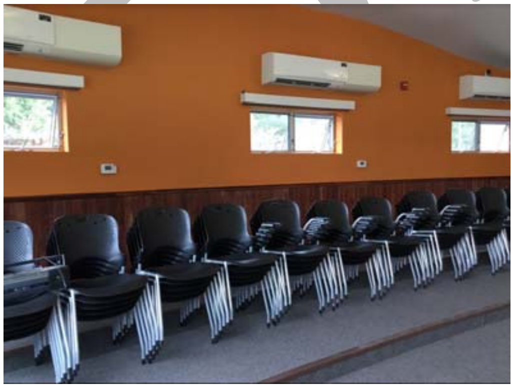


Figure 6: Three Back of the Room Windows Open (Trial 2)

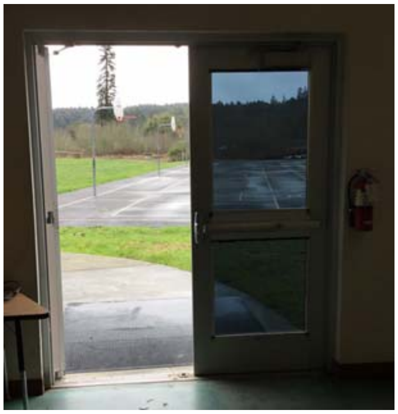


Figure 7: Door to Outside Open (Trial 2)

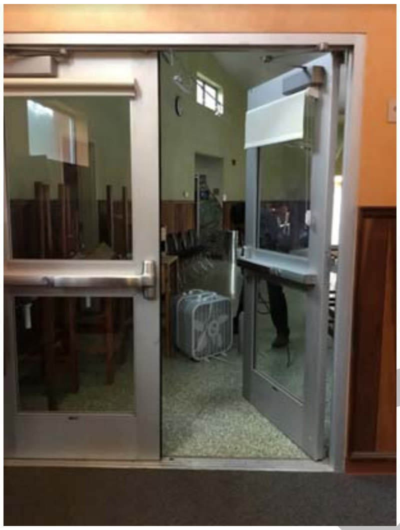


Figure 8: Door to Hallway Open (Trial 2)

CO_2 Natural Ventilation Assessment Data:

Room	Trial	ACH	HEPA CADR Needed for 6 ACH	# of 820m^3/hr IQAir CleanZone HEPA Filters
Assembly Room	1	0.1	2321	5
Assembly Room	2	4.0	794	2

DISCUSSION

This assessment was not a comprehensive evaluation of all HUSD classrooms and buildings. The purpose of this assessment was to find representive examples of potential ventilation issues and provide recommended corrective actions. While it was assumed that all systems were providing ~20% outside air (OA) at a minimum, it is concievable that several air handlers have not yet had their economizers set to the maximum position. As a result, it is possible many of the OA estimates were overestimates. However, once every economizer has been set to open, it is likely that 20% would be a conservative estimate. Meaning that OA would likely be closer to 30%.

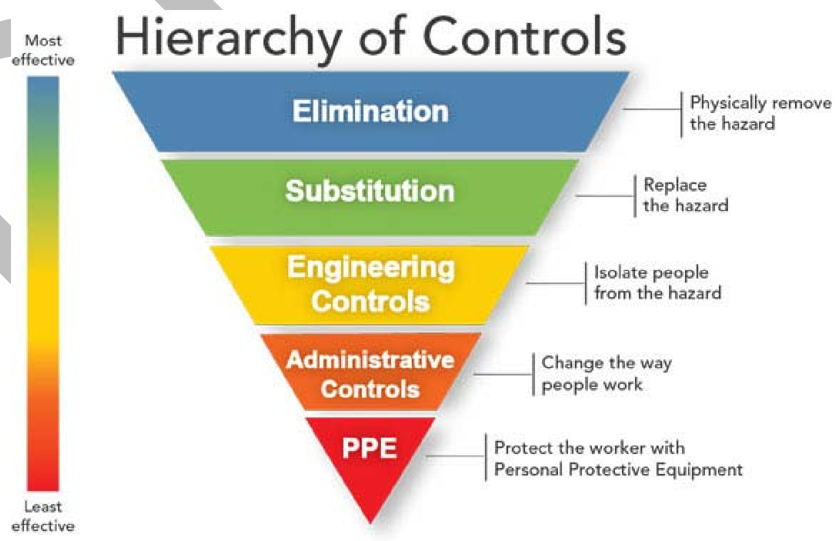
Most all of spaces assessed did not have any MERV filtration. CDC, Cal/OSHA, and CDPH recommend increasing MERV filtration to the highest the system is capable of handling. Many newer systems, such as the ones found at HUSD, are capable of handling at least a MERV 11 filter. However, if this is not true, than the amount of ventilation provided by MERV filtration will need to be adjusted. For the purposes of our calculations, it was assumed that they will have MERV 11 prior to reopening.

In the event MERV 11 filters are compatible with HUSD systems, it is possible that airflow will be slightly reduced after filters are installed. However, opening economizers may conversely increase airflow. The most important thing, is that ventilation systems are used, working, maintained, and that filters are changed out on a routine schedule, per manufacturers instructions.

While HUSD has set an internal benchmark of 6 ACH for each classroom, it is possible that this is not an attainable goal without the use of MERV filtration, and potentially cost prohibitive, if achieved through HEPA filtration alone. While IQ*Air* CleanZone HEPA filters can provide roughly 500cfm/unit, an HVAC unit moving 1,000cfm with MERV 11 filtration will provide roughly the same benefit of ~500cfm of clean air. And for a fraction of the cost (Azimi and Stephens, 2013).

In general, findings from our CO_2 study confirmed our hypotheses, that more windows, particularly where a crossdraft could be achieved would provide the best air exchange rates. Conversely, no windows open resulted in air exchanges comparable to what the EPA recommended for homes, pre-COVID (EPA).

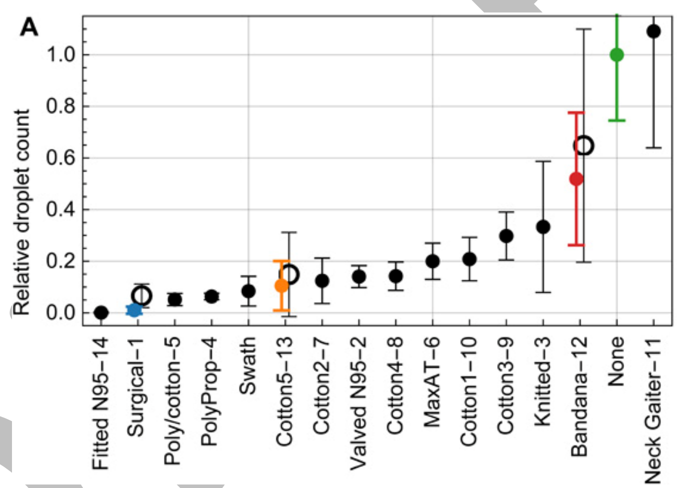
There is no one control that will alone prevent the risk of COVID-19 transmission, the National Institute for Occupational Health & Safety's Hierarchy of Controls is a framework that helps us understand how controls can work together.



Staying home when sick, an example of Elimination. Substituting smaller class sizes or a hybrid model for the conventional class, an example of Substitution. And of course ventilation, an example of an Engineering Control. HUSD's re-opening plan would be an example of an Administrative Control. While face coverings are not Personal Protective Equipment, they do serve to protect those around us.

While there is no better control than staying home when sick, there are estimates of up to 30% of COVID positive individuals are asymptomatic. Meaning they will never show any symptoms of COVID. Reinforcing the importance of face coverings.

A Duke study, indicates that many face coverings can block upwards of 80% of the wearer's respiratory aerosol. While not eliminating aerosol entirely, it is reducing a percentage of aerosol that would otherwise be emitted without a face covering. A classroom with enough HEPA filtration to remove aerosol at a rate of 5 air changes per hour (5 ACH) would take 20 min to remove 80% of an airborne contaminant. An effective, and properly worn face covering (over the nose and mouth) can block upwards of ~80% from entering the environment instantaneously, essentially.



ASHRAE recommends a daily flush of the ventilation prior to occupancy: "Mechanical Systems should be operated in occupied mode (including normal or peak outside air rate introduced to each space) for minimum period of 2 hours prior to occupants re-entering building." However, ASHRAE also states that the primary goal is to achieve 3 air changes.

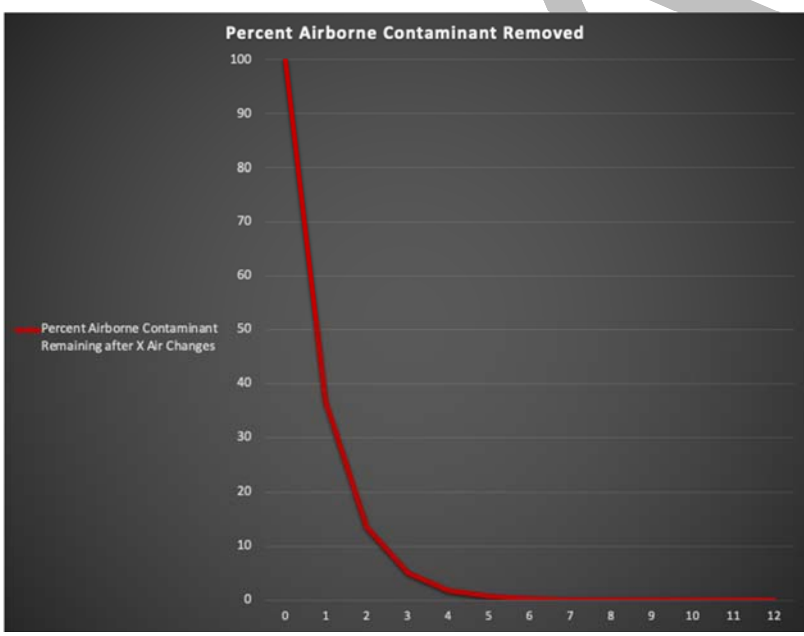
> The building is flushed for a duration sufficient to reduce concentration of airborne infectious particles by 95%. For a well-mixed space, this would require three air changes of building volume based on outside air cfm (or three equivalent air changes including the effect of filtration and air cleaners) (ASHRAE Aug 2020)

Therefore, running HVAC and HEPAs 30 minutes prior to occupancy, and 30 minutes after, should provide sufficient air changes to meet this recommended 3 ACH, assuming HUSD is running at 6 ACH.

While there isn't an agreed upon consensus regarding the appropriate number of air changes for schools, Harvard's Schools for Health, has advocated for between 4-6 air exchanges per hour (ACH). However, worth noting, is that because ACH is an exponential decay function, the law of diminishing returns applies. The biggest reduction in airborne contaminants in a well-mixed room, as seen in the ACH Table, and ACH Graph below, occurs from 0 to 1 ACH, and progressively diminishes as the number of air changes goes up. The difference between 0-1 is ~63%, whereas the difference between 4-5 is 1.1%. Therefore, the most significant gains in COVID mitigation will likely come from ensuring we address those spaces with severely deficient airflow, as opposed to increasing a space from 4 to 6 ACH.

Air Changes	Percent Airborne Contaminant Remaining after X Air Changes
0	100
1	37
2	14
3	5.0
4	1.8
5	0.7
6	0.2
7	0.09
8	0.03
9	0.01
10	0.005
11	0.002
12	0.001

ACH Table



ACH Graph

GENERAL RECOMMENDATIONS

- Fan On, or Fan Occupied Mode: Prior to resuming in-person class instruction, ensure HVAC system is programmed to run when occupied.

Whether this is programming the system with Pelican, or developing an SOP with teachers/custodial staff to manually turn on. If the system is in Fan Auto, and System Auto mode, it will only run when it is not in the "deadband" or "Goldilocks Zone", when the system is calling for heat/cool.

- **Install highest MERV filters:** compatible with existing HVAC systems.

MERV filters can effectively remove aerosol in the respirable fraction, for a reasonable cost. As seen in the table below.

MERV Rating (Based on 52.2-2017)	Filter Droplet Nuclei Efficiency
4	16.80%
5	26.55%
6	32.45%
7	41.13%
8	55.57%
9	62.00%
10	64.65%
11	72.86%
12	83.39%
13	89.93%
14	94.94%
15	96.18%
16	97.40%

Figure 9 https://www.ashrae.org/technical-resources/building-readiness

- **Open Economizers:** to allow for maximal outside fresh air.

- **Preventative Maintenance Plan:** for replacing MERV and HEPA filters, according to manufacturer's recommendations.

Intrinsic would be happy to work with our HVAC Technician to put together a cost effective custom solution to install MERV filters.

- **Confirm Bathroom exhaust fans are operable**.
- **Repair/replace exhaust fans** that are no longer operational.

- **Consider re-measuring airflow** in classrooms once MERV filters are installed
- **Consider CO2 monitors** for classrooms (SF Chronicle)

Conclusion: Respiratory aerosol can remain airborne for hours in stagnant indoor environments, if it is not removed through dilution ventilation or filtration. There is no one control measure that will take our risk of COVID-19 to zero. However, the combination of increasing outside air, installing the highest compatible MERV filtration, ongoing maintenance, and the use of HEPA filters, and encouraging the use of natural sources of dilution ventilation, should provide well in excess of the recommended levels of ventilation for schools. It is essential that HEPA filters be properly maintained, and monitored for when their filters need to be replaced. Prefilters can extend the useful life of a HEPA filter.

While no number of air changes per hour has been established as a standard to be met for mitigating COVID, we do know that <1 ACH is typical of a home environment (EPA). Transmission rates in homes with close contacts has been estimated to be 10 times higher than other contacts. ASHRAE reminds us that 95% of any airborne contaminant in a “well-mixed” space are removed after 3 air changes. Moreover, recent reports indicate “experts” suggest 4-6 ACH to dilute respiratory aerosol (WSJ).

Based upon our assessment and analysis, once HUSD has completed installation of the IQ*Air* CleanZone SL HEPA filters for each planned occupied space, opened economizers to full, installed the highest compatible MERV filtration, and addressed any outstanding ventilation issues, it will be in a position to meet or exceed CDPH, CDC, and Sonoma County guidance for safely reopening schools.

Given how dynamic and unpredictible the pandemic is, it goes without saying, that it is imperative for us to stay in tune with local, County, and State guidance, to ensure a safe return to in-person instruction, when that time comes.

We hope that you find this report helpful in understanding the valuable role ventilation plays in conjunction with a comprehensive Return to School Plan, in keeping Harmony Union School District students, teachers, staff, and community safe as we work together to return to school and work.

David M. Moore, MPH, CIH
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Intrinsic Environment, Health & Safety