FAIRFIELD PUBLIC SCHOOLS

VAN ZELM ENGINEERS

HVAC Systems
Ventilation & Filtration Analysis

FAIRFIELD WARDE HIGH

FAIRFIELD LUDLOWE HIGH

Fairfield Public Schools
Fairfield Warde and Fairfield Ludlowe High Schools

Fairfield, CT

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EXECUTIVE SUMMARY

This study analyzed the existing HVAC systems of each high school and provides a summary of recommendations for revisions to the HVAC system of each building, including references to ventilation requirements for spaces presently without mechanical ventilation, including items that can be easily addressed, items that can be addressed with additional investigation and items that are not practical to be addressed. The analysis of the central air handling systems was in regard to how well these units will prevent the transmission of airborne viruses, particularly COVID-19. The performance of the systems was compared to guidance released by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) on operation of air distribution systems to minimize transmission of airborne contaminants. ASHRAE recommends using air filters with a minimum efficiency reporting value (MERV) of 13 or higher to capture COVID-19 particles in airstreams. They also recommend providing as much outside air as possible to occupied spaces. Additional investigation, including whole-building retro-commissioning is recommended in order to determine if the amount of outside air supplied to occupied spaces meets current Connecticut building code requirements and to make corrections where deemed insufficient.

We do not currently know if the quantities of mechanically supplied outside air meet the minimum ventilation air requirements of the State of Connecticut Building Code, as this would require additional engineering and investigation. Additionally, almost all of the air handling systems surveyed currently have filters rated lower than MERV 13 and should be upgraded. The few MERV13 filters installed, mainly in three units at Fairfield Ludlowe High School, have never been changed. This would be a straightforward replacement as MERV 13 filters will fit into all existing air filter racks in equipment.

From our observations, it appears that all spaces have the capability of being mechanically ventilated based on the installed equipment. However, units that do not operate properly, have excessively clogged filters, or have been abandoned due to lack of functionality leave locations where ventilation is insufficient. The buildings require thorough investigation through whole-building retro-commissioning to help restore them back to better working order.

INTRODUCTION

PROJECT DESCRIPTION

The purpose of this study is to review and analyze the existing ventilation systems throughout the Fairfield Warde and Fairfield Ludlowe High School campuses, evaluate existing conditions regarding ventilation and filtration, and make recommendations for improvements; particularly regarding the prevention of the transmission of airborne viruses, specifically COVID-19 (SARS-CoV-2), via the building HVAC systems.

PROCESS

The following steps were undertaken to complete the study:

1. Obtain and review floor plans of existing HVAC drawings for each school.
2. Undertake field work to observe the condition, operation, and controls of all existing, ventilating HVAC systems. Document condition and any observed operational issues.
3. Meet with Fairfield Public Schools facilities maintenance staff and review any problems, issues, or environmental problems with existing HVAC systems.
4. Review existing industry standards regarding transmission of infectious disease via HVAC systems and recommendations to minimize transmission potential as they relate to observed conditions.
5. Develop and evaluate options to provide the required ventilation air to selected presently unventilated spaces and buildings.
6. Discuss options to improve indoor air quality and minimize potential for transmission of infectious disease including:
    a. Improved filter efficiency
    b. Alternative filtration approaches (bi-polar ionization, electrostatic, etc.)
    c. Increase airflow and/or ventilation rates
    d. Ultraviolet sterilization
    e. Heat recovery applications
    f. Air system equipment and duct cleaning
    g. Air distribution improvements
    h. Control system upgrades and changes to the sequences of operation
7. Review options with Fairfield Public Schools facilities maintenance staff and develop final recommendations.
8. Develop this summary report with findings, conclusions and recommendations

The Fairfield Warde and Fairfield Ludlowe High School buildings were field surveyed to determine currently installed HVAC systems and their condition. A general survey of all building ventilation systems was undertaken, with most detail focused on central air handling units that provide ventilation and temperature control to spaces. These central air handlers provide heating to the buildings, some also provide cooling, and they have the potential risk for spreading airborne contaminants because of the configuration of the systems. Primary heating equipment such as boilers and steam distribution piping were not surveyed, as these do not have the potential to circulate airborne contaminants.

After surveying central air handlers, construction documents detailing the installation of these units were reviewed to verify field observations of areas served. The air filtration effectiveness measured in MERV (Minimum Efficiency Reporting Value) was determined for each unit based on current filtration. The general condition and approximate year of installation were also determined for the units. In some cases, this information was not available.

EXISTING CONDITIONS

BUILDING SYSTEMS

All buildings have some sort of unit capable of providing mechanical ventilation. At Warde, this is almost completely accomplished with rooftop units for each building section. At Ludlowe there are sections of the building served by unit ventilators, which serve only the space they are in, which have outside air ductwork or louvers. Otherwise, all other sections are served by rooftop units, air handling units, or makeup air units.

EVALUATION

INDUSTRY STANDARDS

The supply of outside air to interior occupied spaces is governed by the 2018 Connecticut Building Code, which is based on the 2015 International Mechanical Code. This code prescribes the flow rate of outside air that must be supplied mechanically to occupied areas based on occupancy classifications. Depending on the type of use of a space, outdoor air flow rates in cubic feet per minute (CFM) per person are defined when the number of occupants within a space is known. When total occupants per space are unknown, the code defines occupant density for each classification type in number of occupants per space floor area. The final flow rate in CFM for every occupied space can thus be calculated.

As an alternative to providing outside air mechanically to occupied spaces, the building code also allows for outside air to enter occupied areas naturally through operable windows. If the area of operable windows for an occupied space is at least 4% of the space’s floor area, mechanical ventilation for that space is not required by code. However, although spaces with sufficient operable window area may satisfy code requirements, this is not a realistic way of providing adequate ventilation during periods of cold or hot weather, and this often adversely affects the humidity levels within the building.

The amount of outside air supplied to occupied spaces is important for occupant comfort and health because contaminants generated by people and materials in the space must be removed or they will build up to unhealthy levels. Diluting interior air with outside air reduces the concentration of various airborne contaminants, including viral particles that carry the COVID-19 virus and other viral and bacterial contaminants.

Since the emergence of the COVID-19 virus in December 2019 and the threat it poses to public health, precautions must be taken to prevent the spread of the virus. ASHRAE has been investigating the transmission of COVID-19 through HVAC systems and has made recommendations on how to adapt existing HVAC systems to minimize transmission of COVID-19. On April 14, 2020, they released a document "ASHRAE Position Document on Infectious Aerosols". This report is provided in Appendix 2. ASHRAE also gave a presentation on June 16, 2020 regarding Recommendations and Activities for re-opening schools for the fall 2020 academic semester. ASHRAE's recommendations for reducing the transmission of infectious aerosols through HVAC systems as they apply to schools are as follows:

- Increase outdoor ventilation rates (Dilution); more is better. Follow ASHRAE Standard 62.1 as a minimum, increase where possible.
- Improve filtration rates (Pathogen Reduction); higher efficiency filtration is better.
- Increase air change rates to decrease in-room concentration of infectious particles. Room air change rates should be around 6 ACH where possible.
- Flush or purge building before and after occupancy for at least two (2) hours, if possible.
- Upgrade RTUs and AHUs to operate with a MERV 13, 14, or HEPA filtration.
- Consider installation of UV-C or bi-polar ionization to recirculating air systems.
- Provide humidification to maintain 40% RH during the heating seasons, if possible.
- Provide dehumidification in the summer to maintain room RH below 60%.
- Supplement poorly ventilated areas with portable HEPA filtration units in classrooms.
- Add low return / high supply airflow paths or utilize displacement ventilation where possible.
- Increase restroom exhaust to minimize transmission.
- Perform duct cleaning for existing systems.

GUIDANCE FOR SCHOOL SYSTEMS FOR THE OPERATION OF CENTRAL AND NON-CENTRAL VENTILATION SYSTEMS DURING THE COVID-19 PANDEMIC

The Connecticut Department of Public Health (DPH) has released "Guidance for School Systems for the Operation of Central and non-Central Ventilation Systems which has been included for reference in Appendix 3. Many of the recommendations in this document are in line with what ASHRAE recommends.

We offer the following response to address the questions raised in the DPH guidelines, as they pertain to the Commissioning of the Building Mechanical Systems:

Question 1. How many and what types of systems serve your buildings, and which area of the building does each separate system serve?

Response: Most of the systems that circulate filtered and conditioned air throughout the schools are located upon the roof. Most of these systems provide heating, cooling and outdoor ventilation directly to *the spaces served but a few units provide this through area terminal equipment and then to the spaces being conditioned. A complete field survey was conducted for both high schools and a listing of the systems, their location, and the areas that they serve have been included as part of Appendix 1.This list also includes the filter media sizes, which can be used to assist when implementing the air filtration upgrade.*

Question 2. What are the capabilities of the systems present in your school buildings?

Response: As noted above in the executive summary, it appears that all but a few spaces have the capability of being partially or fully mechanically ventilated with filtered outdoor and recirculated air. The air delivery systems have the ability to vary the amount of outdoor air from a minimum level up to 100% outdoor air as conditions and mechanical heating or cooling capacities allow. Systems are also controlled by a building automation system that can allow monitoring and adjustments to conditioned air being delivered.

Question 3. Are the systems currently working to their full capabilities?

Response: Based on our initial survey and review, many of the air distribution mechanical systems are older and may need additional maintenance, repair or replacement to achieve increased performance and reliability. Current occupancy and area use requirements could be incorporated into a more granular unit-by-unit evaluation as part of a follow-up Retro-Commissioning phase to further verify system performance in meeting current operational needs.

Question 4. Are the current systems' capabilities enough to satisfy full capacity for how the buildings need to operate now?

Response: Systems are typically designed with some cushioning to meet the current building and occupant requirements for heating cooling and ventilation. It is our belief that the systems, if operating as designed, will satisfy full capacity. Furthermore, it is realized that classroom sizes have been decreased, which will result in even greater ability to satisfy new airflow requirements.

Question 5. Can demand-based systems be converted to constant volume until cooling season is over (if systems provide central cooling)? During heating season? Longer-term?

Response: Currently we believe the air distribution systems operate through a building automation system on a scheduled basis that allows constant air flow distribution during occupied periods. The building automation system can allow additional operation prior to or after building occupancy and also has the ability with most systems to vary ventilation air during both occupied and unoccupied periods.

Question 6. Can recirculation of air be suspended (economizers disabled)?

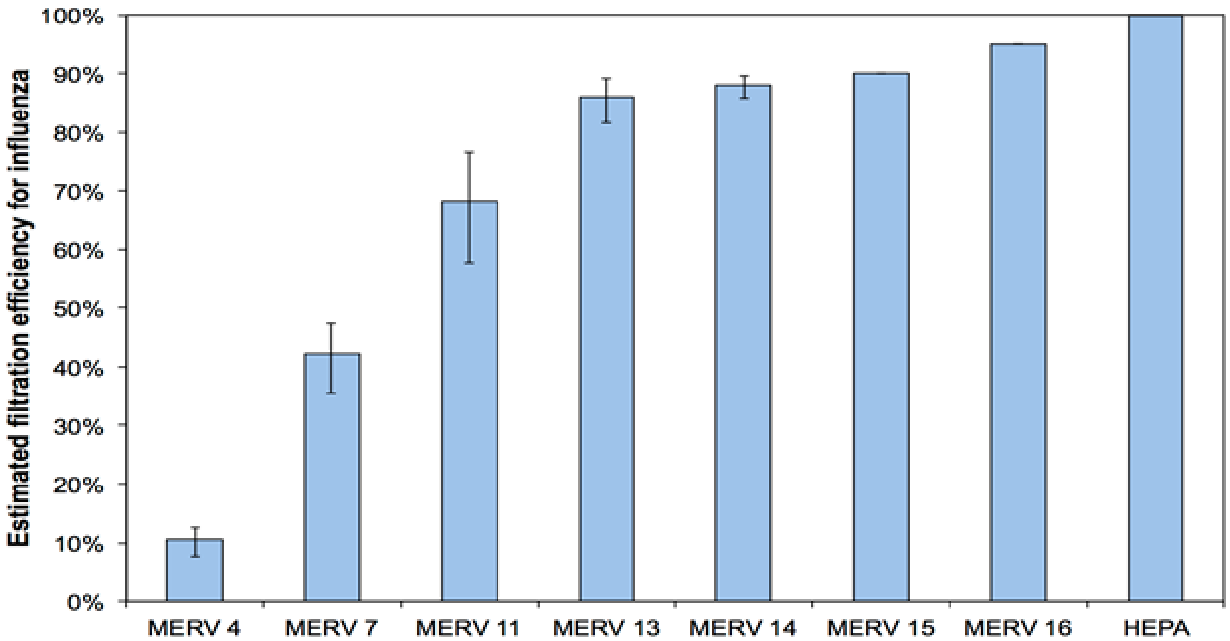
Response: It is not yet clear if recirculation units can be converted to allow for 100% outside air. In many cases, the amount of outside air can, and will be increased but only to the point where the heating or cooling capacity of the coils is not exceeded. This will be determined during the Retro-Commissioning phase where revised unit capacities will be evaluated and recorded.

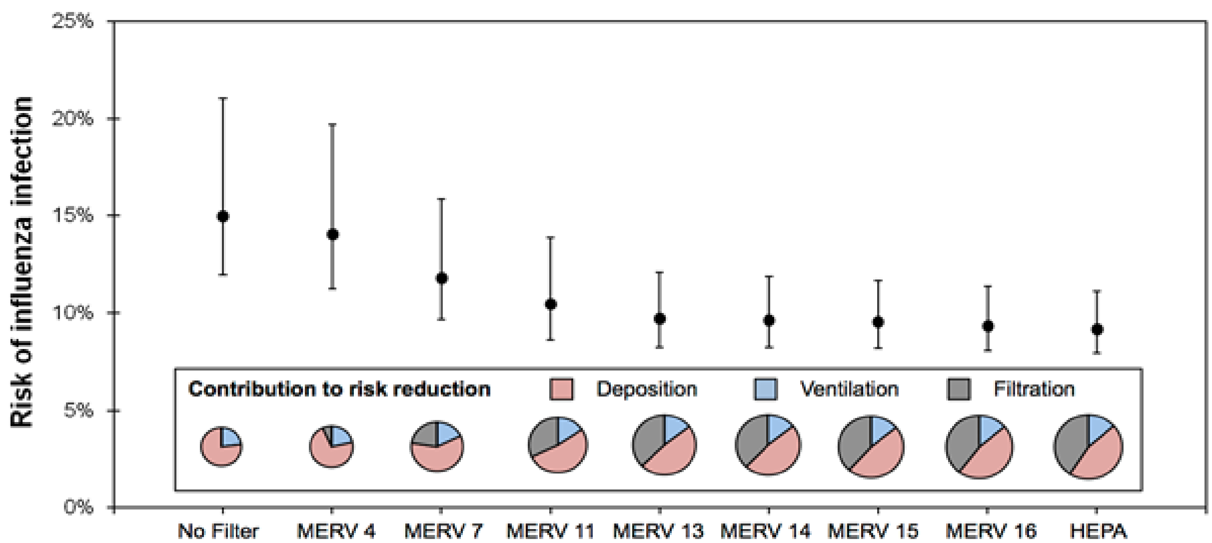
Question 7. Can they provide a summary of performance expectations for mechanical systems in the building?

Response: Mechanical systems within the building will be expected to deliver filtered, conditioned air to all areas of the building to satisfy environmental space conditioning and ventilation needs. With the new guidelines, the expectation is to increase filtration levels to a minimum of MERV 13 and to increase the amount of ventilation air (outside air) to all the spaces from all units. Additional guidelines also recommend if possible, space air exchange rate of 6 air exchanges per hour (ACH), 2 of which should be outdoor ventilation air.

FILTRATION EFFICIENCY TABLES

A recent study by the National Air Filtration Association Foundation tested the filtration efficiency of different filter types on an influenza-like virus. These results are summarized in the two figures below:





GENERAL FINDINGS

VENTILATION

Where possible, code-required mechanical ventilation air flow rates for representative interior occupancy classifications were compared to actual mechanical ventilation as determined during the field visit and from examination of construction or renovation documents for the spaces.

FILTRATION

The Connecticut Building Code requires that heating and air conditioning systems be provided with approved air filters, but the level of filtration effectiveness is not specified. In light of the emergence of COVID-19, ASHRAE is recommending that filters with a minimum effectiveness rating of MERV 13 be used to capture COVID-19 particles in HVAC systems.

RECOMMENDATIONS

Where any building sections are not currently being provided with mechanical ventilation, mainly due to the units meant to serve those sections being abandoned or are in a state of disrepair, we recommend providing small Energy Recovery Ventilators (ERV) with duct mounted hot water heating coils. Energy Recovery Ventilators are packaged heat recovery units with an air to air heat exchanger to recover waste heat from the exhaust air and transfer it to the outside air and supply and exhaust air fans. ERVs require ducted outside and exhaust air to the outside of the building; the inlet and exhaust air openings should be at least 10 feet apart to comply with the Building Code. Depending on the location, general exhaust fan ductwork could be repurposed for these units.

ASHRAE has released numerous recommendations to prevent the spread of COVID-19 particles via HVAC systems since the pandemic began. The following recommendations should be investigated for all existing campus air handler units and implemented as feasible for each unit.

The more outside air that can be supplied to occupied areas, the better. Greater outside airflow rates will reduce concentrations of airborne particles by dilution. Each existing air handler should be investigated to determine if outside air flow rates above current setpoints can be obtained. Even units that currently meet code requirements for ventilation flow rates should be increased if possible, because increased dilution further reduces the risk of transmitting COVID-19 or other harmful particles. Outside air flow rates should be increased until the capacity of the unit to heat or cool the air is exceeded. Space air change rates, the rate of recirculation of room air, should also be increased to the extent possible along with increases in outside air flow to better remove contaminants from the air. This can typically be done by increasing the minimum flow setting on the air damper position commands. Control system sequences should also be altered so that maximum outside air is supplied to spaces two hours before occupancy begins and is kept running for two hours after occupancy ends. This will allow the air in spaces to be purged before and after occupancy to remove airborne contaminants.

Areas that currently have air filtration less than MERV 13 should be brought up to MERV 13 filtration, as this is the minimum filtration effectiveness level that will capture COVID-19 particles, with the exception of air systems delivering 100% outside air. Existing air handlers surveyed were found to be all equipped for a minimum of 2” deep air filters; a few units had additional racks that could fit 4” filters, and some units at Ludlowe also had slots for 12” box or v-cell filters. MERV 13 filters are available in 1”, 2”, 4”, and 12” deep sizes. No air handlers with only 2” or 4” deep filter racks currently contain MERV 13 filters and the units with larger box filters, while rated MERV 13, have not had those filters changed for many years (e.g. RTU-5’s were last changed in January of 2016). Units with less than 100% outside air should be retrofitted with MERV 13 filters. After retrofit, these filters should be checked frequently as it is likely filters will become loaded more quickly than currently installed filters. Prefilter material with lower filtration effectiveness should be added to these units upstream of the MERV 13 filters to prevent the MERV 13 filters from loading too quickly. Some units equipped with 4” deep filter racks already contain 2” prefilters, though both filter sizes in this case are rated MERV 8. For these units, the 4” deep filters should be replaced with MERV 13 if not already present, and lower effectiveness prefilters should be kept, as these are typically MERV 8. It is understood that a third-party company performs the filter changes for both schools. Any changes to the filtration requirements of the units should be discussed with that company to ensure that they perform what is needed. The status of the filters varies widely throughout both schools, based on occupancy, activities, unit operation, and change frequency; some unit filters have become so loaded that they have collapsed and are allowing unfiltered air into the building. While these updated filtration arrangements are established, it is important to at least keep up with the MERV 8 filter changes to maintain indoor air quality levels as high as possible.

Once units have been upgraded with MERV 13 filtration, each unit should be investigated to determine if total system air flow rates can be increased. Total flow rates should be increased to the extent the units can handle while still maintaining thermal comfort. ASHRAE recommends flow rates that yield approximately six air changes per hour. Higher system flow rates will remove airborne contaminants from occupied areas more quickly, and with MERV 13 filtration present, COVID-19 particles will be captured within the filters.

Supplemental air cleaning technology, such as ultraviolet-C (UV-C) light or bi-polar ionization, is available could be considered if additional disinfection measures are desired. UV-C is short wavelength ultraviolet light that has been found to effectively kill COVID-19 particles. UV-C systems are already in use in HVAC systems where they are installed in air streams to kill bacteria and other harmful living organisms. These systems can be installed relatively easily in already constructed system ductwork or air handlers without taking up extensive space. Bi-polar ionization systems are also installed in ductwork or air handlers and use an electric charge to create a concentration of positively and negatively charged particles in an airstream. These particles cause pathogens to stick to each other and become larger, thus increasing the probability of them being captured by air filters. The charged particles created also leave the ductwork and remain charged when they enter occupied spaces. If the particles come in contact with pathogens in the occupied space, the charge removes hydrogen from the pathogen so that it is no longer able to sustain itself. For this reason, bi-polar ionization is preferred to UV-C air cleaning because bi-polar ionization has the ability to decontaminate pathogens outside of the ductwork whereas UV-C only decontaminates pathogens that enter the ducts.

ASHRAE recommends relative humidity values between 40 and 65% as these values have been shown to hamper the ability of COVID-19 to travel. When cooling systems are in operation, ensure dehumidification is adequate to keep relative humidity below 65%. During heating system operation, relative humidity values are typically less than 40%. Adding humidification to the existing HVAC systems would be very difficult and costly; additionally, humidification for HVAC systems can be problematic if not well maintained and adds to operating costs. For this reason, recommendations discussed above should be enacted before humidification is considered.

In order to best confirm that the implementation of the above recommendations is met as well as other improvements, we recommend performing retro-commissioning of each high school. This is an extensive procedure that will help with fully documenting the building systems, their capabilities, and optimizes the control system to maintain the best performance while conserving the most energy. In general, retro-commissioning should be performed approximately once every five years to keep the buildings operating smoothly.

Additional specific recommendations are discussed below:

Control System Recommendations

- Automated Logic Corporation (ALC) has been performing structural upgrades to the control systems at select public schools throughout Fairfield. The first of these schools was Warde High School, which they have completed already. Ludlowe High School is in progress at the time of writing this report. Their work, while it does not alter sequences of operation, should make the process of adjusting parameters easier for future work. Without retro-commissioning the building, it is not possible to tell exactly how much of the control system needs adjustments, but a cursory review of what was available indicates great need.
- Look to program units to provide a pre and post occupancy purge for all occupied spaces.
- Increase airflow to each space.
- Increase OA % for each unit, where available.

Air Handling Unit Upgrade Recommendations

For any unit that operates only with 100% outside air (e.g. makeup air units, dedicated outside air units, etc.) MERV 8 filters can continue to be used. Most units, however, allow for some amount of recirculation, so the following are recommendations for upgrading the air handling units:

- Where any unit can only provide 100% outside air, the filters can continue to be MERV 8. For any of these units, should they need to be replaced, we recommend considering a unit with energy recovery (either a wheel or cross-flow heat exchanger). This will conserve energy and will allow for systems to operate with more outside air.
- Where any unit only has room for a 2” filter, upgrade the air filters to 2” MERV 13.
- Where any unit only has room for a 4” filter, upgrade the air filters to 4” MERV 13. If there is any room in front of the MERV 13 filters to include a 2” pre-filter rack, for it to then be installed for MERV 8 filters to pre-filter.
- Where any unit has a two filter racks where the first has room for 2” filters and the second has room for 4” or greater filters, the 2” filters can remain as MERV 8 for pre-filtering, but the larger filters should be upgraded to MERV 13.
- All existing MERV 13 filters should be replaced with the new filters of the same style. None of the currently installed MERV 13 filters are in acceptable condition.
- After a building-wide filter change, filter changes should be performed more frequently. The party responsible for changing the filters should note which unit filters become dirty quicker and should further increase the frequency of changes to those units.
- Consider adding Bi-polar ionization or another means of air disinfection wherever possible.

- Consider investigating the potential of increasing the ventilation air flow rate wherever possible.
- For any defunct units or disabled units needing serious repair or replacement, consider replacing with a unit that has energy recovery (either a wheel or cross-flow heat exchanger).
- Appendix 4 has our field survey findings. We recommend that all of the items noted within that section are addressed by the facilities personnel. While this is not a substitute for a proper building retro-commissioning service, these corrections are the low-hanging fruit that will quickly improve indoor air quality and energy consumption rates. Some typical issues include, but are not limited to:
    - Cleaning all unit coils: steam coils, DX refrigerant evaporator and condenser coils. Some are in worse shape than others. Cleaning the coils will improve airflow patterns through the coil, increasing coil effectiveness and preventing deterioration due to rust or corrosion.
    - Coil Fin Straightening: All unit coils should be combed to straighten the fins. This will improve coil performance and reduce the accumulation of dirt/debris on the coil that makes its way past the filters. Once the fins are straight, they should not become damaged again unless care is not taken during filter changes or subsequent coil cleaning. Coils with significant damage might not be able to be combed and could require replacement.
    - Damper Grease: All unit dampers should be greased and tested throughout their movement range. As dampers age, grease falls away and dirt builds up causing the actuator to need to push harder to move the damper. Too much build-up can result in burnt-out actuators or broken linkages, which would need to be replaced.
    - Condensate Trap Heights: All condensate trap heights should be reviewed. Any unit with water pooling in the condensate pan while the unit is running likely has an incorrectly installed trap. Further detail on this can be found in appendix 4.
    - Exterior Insulation: ductwork and piping should have UV-resistant coating or shields. Typically, foil-faced aluminum insulation or banded aluminum jacketing worse for this. For exposed refrigerant piping, these should be reinsulated with elastomeric insulation and coated with a UV-resistant paint. This will prevent deterioration from the sun and avoid costly repairs since almost all air handling and refrigerant equipment is located on the rooves.
    - General Unit Cleanliness: All units should be cleaned and vacuumed out to remove any dirt or debris that has accumulated. Some units have papers, cardboard, and other materials within that can become a breeding ground for bacteria and molds should those materials become wet. Sections of units that have developed rust or corrosion should be kept dry and cleaned with appropriate chemicals for removing the build-up. It is difficult to successfully repair a unit with a compromised casing.
    - Fan Belt Tension: All fen belts should be reviewed for fit. Some motors might need to be repositioned in the unit to fix the tension or adjust for alignment. Consider installing belt tensioners where possible to extend intervals between belt changes without compromising on unit efficiency as the belt wears out.

CONCLUSIONS

This study found that most existing Fairfield Warde and Fairfield Ludlowe High School central air handling systems contain air filters below the MERV 13 minimum that ASHRAE recommends capturing airborne COVID-19 and other contaminants, and the MERV 13 filters that are installed are in bad condition and require immediate replacement. Filters in all units can easily be replaced with MERV 13 filters and should be upgraded as they become available.

We do not currently know if all of the existing central air handling unit systems surveyed meet the minimum ventilation air requirements of the State of Connecticut Building Code based on their current operation. We highly recommend further evaluation should be performed on the ventilation aspect including whole-building retro-commissioning and engineered ventilation calculations to determine compliance and to bring the systems back up to better working order.

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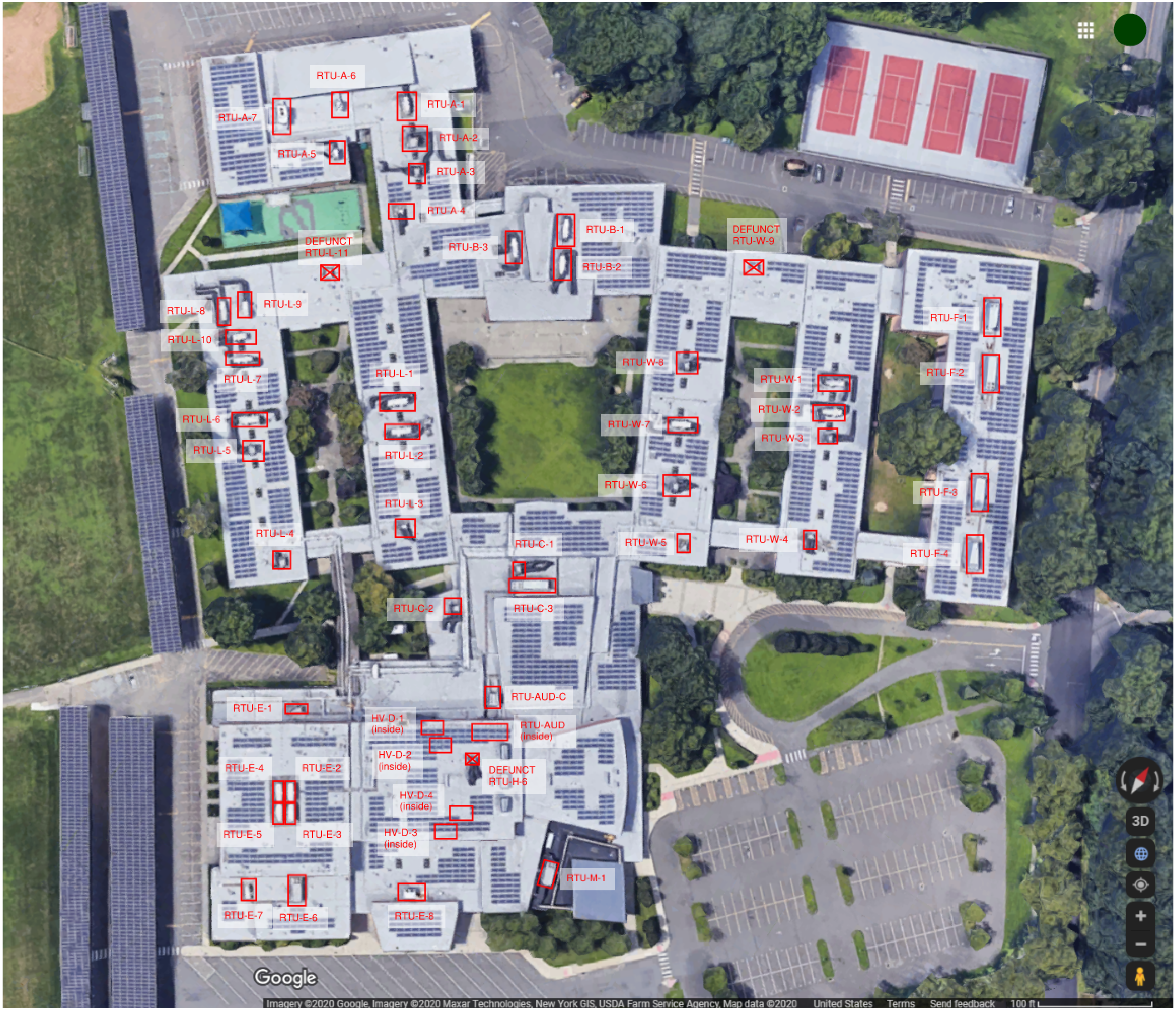
VANZELM ENGINEERS

APPENDIX 1

Air Handling Unit List

Note: All filters at Fairfield Warde High School are MERV 8

Survey ID	School	Tag	Make	Model	Serial	Filters	CFM	Location	Serving	Notes
20	Warde	RTU-A-1	York	CP 125 FC 5 0 460	AGNM 014467	4-24x24x2, 4-12x24x2	6000	Roof-A	Wood Shop	
19	Warde	RTU-A-2	York	DH180C00B4DJD2A	NGNM085283	2-24x24x2, 2-18x25x2	7000	Roof-A	Computer Repair	
18	Warde	RTU-A-3	York	DH078C00N4DAG3C	NFNM079333	4-20x25x2	2500	Roof-A	Graphic Arts	
17	Warde	RTU-A-4	York	D1EE048A46ECC	NDJM045267	2-15x20x2, 1-14x25x2 w/ 5" plate	1430	Roof-A	Nursery	
23	Warde	RTU-A-5	AAON	RM-006-2-0-AA01-CHH	200308-AMSF00021	4-16x20x4	2500	Roof-A	Black Box Theater	"RTU-A-2"
21	Warde	RTU-A-6	AAON	RK-15-3-00-640	200308-AKSL00294	6-16x20x4	6000	Roof-A	Tech Ed	"RTU-A-3"
22	Warde	RTU-A-7	AAON	RK-40-3-E0-640	200308-AKST00295	10-20x25x4	16000	Roof-A	Early Childhood Center	"RTU-A-1"
2	Warde	RTU-B-1	York	CP 65 FC 1 1 460	AGNM 014468	2-24x24x2, 2-12x24x2	1400	Roof-B	Servery	
3	Warde	RTU-B-2	York	CP 65 FC 5 5 460	AGNM 014469	2-24x24x2, 2-12x24x2	3500	Roof-B	Student Commons	
1	Warde	RTU-B-3	York	CP 65 FC 1-1/2 1 460	AGNM 014470	2-24x24x2, 2-12x24x2	2000	Roof-B	Faculty Lounge	
35	Warde	RTU-C-1	York	DH090C00S4DJD3C	NFNM081594	4-20x25x2	1950	Roof-C	Main Office	
37	Warde	RTU-C-2	York	DH07C00E4DJC3C	NFNM080730	4-20x25x2	3000	Roof-C	Health Center	
36	Warde	RTU-C-3	Trane	SSHLF40E5R46	C17E03454	6-24x24x2, 5-12x24x2, 6-24x24x4, 5-12x24x4	10000	Roof-C	Media Center	Model Cont.: #7BE8C0100CE0V0BA002Z0M8000#
38	Warde	RTU-E-1	York	CP 65 FC 3 0 460	AGNM 014471	2-24x24x2, 2-12x24x2	2700	Roof-D	Girls Locker Large Gym	
39	Warde	RTU-E-2	York	CP 170 DWDI AF 20 0 460	AGNM 014478	4-24x24x2	10000	Roof-D	Large Gym	
40	Warde	RTU-E-3	York	CP 170 DWDI AF 20 0 460	AGNM 014479	4-24x24x2	10000	Roof-D	Large Gym	
41	Warde	RTU-E-4	York	CP 170 DWDI AF 20 0 460	AGNM 014480	4-24x24x2	10000	Roof-D	Large Gym	
42	Warde	RTU-E-5	York	CP 170 DWDI AF 20 0 460	AGNM 014481	4-24x24x2	10000	Roof-D	Large Gym	
51	Warde	RTU-E-6	York	CP 215		4-16x25x2, 6-20x25x2	10800	Roof-E	Fitness	
52	Warde	RTU-E-7	York	CP 65 FC 1-1/2 0 460	AGNM 014472	2-24x24x2, 2-12x24x2	1500	Roof-L	Coaches	
50	Warde	RTU-E-8	AAON	RM-020-8-0-AA02-CJK	200809-AMSP00288	6-20x25x2		Roof-E	Orchestra	
13	Warde	RTU-F-1	Trane	SSHCC406HJ45A69D1C01RTX5A	J90B70533	16-20x20x2	10000	Roof-F	Classrooms Fitts North	
14	Warde	RTU-F-2	Trane	SSHCC406HJ45A69D1C01RTX5A	J90B70535	16-20x20x2	10000	Roof-F	Classrooms Fitts North	
15	Warde	RTU-F-3	Trane	SSHLF40E5S44	C19E03448	16-20x20x2	10000	Roof-F	Classrooms Fitts South	Model Cont.: A59EC00100CE0V00A002W0M8000#
16	Warde	RTU-F-4	Trane	SSHCC406HJ45A69D1C01RTX5A	J90B70532	16-20x20x2	10000	Roof-F	Classrooms Fitts South	
43	Warde	RTU-H-6	Trane					Roof-H	Auditorium	Defunct/Abandoned in place
32	Warde	RTU-L-1	York	CP 85 FC 7-1/2 5 460	AGNM 014473	4-24x24x2	5000	Roof-L	Classrooms	
33	Warde	RTU-L-2	York	CP 85 FC 7-1/2 5 460	AGNM 014474	4-24x24x2	5000	Roof-L	Classrooms	
34	Warde	RTU-L-3	York	DH078C00S4DJC3	N0C5711026	4-20x25x2	1950	Roof-L	Career Center	
31	Warde	RTU-L-4	York	DH102C00S4DJD3C	NENM052972	4-20x25x2	3000	Roof-L	Pequot Offices/Guidance	
30	Warde	RTU-L-5	York	DH078C00S4DJD3C	NENM052939	4-20x25x2	2000	Roof-L	Computer Lab	
29	Warde	RTU-L-6	York	CP 85 FC 7-1/2 5 460	AGNM 014460	4-24x24x2	4400	Roof-L	Classrooms	
28	Warde	RTU-L-7	York	CP 65 FC 3 3 460	AGNM 014461	2-24x24x2, 2-12x24x2	3000	Roof-L	Classrooms	
26	Warde	RTU-L-8	York	CP 65 FC 1-1/2 1 460	AGNM 014462	2-24x24x2, 2-12x24x2	1950	Roof-L	Kitchen	
25	Warde	RTU-L-9	York	CP 125 FC 5 0 460	AGNM 014463	4-24x24x2, 4-12x24x2	6000	Roof-L	Barlowes Restaurant	
27	Warde	RTU-L-10	York	CP 85 FC 5 0 460	AGNM 014464	4-24x24x2	4200	Roof-L	Classrooms	
24	Warde	RTU-L-11	MagicAire					Roof-L	Classrooms	Defunct/Abandoned in place
49	Warde	RTU-M-1	York	Y22AX14Q9KBSBI	N0E5194118	6-20x25x2, 4-16x25x2		Roof-M	Music Education	
12	Warde	RTU-W-1	York	CP 65 FC 3 3 460	AGNM 014475	2-24x24x2, 2-12x24x2	3000	Roof-W	Classrooms	
11	Warde	RTU-W-2	York	CP 85 FC 7-1/2 7-1/2 460	AGNM 014476	4-24x24x2	4200	Roof-W	Classrooms	
10	Warde	RTU-W-3	York	DH078C00E4DJC3C	NFNM080729	4-20x25x2	2000	Roof-W	Comp. Labs	
9	Warde	RTU-W-4	York	DH102C00S4DJC3C	NFNM080767	4-20x25x2	3000	Roof-W	Townsend Offices/Guidance	
8	Warde	RTU-W-5	York	D1EE048A46EBD	NFNM082198	2-15x20x2, 1-14x25x2 w/ 5" plate	1200	Roof-W	Security	
7	Warde	RTU-W-6	York	DH102C00S4DAG3C	NFNM080095	4-20x25x2	3000	Roof-W	Social Work/Counseling	
6	Warde	RTU-W-7	York	CP 85 DWDI A5 7-1/2 5 460	AGNM 014477	4-24x24x2	5000	Roof-W	Classrooms	
5	Warde	RTU-W-8	York	DH078C00E4DAG3C	NFNM079332	4-20x25x2	2000	Roof-W	Special Ed	
4	Warde	RTU-W-9	MagicAire					Roof-W	Classrooms	Defunct/Abandoned in place
44	Warde	HV-D-1	McQuay	CAH006FHAM	FBOU040700547	2-24x24x2		SG MER N	Girls Locker Small Gym	
45	Warde	HV-D-2	McQuay	CAH018FVAM	FBOU040700541	4-20x24x2, 4-12x24x2		SG MER N	Small Gym North	
46	Warde	RTU-AUD	Trane	CSAA030UAC00	K12E53712	3-12x24x4, 2-16x20x4, 6-20x24x4		SG MER N	Auditorium	
46.5	Warde	RTU-AUD-C	Trane	RAUJC60EBC0300DF00000	C12E03668	N/A	N/A	Roof-C	RTU-AUD	Condensing Unit for RTU-AUD
47	Warde	HV-D-3	McQuay	CAH006FHAM	FBOU040700549	2-24x24x2		SG MER S	Boys Locker Small Gym	
48	Warde	HV-D-4	McQuay	CAC030FHAM	FBOU040700548	4-20x24x2, 4-12x24x2		SG MER S	Small Gym South	


RTU-A-6
RTU-A-7
RTU-A-1
RTU-A-2
RTU-A-5
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RTU-A-4
DEFUNCT RTU-L-11
RTU-B-3
RTU-B-1
RTU-B-2
DEFUNCT RTU-W-9
RTU-L-8
RTU-L-9
RTU-L-10
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RTU-F-4
RTU-C-1
RTU-C-2
RTU-C-3
RTU-AUD-C
RTU-E-1
HV-D-1 (inside)
RTU-AUD (inside)
HV-D-2 (inside)
DEFUNCT RTU-H-6
RTU-E-4
RTU-E-2
HV-D-4 (inside)
RTU-E-5
RTU-E-3
HV-D-3 (inside)
RTU-M-1
RTU-E-7
RTU-E-6
RTU-E-8
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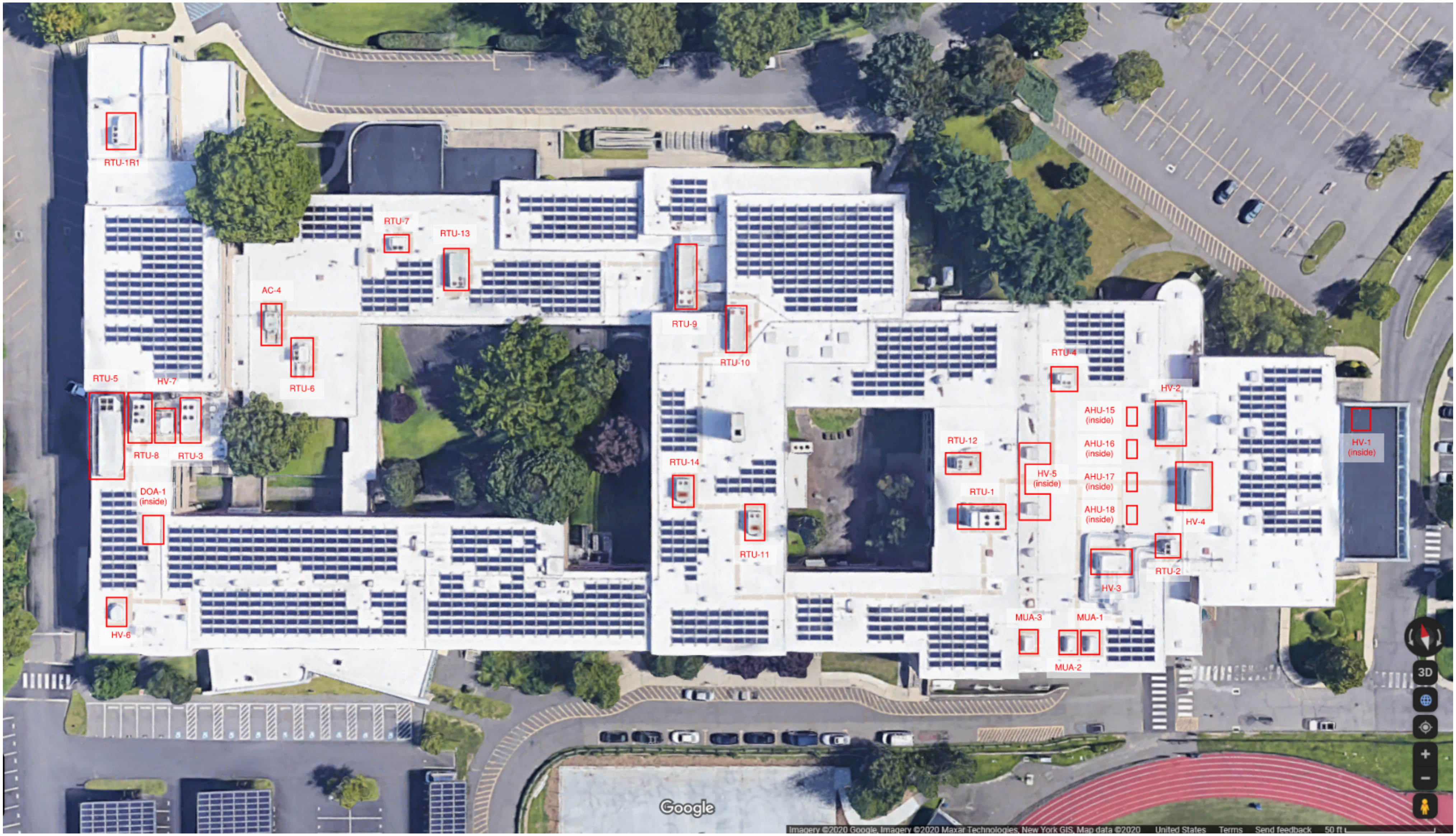
Note: All filters at Fairfield Ludlowe High School are MERV 8 except where indicated with "(13)" after the filter size

Survey ID	School	Tag	Make	Model	Serial	Filters	CFM	Location	Serving	Notes
20	Ludlowe	HV-1	AAON	V2-D2-2-00-100	200312-CBSD00117	9-16x20x2	6500	003 Storage	Art Rooms	
13	Ludlowe	HV-2	AAON	RN-026-3-0-0000-CHM	200402-ANSS00004	OA: 4-24x24x4, SA: 8-24x24x2, 8-24x24x4	11200	Roof	Phys. Ed	
10	Ludlowe	HV-3	AAON	RN-026-3-0-0000-CHH	200401-ANSS00005	8-24x24x2, 8-24x24x4	11500	Roof	Auto Shop	
12	Ludlowe	HV-4	Temtrol	ITF-RHV61	U101099-001-00	12-24x24x2, 7-24x12x2, 12-24x24x4, 7-24x12x4	31000	Roof	Main Gym	
31	Ludlowe	HV-5	Trane	CLCH50			23000	Aux. Gym	Aux. Gym	Could not access the units (duplex setup, suspended from ceiling)
1	Ludlowe	HV-6	AAON	RM-008-3-0-A402-CJH	200401-AMSH00032	6-16x20x4	4500	Roof	Kitchen	
5	Ludlowe	HV-7	AAON	RM-008-3-0-0000-CJM	200402-AMSH00033	6-16x20x4	3700	Roof	Food Lab	
9	Ludlowe	MUA-1	AAON	RK-02-2-00-640	200308-AKSA00290	4-16x20x2	1000	Roof	Biolab 200	
8	Ludlowe	MUA-2	AAON	RK-02-2-00-640	200308-AKSA00291	4-16x20x2	1000	Roof	Biolab 202	
7	Ludlowe	MUA-3	AAON	RK-02-2-00-640	200308-AKSA00292	4-16x20x2	1000	Roof	Biolab 205	
24	Ludlowe	AHU-15	Trane		K98C20037	4-16x20x2	5000	003 MER	Offices	
23	Ludlowe	AHU-16	Trane	MCCA006	K98C20040	4-16x20x2	5000	003 MER	Band	Model Cont.: GAT0AAA000C0CCA00B0A0000AE000B000000A0
22	Ludlowe	AHU-17	Trane	MCCA008	K98C20076	4-20x20x2	5000	003 MER	Orchestra	Model Cont.: GAT0AAB000D0CCA00B0A0000BE000B000000A0
21	Ludlowe	AHU-18	Trane	MCCA012	K98C20842	6-20x20x2	5000	003 MER	Choral	Model Cont.: MAG0B0B0A00AA000000
30	Ludlowe	AC-4	Trane	TSD150G3R0A0R0000000	190910574D		4500	Roof	Reading	
15	Ludlowe	RTU-1	AAON	RN-026-3-0-AB02-CHM	200402-ANSS00006	8-24x24x2, 8-24x24x4	10400	Roof	Graphics	
11	Ludlowe	RTU-2	AAON	RM-015-3-0-AB02-CJH	200401-AMSL00034	6-16x20x4	6000	Roof	Group Exercise	
3	Ludlowe	RTU-3	AAON	RN-040-3-0-AA02-CHM	200402-ANSV00007	8-24x24x2, 8-24x24x4	16400	Roof	Classrooms	
14	Ludlowe	RTU-4	AAON	RM-007-3-0-AB01-CJH	200402-AMSG00037	4-16x20x4	2800	Roof	Theater	
4	Ludlowe	RTU-5	AAON	RL-095-3-0-0B04-CAH	200402-BLSJ00012	16-24x24x2, 16-24x24x12(13)	35000	Roof	Webster Hall	
29	Ludlowe	RTU-6	AAON	RM-013-3-0-AA02-CJH	200401-AMSK00035	6-16x24x4	5200	Roof	Admin/Faculty	
28	Ludlowe	RTU-7	AAON	RM-013-3-0-AA02-CJH	200401-AMSK00036	6-16x24x4	5200	Roof	Lecture Hall	
2	Ludlowe	RTU-8	AAON	RN-070-3-0-AA04-CHH	200401-ANSY00008	12-24x24x2, 12-24x24x4	28000	Roof	Webster Hall	
26	Ludlowe	RTU-9	McQuay	RPS040CLS	FBOU040601545 02	4-12x24x2, 4-24x24x2, 4-12x24x12(13), 4-24x24x12(13)	16000	Roof	Auditorium	
25	Ludlowe	RTU-10	McQuay	RPS018CSS	FBOU040601551 00	4-12x24x2, 4-24x24x2, 4-12x24x12(13), 4-24x24x12(13)	7200	Roof	Main Office	
17	Ludlowe	RTU-11	Trane	TCD211C300AA	N06100562D	4-20x20x2, 4-20x25x2	7000	Roof	Science Lab	
16	Ludlowe	RTU-12	Trane	TCD151C300AA	N06100558D	6-20x20x2	5000	Roof	Computer Lab	
27	Ludlowe	RTU-13	Trane	TCD330AE0C2A1CD1D	J98B90350	16-16x20x2	11000	Roof	Media Center	"RTU-3 Existing"
18	Ludlowe	RTU-14	Trane	TCD211C300AA	N06100561D	4-20x20x2, 4-20x25x2	7000	Roof	Career Center	"RTU-2 Existing"
6	Ludlowe	RTU-1R1	Trane	RN-025-3-0-EB09-389	201504-BNGR44289	OA: 6-16x20x2, SA: 6-20x25x2, 6-20x25x4		Roof	Science Labs	ERW w/ bypass, Possibly listed as "AHU-20" in BAS, NG Heat
19	Ludlowe	DOA-1	Daikin		FBOU150602296	2-12x24x2, 6-24x24x2, 2-12x24x12(13), 6-24x24x12(13)		140 MER	Cafeteria	
N/A	Ludlowe	AHU-20							Science Lab	BAS lists this unit: Could not locate, Possibly RTU-1R1
N/A	Ludlowe	AHU-24							Lab 409	BAS lists this unit: Could not locate
N/A	Ludlowe	AHU-25							Lab 549	BAS lists this unit: Could not locate
N/A	Ludlowe	AHU-26							Lab 554	BAS lists this unit: Could not locate


RTU-1R1
RTU-7
RTU-13
AC-4
RTU-9
RTU-10
RTU-6
RTU-4
RTU-5
HV-7
HV-2
AHU-15
(inside)
AHU-16
(inside)
HV-1
(inside)
RTU-8
RTU-3
RTU-12
HV-5
(inside)
AHU-17
(inside)
RTU-14
RTU-1
AHU-18
(inside)
DOA-1
(inside)
HV-4
RTU-11
RTU-2
HV-3
HV-6
MUA-3
MUA-1
MUA-2
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APPENDIX 2

ASHRAE Position Statement on Infectious Aerosols

ASHRAE Position Document on Infectious Aerosols

Approved by ASHRAE Board of Directors
April 14, 2020

Expires
April 14, 2023

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404-636-8400 • fax: 404-321-5478 • www.ashrae.org

COMMITTEE ROSTERS

The ASHRAE Position Document on Infectious Aerosols was developed by the Society's Environmental Health Position Document Committee formed on April 24, 2017, with Erica Stewart as its chair.

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HISTORY OF REVISION/REAFFIRMATION/WITHDRAWAL DATES

The following summarizes this document's revision, reaffirmation, and withdrawal dates:

6/24/2009—BOD approves Position Document titled *Airborne Infectious Diseases*

1/25/2012—Technology Council approves reaffirmation of Position Document titled *Airborne Infectious Diseases*

1/19/2014—BOD approves revised Position Document titled *Airborne Infectious Diseases*

1/31/2017—Technology Council approves reaffirmation of Position Document titled *Airborne Infectious Diseases*

2/5/2020—Technology Council approves reaffirmation of Position Document titled *Airborne Infectious Diseases*

4/14/2020—BOD approves revised Position Document titled *Infectious Aerosols*

Note: ASHRAE's Technology Council and the cognizant committee recommend revision, reaffirmation, or withdrawal every 30 months.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

CONTENTS

ASHRAE Position Document on Infectious Aerosols

ABSTRACT

The pathogens that cause infectious diseases are spread from a primary host to secondary hosts via several different routes. Some diseases are known to spread by infectious aerosols; for other diseases, the route of transmission is uncertain. The risk of pathogen spread, and therefore the number of people exposed, can be affected both positively and negatively by the airflow patterns in a space and by heating, ventilating, and air-conditioning (HVAC) and local exhaust ventilation (LEV) systems. ASHRAE is the global leader and foremost source of technical and educational information on the design, installation, operation, and maintenance of these systems. Although the principles discussed in this position document apply primarily to buildings, they may also be applicable to other occupancies, such as planes, trains, and automobiles.

ASHRAE will continue to support research that advances the knowledge base of indoor air-management strategies aimed to reduce occupant exposure to infectious aerosols. Chief among these ventilation-related strategies are dilution, airflow patterns, pressurization, temperature and humidity distribution and control, filtration, and other strategies such as ultraviolet germicidal irradiation (UVGI). While the exact level of ventilation effectiveness varies with local conditions and the pathogens involved, ASHRAE believes that these techniques, when properly applied, can reduce the risk of transmission of infectious diseases through aerosols.

To better specify the levels of certainty behind ASHRAE's policy positions stated herein, we have chosen to adopt the Agency for Healthcare Research and Quality (AHRQ) rubric for expressing the scientific certainty behind our recommendations (Burns et al. 2011). These levels of certainty, as adapted for this position document, are as follows:

Evidence Level	Description
A	Strongly recommend; good evidence
B	Recommend; at least fair evidence
C	No recommendation for or against; balance of benefits and harms too close to justify a recommendation
D	Recommend against; fair evidence is ineffective or the harm outweighs the benefit
E	Evidence is insufficient to recommend for or against routinely; evidence is lacking or of poor quality; benefits and harms cannot be determined

ASHRAE's position is that facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice. ANSI/ASHRAE Standards 62.1 and 62.2 (ASHRAE 2019a, 2019b) include requirements for outdoor air ventilation in most residential and nonresidential spaces, and ANSI/ASHRAE/ASHE Standard 170 (ASHRAE 2017a) covers both outdoor and total air ventilation in healthcare facilities. Based on risk assessments or owner project requirements, designers of new and existing facilities could go beyond the minimum requirements of these standards, using techniques covered in various ASHRAE publications, including the ASHRAE Handbook volumes, Research Project final reports, papers and articles, and design guides, to be even better prepared to control the dissemination of infectious aerosols.

EXECUTIVE SUMMARY

With infectious diseases transmitted through aerosols, HVAC systems can have a major effect on the transmission from the primary host to secondary hosts. Decreasing exposure of secondary hosts is an important step in curtailing the spread of infectious diseases.

Designers of mechanical systems should be aware that ventilation is not capable of addressing all aspects of infection control. HVAC systems,[1] however, do impact the distribution and bio-burden of infectious aerosols. Small aerosols may persist in the breathing zone, available for inhalation directly into the upper and lower respiratory tracts or for settling onto surfaces, where they can be indirectly transmitted by resuspension or fomite[2] contact.

Infectious aerosols can pose an exposure risk, regardless of whether a disease is classically defined as an "airborne infectious disease." This position document covers strategies through which HVAC systems modulate aerosol[3] distribution and can therefore increase or decrease exposure to infectious droplets,[4] droplet nuclei,[5] surfaces, and intermediary fomites[6] in a variety of environments.

This position document provides recommendations on the following:

- The design, installation, and operation of heating, ventilating, and air-conditioning (HVAC) systems, including air-cleaning, and local exhaust ventilation (LEV) systems, to decrease the risk of infection transmission.
- Non-HVAC control strategies to decrease disease risk.
- Strategies to support facilities management for both everyday operation and emergencies.

Infectious diseases can be controlled by interrupting the transmission routes used by a pathogen. HVAC professionals play an important role in protecting building occupants by interrupting the indoor dissemination of infectious aerosols with HVAC and LEV systems.

COVID-19 Statements

Separate from the approval of this position document, ASHRAE's Executive Committee and Epidemic Task Force approved the following statements specific to the ongoing response to the COVID-19 pandemic. The two statements are appended here due to the unique relationship between the statements and the protective design strategies discussed in this position document:

Statement on airborne transmission of SARS-CoV-2: Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.

Statement on operation of heating, ventilating, and air-conditioning systems to reduce SARS-CoV-2 transmission: Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus

[1] Different HVAC systems are described in *ASHRAE Handbook—HVAC Systems and Equipment* (ASHRAE 2020).
[2] An object (such as a dish or a doorknob) that may be contaminated with infectious organisms and serve in their transmission.
[3] An aerosol is a system of liquid or solid particles uniformly distributed in a finely divided state through a gas, usually air. They are small and buoyant enough to behave much like a gas.
[4] In this document, *droplets* are understood to be large enough to fall to a surface in 3–7 ft (1–2 m) and thus not become aerosols.
[5] Droplet nuclei are formed from droplets that become less massive by evaporation and thus may become aerosols.
[6] Fomite transmission is a form of indirect contact that occurs through touching a contaminated inanimate object such as a doorknob, bed rail, television remote, or bathroom surface.

the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus.

1. THE ISSUE

The potential for airborne dissemination of infectious pathogens is widely recognized, although there remains uncertainty about the relative importance of the various disease transmission routes, such as airborne, droplet, direct or indirect contact, and multimodal (a combination of mechanisms). Transmission of disease varies by pathogen infectivity, reservoirs, routes, and secondary host susceptibility (Roy and Milton 2004; Shaman and Kohn 2009; Li 2011). The variable most relevant for HVAC design and control is disrupting the transmission pathways of infectious aerosols.

Infection control professionals describe the chain of infection as a process in which a pathogen (a microbe that causes disease) is carried in an initial host or reservoir, gains access to a route of ongoing transmission, and with sufficient virulence finds a secondary susceptible host. Ventilation, filtration, and air distribution systems and disinfection technologies have the potential to limit airborne pathogen transmission through the air and thus break the chain of infection.

Building science professionals must recognize the importance of facility operations and ventilation systems in interrupting disease transmission. Non-HVAC measures for breaking the chain of infection, such as effective surface cleaning, contact and isolation precautions mandated by employee and student policies, and vaccination regimens, are effective strategies that are beyond the scope of this document. Dilution and extraction ventilation, pressurization, airflow distribution and optimization, mechanical filtration, ultraviolet germicidal irradiation (UVGI), and humidity control are effective strategies for reducing the risk of dissemination of infectious aerosols in buildings and transportation environments.

Although this position document is primarily applicable to viral and bacterial diseases that can use the airborne route for transmission from person to person, the principles of containment may also apply to infection from building reservoirs such as water systems with *Legionella spp.* and organic matter containing spores from mold (to the extent that the microorganisms are spread by the air). The first step in control of such diseases is to eliminate the source before it becomes airborne.

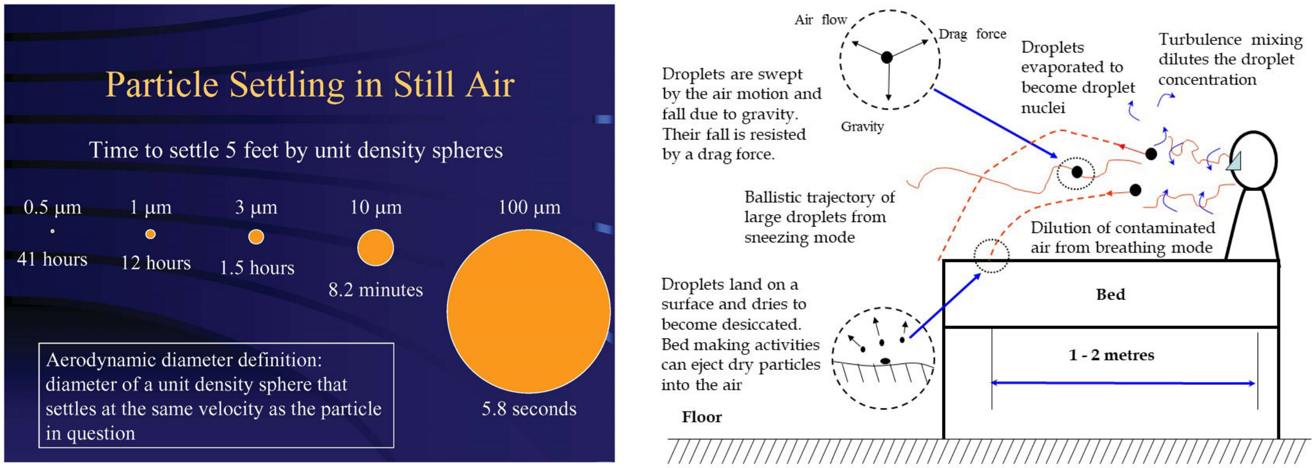
2. BACKGROUND

ASHRAE provides guidance and develop standards intended to mitigate the risk of infectious disease transmission in the built environment. Such documents provide engineering strategies for reducing the risk of disease transmission and therefore could be employed in a variety of other spaces, such as planes, trains, and automobiles.

This position document covers the dissemination of infectious aerosols and indirect transmission by resuspension but not direct-contact routes of transmission. *Direct contact* generally refers to bodily contact such as touching, kissing, sexual contact, contact with oral secretions or skin lesions and routes such as blood transfusions or intravenous injections.

2.1 Airborne Dissemination

Pathogen dissemination through the air occurs through droplets and aerosols typically generated by coughing, sneezing, shouting, breathing, toilet flushing, some medical procedures, singing, and talking (Bischoff et al. 2013; Yan et al. 2018). The majority of larger emitted droplets are drawn by gravity to land on surfaces within about 3–7 ft (1–2 m) from the source (see Figure 1). General dilution ventilation and pressure differentials do not significantly influ-



(a) (b)

Figure 1 (a) Comparative settling times by particle diameter for particles settling in still air (Baron n.d.) and (b) theoretical aerobiology of transmission of droplets and small airborne particles produced by an infected patient with an acute infection (courtesy Yuguo Li).

ence short-range transmission. Conversely, dissemination of smaller infectious aerosols, including droplet nuclei resulting from desiccation, can be affected by airflow patterns in a space in general and airflow patterns surrounding the source in particular. Of special interest are small aerosols (<10 µm), which can stay airborne and infectious for extended periods (several minutes, hours, or days) and thus can travel longer distances and infect secondary hosts who had no contact with the primary host.

Many diseases are known to have high transmission rates via larger droplets when susceptible individuals are within close proximity, about 3–7 ft (1–2 m) (Nicas 2009; Li 2011). Depending on environmental factors, these large (100 µm diameter) droplets may shrink by evaporation before they settle, thus becoming an aerosol (approximately <10 µm). The term *droplet nuclei* has been used to describe such desiccation of droplets into aerosols (Siegel et al. 2007). While ventilation systems cannot interrupt the rapid settling of large droplets, they can influence the transmission of droplet nuclei infectious aerosols. Directional airflow can create clean-to-dirty flow patterns and move infectious aerosols to be captured or exhausted.

3. PRACTICAL IMPLICATIONS FOR BUILDING OWNERS, OPERATORS, AND ENGINEERS

Even the most robust HVAC system cannot control all airflows and completely prevent dissemination of an infectious aerosol or disease transmission by droplets or aerosols. An HVAC system's impact will depend on source location, strength of the source, distribution of the released aerosol, droplet size, air distribution, temperature, relative humidity, and filtration. Furthermore, there are multiple modes and circumstances under which disease transmission occurs. Thus, strategies for prevention and risk mitigation require collaboration among designers, owners, operators, industrial hygienists, and infection prevention specialists.

3.1 Varying Approaches for Facility Type

Healthcare facilities have criteria for ventilation design to mitigate airborne transmission of infectious diseases (ASHRAE 2013, 2017a, 2019a; FGI 2010); however, infections are also transmitted in ordinary occupancies in the community and not only in industrial or healthcare occupancies. ASHRAE provides general ventilation and air quality requirements in Standards 62.1, 62.2, and 170 (ASHRAE 2019a, 2019b, 2017a); ASHRAE does not provide specific requirements for infectious disease control in homes, schools, prisons, shelters, transportation, or other public facilities.

In healthcare facilities, most infection control interventions are geared at reducing direct or indirect contact transmission of pathogens. These interventions for limiting airborne transmission (Aliabadi et al. 2011) emphasize personnel education and surveillance of behaviors such as hand hygiene and compliance with checklist protocols and have largely been restricted to a relatively small list of diseases from pathogens that spread only through the air. Now that microbiologists understand that many pathogens can travel through both contact and airborne routes, the role of indoor air management has become critical to successful prevention efforts. In view of the broader understanding of flexible pathogen transmission modes, healthcare facilities now use multiple modalities simultaneously (measures that are referred to as *infection control bundles*) (Apisarnthanarak et al. 2009, 2010a, 2010b; Cheng et al. 2010). For example, in the cases of two diseases that clearly utilize airborne transmission, tuberculosis and measles, bundling includes administrative regulations, environmental controls, and personal protective equipment protocols in healthcare settings. This more comprehensive approach is needed to control pathogens, which can use both contact and airborne transmission pathways. Similar strategies may be appropriate for non-healthcare spaces, such as public transit and airplanes, schools, shelters, and prisons, that may also be subject to close contact of occupants.

Many buildings are fully or partially naturally ventilated. They may use operable windows and rely on intentional and unintentional openings in the building envelope. These strategies create different risks and benefits. Obviously, the airflow in these buildings is variable and unpredictable, as are the resulting air distribution patterns, so the ability to actively manage risk in such buildings is much reduced. However, naturally ventilated buildings can go beyond random opening of windows and be engineered intentionally to achieve ventilation strategies and thereby reduce risk from infectious aerosols. Generally speaking, designs that achieve higher ventilation rates will reduce risk. However, such buildings will be more affected by local outdoor air quality, including the level of allergens and pollutants within the outdoor air, varying temperature and humidity conditions, and flying insects. The World Health Organization has published guidelines for naturally ventilated buildings that should be consulted in such projects (Atkinson et al. 2009).

3.2 Ventilation and Air-Cleaning Strategies

The design and operation of HVAC systems can affect infectious aerosol transport, but they are only one part of an infection control bundle. The following HVAC strategies have the potential to reduce the risks of infectious aerosol dissemination: air distribution patterns, differential room pressurization, personalized ventilation, source capture ventilation, filtration (central or local), and controlling temperature and relative humidity. While UVGI is well researched and validated, many new technologies are not (ASHRAE 2018). (Evidence Level B)

Ventilation with effective airflow patterns (Pantelic and Tham 2013) is a primary infectious disease control strategy through dilution of room air around a source and removal of infectious agents (CDC 2005). However, it remains unclear by how much infectious particle loads must be reduced to achieve a measurable reduction in disease transmissions (infectious doses vary widely among different pathogens) and whether these reductions warrant the associated costs (Pantelic and Tham 2011; Pantelic and Tham 2012). (Evidence Level B)

Room pressure differentials and directional airflow are important for controlling airflow between zones in a building (CDC 2005; Siegel et al. 2007) (Evidence Level B). Some designs for airborne infection isolation rooms (AIIRs) incorporate supplemental dilution or exhaust/capture ventilation (CDC 2005). Interestingly, criteria for AIIRs differ substantially between regions and countries in several ways, including air supply into anterooms, exhaust from space, and required amounts of ventilation air (Fusco et al. 2012; Subhash et al. 2013). A recent ASHRAE Research Project found convincing evidence that a properly configured and operated anteroom is an effective means to maintain pressure differentials and create containment in hospital rooms (Siegel et al. 2007; Mousavi et al. 2019). Where a significant risk of transmission of aerosols has been identified by infection control risk assessments, design of AIIRs should include anterooms. (Evidence Level A)

The use of highly efficient particle filtration in centralized HVAC systems reduces the airborne load of infectious particles (Azimi and Stephens 2013). This strategy reduces the transport of infectious agents from one area to another when these areas share the same central HVAC system through supply of recirculated air. When appropriately selected and deployed, single-space high-efficiency filtration units (either ceiling mounted or portable) can be highly effective in reducing/lowering concentrations of infectious aerosols in a single space. They also achieve directional airflow source control that provides exposure protection at the patient bedside (Miller-Leiden et al. 1996; Mead and Johnson 2004; Kujundzic et al. 2006; Mead et al. 2012; Dungi et al. 2015). Filtration will not eliminate all risk of transmission of airborne particulates because many other factors besides infectious aerosol concentration contribute to disease transmission. (Evidence Level A)

The entire ultraviolet (UV) spectrum can kill or inactivate microorganisms, but UV-C energy (in the wavelengths from 200 to 280 nm) provides the most germicidal effect, with 265 nm being the optimum wavelength. The majority of modern UVGI lamps create UV-C energy at a near-optimum 254 nm wavelength. UVGI inactivates microorganisms by damaging the structure of nucleic acids and proteins with the effectiveness dependent upon the UV dose and the susceptibility of the microorganism. The safety of UV-C is well known. It does not penetrate deeply into human tissue, but it can penetrate the very outer surfaces of the eyes and skin, with the eyes being most susceptible to damage. Therefore, shielding is needed to prevent direct exposure to the eyes. While *ASHRAE Position Document on Filtration and Air Cleaning* (2018) does not make a recommendation for or against the use of UV energy in air systems for minimizing the risks from infectious aerosols, Centers for Disease Control and Prevention (CDC) has approved UVGI as an adjunct to filtration for reduction of tuberculosis risk and has published a guideline on its application (CDC 2005, 2009).[7] (Evidence Level A)

Personalized ventilation systems that provide local exhaust source control and/or supply 100% outdoor, highly filtered, or UV-disinfected air directly to the occupant's breathing zone (Cermak et al. 2006; Bolashikov et al., 2009; Pantelic et al. 2009, 2015; Licina et al. 2015a, 2015b) may offer protection against exposure to contaminated air. Personalized ventilation may be effective against aerosols that travel both long distances as well as short ranges (Li 2011).

[7] In addition to UVGI, optical radiation in longer wavelengths as high as 405 nm is an emerging disinfection technology that may also have useful germicidal effectiveness.

Personalized ventilation systems, when coupled with localized or personalized exhaust devices, further enhance the overall ability to mitigate exposure in breathing zones, as seen from both experimental and computational fluid dynamics (CFD) studies in healthcare settings (Yang et al. 2013, 2014, 2015a, 2015b; Bolashikov et al. 2015; Bivolarova et al. 2016). However, there are no known epidemiological studies that demonstrate a reduction in infectious disease transmission. (Evidence Level B)

Advanced techniques such as computational fluid dynamics (CFD) analysis, if performed properly with adequate expertise, can predict airflow patterns and probable flow paths of airborne contaminants in a space. Such analyses can be employed as a guiding tool during the early stages of a design cycle (Khankari 2016, 2018a, 2018b, 2018c).

3.3 Temperature and Humidity

HVAC systems are typically designed to control temperature and humidity, which can in turn influence transmissibility of infectious agents. Although HVAC systems can be designed to control relative humidity (RH), there are practical challenges and potential negative effects of maintaining certain RH set points in all climate zones. However, while the weight of evidence at this time (Derby et al. 2016), including recent evidence using metagenomic analysis (Taylor and Tasi 2018), suggests that controlling RH reduces transmission of certain airborne infectious organisms, including some strains of influenza, this position document encourages designers to give careful consideration to temperature and RH.

In addition, immunobiologists have correlated mid-range humidity levels with improved mammalian immunity against respiratory infections (Taylor and Tasi 2018). Mousavi et al. (2019) report that the scientific literature generally reflects the most unfavorable survival for microorganisms when the RH is between 40% and 60% (Evidence Level B). Introduction of water vapor to the indoor environment to achieve the mid-range humidity levels associated with decreased infections requires proper selection, operation, and maintenance of humidification equipment. Cold winter climates require proper building insulation to prevent thermal bridges that can lead to condensation and mold growth (ASHRAE 2009). Other recent studies (Taylor and Tasi 2018) identified RH as a significant driver of patient infections. These studies showed that RH below 40% is associated with three factors that increase infections. First, as discussed previously, infectious aerosols emitted from a primary host shrink rapidly to become droplet nuclei, and these dormant yet infectious pathogens remain suspended in the air and are capable of traveling great distances. When they encounter a hydrated secondary host, they rehydrate and are able to propagate the infection. Second, many viruses and bacteria are anhydrous resistant (Goffau et al. 2009; Stone et al. 2016) and actually have increased viability in low-RH conditions. And finally, immunobiologists have now clarified the mechanisms through which ambient RH below 40% impairs mucus membrane barriers and other steps in immune system protection (Kudo et al. 2019). (Evidence Level B)

This position document does not make a definitive recommendation on indoor temperature and humidity set points for the purpose of controlling infectious aerosol transmission. Practitioners may use the information herein to make building design and operation decisions on a case-by-case basis.

3.4 Emerging Pathogens and Emergency Preparedness

Disease outbreaks (i.e., epidemics and pandemics) are increasing in frequency and reach. Pandemics of the past have had devastating effects on affected populations. Novel microorganisms that can be disseminated by infectious aerosols necessitate good design, construction, commissioning, maintenance, advanced planning, and emergency drills to facilitate fast action to mitigate exposure. In many countries, common strategies include naturally ventilated buildings and isolation. Control banding is a risk management strategy that should be considered for applying the hierarchy of controls to emerging pathogens, based on the likelihood and duration of exposure and the infectivity and virulence of the pathogen (Sietsema 2019) (Evidence Level B). Biological agents that may be used in terrorist attacks are addressed elsewhere (USDHHS 2002, 2003).

4. CONCLUSIONS AND RECOMMENDATIONS

Infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows. Various strategies have been found to be effective at controlling transmission, including optimized airflow patterns, directional airflow, zone pressurization, dilution ventilation, in-room air-cleaning systems, general exhaust ventilation, personalized ventilation, local exhaust ventilation at the source, central system filtration, UVGI, and controlling indoor temperature and relative humidity. Design engineers can make an essential contribution to reducing infectious aerosol transmission through the application of these strategies. Research on the role of airborne dissemination and resuspension from surfaces in pathogen transmission is rapidly evolving. Managing indoor air to control distribution of infectious aerosols is an effective intervention which adds another strategy to medical treatments and behavioral interventions in disease prevention.

4.1 ASHRAE's Positions

- HVAC design teams for facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice. Based on risk assessments or owner project requirements, designers of new and existing facilities could go beyond the minimum requirements of these standards, using techniques covered in various ASHRAE publications, including the ASHRAE Handbook volumes, Research Project final reports, papers and articles, and design guides, to be even better prepared to control the dissemination of infectious aerosols.
- Mitigation of infectious aerosol dissemination should be a consideration in the design of all facilities, and in those identified as high-risk facilities the appropriate mitigation design should be incorporated.
- The design and construction team, including HVAC designers, should engage in an integrated design process in order to incorporate the appropriate infection control bundle in the early stages of design.
- Based on risk assessments, buildings and transportation vehicles should consider designs that promote cleaner airflow patterns for providing effective flow paths for airborne particulates to exit spaces to less clean zones and use appropriate air-cleaning systems. (Evidence Level A)
- Where a significant risk of transmission of aerosols has been identified by infection control risk assessments, design of AIIRs should include anterooms. (Evidence Level A)

- Based on risk assessments, the use of specific HVAC strategies supported by the evidence-based literature should be considered, including the following:
  - Enhanced filtration (higher minimum efficiency reporting value [MERV] filters over code minimums in occupant-dense and/or higher-risk spaces) (Evidence Level A)
  - Upper-room UVGI (with possible in-room fans) as a supplement to supply airflow (Evidence Level A)
  - Local exhaust ventilation for source control (Evidence Level A)
  - Personalized ventilation systems for certain high-risk tasks (Evidence Level B)
  - Portable, free-standing high-efficiency particulate air (HEPA) filters (Evidence Level B)
  - Temperature and humidity control (Evidence Level B)
- Healthcare buildings[8] should consider design and operation to do the following:
  - Capture expiratory aerosols with headwall exhaust, tent or snorkel with exhaust, floor-to-ceiling partitions with door supply and patient exhaust, local air HEPA-grade filtration.
  - Exhaust toilets and bed pans (a must).
  - Maintain temperature and humidity as applicable to the infectious aerosol of concern.
  - Deliver clean air to caregivers.
  - Maintain negatively pressurized intensive care units (ICUs) where infectious aerosols may be present.
  - Maintain rooms with infectious aerosol concerns at negative pressure.
  - Provide 100% exhaust of patient rooms.
  - Use UVGI.
  - Increase the outdoor air change rate (e.g., increase patient rooms from 2 to 6 ach).
  - Establish HVAC contributions to a patient room turnover plan before reoccupancy.
- Non-healthcare buildings should have a plan for an emergency response. The following modifications to building HVAC system operation should be considered:
  - Increase outdoor air ventilation (disable demand-controlled ventilation and open outdoor air dampers to 100% as indoor and outdoor conditions permit).
  - Improve central air and other HVAC filtration to MERV-13 (ASHRAE 2017b) or the highest level achievable.
  - Keep systems running longer hours (24/7 if possible).
  - Add portable room air cleaners with HEPA or high-MERV filters with due consideration to the clean air delivery rate (AHAM 2015).
  - Add duct- or air-handling-unit-mounted, upper room, and/or portable UVGI devices in connection to in-room fans in high-density spaces such as waiting rooms, prisons, and shelters.
  - Maintain temperature and humidity as applicable to the infectious aerosol of concern.
  - Bypass energy recovery ventilation systems that leak potentially contaminated exhaust air back into the outdoor air supply.
- Design and build inherent capabilities to respond to emerging threats and plan and practice for them. (Evidence Level B)

[8] It is assumed that healthcare facilities already have emergency response plans.

4.2 ASHRAE's Commitments

- Address research gaps with future research projects, including those on the following topics:
  - Investigating and developing source generation variables for use in an updated ventilation rate procedure
  - Understanding the impacts of air change rates in operating rooms on patient outcomes
  - Determining the effectiveness of location of supply, return, and exhaust registers in patient rooms
  - Conducting controlled interventional studies to quantify the relative airborne infection control performance and cost-effectiveness of specific engineering strategies, individually and in combination, in field applications of high-risk occupancies
  - Evaluating and comparing options to create surge airborne isolation space and temporary negative pressure isolation space and the impacts on overall building operation
  - Understanding the appropriate application of humidity and temperature control strategies across climate zones on infectious aerosol transmission
  - Investigating how control banding techniques can be applied to manage the risk of infectious aerosol dissemination
- Partner with infection prevention, infectious disease, and occupational health experts and building owners to evaluate emerging control strategies and provide evidence-based recommendations.
- Educate stakeholders and disseminate best practices.
- Create a database to track and share knowledge on effective, protective engineering design strategies.
- Update standards and guidelines to reflect protective evidence-based strategies.

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APPENDIX 3

Department of Public Health Guidance for School Systems

STATE OF CONNECTICUT
DEPARTMENT OF PUBLIC HEALTH

Deidre S. Gifford, MD, MPH
Acting Commissioner

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Governor
Susan Bysiewicz
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Guidance for School Systems for the Operation of Central and non-Central Ventilation Systems during the COVID-19 Pandemic

Improving ventilation in school buildings is just one part of system of procedures that will safeguard the health and safety of students, teachers, and school staff during the COVID-19 pandemic. Other parts of this system of procedures include physical distancing, face coverings, and efficient identification and isolation of sick students and staff. While improving ventilation is not necessarily the most effective tool for reducing transmission of the virus that causes COVID-19 (maintaining social distancing and wearing face coverings are far more effective), some studies suggest that adjustments and attention to proper ventilation can reduce the viable virus load in indoor spaces. In addition, we know that providing good ventilation in schools is important even outside of the COVID-19 pandemic, because it has been shown to improve student and staff performance in educational settings.

This guidance provides actions schools should take to ensure that their ventilation systems are performing optimally. The goal is not for schools to invest in costly upgrades and add-ons to existing mechanical systems. Rather, schools should understand what their current mechanical systems are capable of and how they can adjust the function of those systems to optimize their capabilities.

Before School Opens:

1. Commission building mechanical systems for full occupancy (see details below for tips about how and why to commission mechanical systems for fall start-up).
2. Operate all ventilation systems at full capacity for one (1) week prior to the reopening of school buildings.
3. Discuss with the entire facilities team and school administrators the general principles about what changes are planned to the usual ventilation system operation for the coming year. It will be important to communicate with school staff the importance of not making any adjustments to the mechanical systems inside school buildings (thermostats, fan speeds, etc.) without input from the facilities team.

After School Opens:

1. Flush the air inside the building for a minimum of two (2) hours prior to occupancy and one (1) hour after occupancy (after the night-shift custodians leave), with the dampers open as fully as possible (i.e. to maximize fresh air intake) during this flushing period.

2. Program and lock fan schedules to align with the building occupancy schedule (i.e. provide flushing ventilation starting two (2) hours before building occupancy and one (1) hour post occupancy).

3. Develop a system for building users to notify the facilities department if the building needs to be open longer than usual so that the fan schedule can be altered for that day.

4. Keep the ventilation system running during all hours that the building is occupied.

5. Do not allow teachers or other staff to make changes to ventilation system controls in their respective rooms. Explain to them the importance of keeping fans running all day. If temperature, noise, or other issues exist in certain areas, encourage staff to discuss the problem with the facilities department to try to identify a suitable fix that does not negatively impact ventilation.

6. Keep bathroom exhaust systems running all day, every day (24 hours a day/7 days a week).

7. For isolation rooms to be used for holding sick students prior to dismissal, consider adding supplemental filtration, such as a portable air cleaner. This is particularly important if the ventilation serving those rooms cannot be run at 100% exhaust at all times. If a portable air cleaner is used, it should:

    - Contain HEPA filters only without ionizers, ozone generators, UV light, or other add-ons.

    - Be correctly sized for the space, with an appropriate CADR (clean air delivery rate).

    - Be located for greatest efficiency within the space.

    - Be turned on at all times that the space is occupied.

8. Develop a specific plan for performing routine inspections and maintenance of mechanical systems, as specified in the commissioning process.

9. For buildings without central ventilation systems or with certain areas not served by the central ventilation system, there are other important design considerations facility managers should be aware of, and in control of, in order to maximize available dilution ventilation and minimize the spread of virus particles inside their facilities.

- At a minimum, where temperature allows and no other means of ventilation is available, windows should be opened to allow for some minimum level of fresh air exchange into occupied spaces.
- Window air conditioning units should be adjusted to maximize fresh air intake into the system. Air conditioner blower fans should be set on low speed and pointed away from room occupants to the extent possible.
- Ceiling fans should be adjusted so that fins are rotating in a direction that draws air up toward the ceiling rather than down onto occupants.
- Window fans should be turned to exhaust air out of the window in the direction of the outdoors. Ensure that fans are not blowing out of windows directly into walking paths or areas where individuals may congregate.
- Window fans that blow air into a room or free-standing fans that only serve to circulate existing air around a room should not be used.
- In addition, we do not recommend separate, free-standing air cleaner or HEPA filter units for individual classrooms. These units are highly variable in their effectiveness in larger open spaces such as classrooms and in general, any effect on indoor air quality is likely insignificant and greatly outweighed by the additional costs to school systems.

How to Commission Building Mechanical Systems for fall school reopening

1. If your school system does not already have one that it routinely works with, hire a mechanical engineering firm with a proven track record in evaluating, adjusting, and balancing ventilation systems, particularly ventilation systems in school buildings, to commission all of the buildings' mechanical systems for full occupancy. The school facilities manager should be part of the discussion team talking with the engineering firm and the commissioning agent.

   Consider asking your Commissioning Agent the following questions:

   - How many and what types of systems serve your buildings, and which area of the building does each separate system serve?
   - What are the capabilities of the systems present in your school buildings?
   - Are the systems currently working to their full capabilities?
   - Are the current systems' capabilities enough to satisfy full capacity for how the buildings need to operate now?
   - Can demand-based systems be converted to constant volume until cooling season is over (if systems provide central cooling)? During heating season? Longer-term?

- Can recirculation of air be suspended (economizers disabled)?
- Can they provide a summary of performance expectations for mechanical systems in the building?

2. Include the following items in the commissioning process:

- A complete set of measurements to understand total air distribution throughout the building.
- Inspection and evaluation of all building ventilation systems, both automated and manual.
- Air balancing and appropriate retesting to ensure parameters that satisfy the conditions of full occupancy of the buildings.
- Inspections:
    - Filter frames - Decide what kind of filter thickness and type you will be using if you decide to upgrade to a higher-rated filter. Discuss this with your ventilation engineering firm. Either way, all filter frames will need to be inspected. Replace or fix all bent, broken, misshapen frames to prevent air from by-passing the filter.
    - Dampers and all associated controllers and actuators need to be visually inspected. Do not rely only on looking at a computer screen if you have an automated building system.
    - Inspect, verify, and modify automated set points, if needed. Discuss both temperature and CO_2 set points in newer buildings that utilize these variables for automated decision-making.
    - Locations of supply and return diffusers. Look at ventilation effectiveness and whether short-circuiting is occurring. This happens frequently when supply and return diffusers are too close to each other. Discuss the possibility of moving them farther apart if this is occurring. If supplies and returns are ducted using flex duct and the room has a suspended ceiling, relocating can be performed more easily.

    - Air balancing, inspections, and other work should be performed in accordance with one of these certification bodies: NEBB (https://www.nebb.org/); TABB (https://www.tabbcertified.org/); AABC (https://www.aabc.com/)

3. Strive toward the following ventilation goals.

- Increase outdoor air ventilation as much as possible by disabling demand-controlled ventilation systems and opening outdoor air dampers to 100%, as indoor and outdoor conditions permit. Disabling demand-based systems will allow fans to run continuously.
- Tune ventilation systems to enable them to perform to the maximum capacity consistent with full occupancy conditions for the building.

- Bypass energy recovery ventilation systems that leak or recirculate potentially contaminated exhaust air back into the outdoor air supply.
- Once fans are running continuously, provide increased particle capture by increasing air filtering capacity through repair/upgrades to current system, where needed. This includes filter frames, filter configuration, and filter rating (ASHRAE recommends striving for filters with a MERV-13 rating where possible).

Why it is Important to Commission Building Mechanical Systems

1. Commissioning verifies that existing equipment is working properly. Adjustments can then be made to allow current systems to operate to the best of their ability.
2. Adjusting mechanical systems to satisfy full building occupancy, even if buildings will have reduced occupancy in the fall, will result in increased ventilation per person without over-taxing the equipment and potentially causing premature equipment failure.
3. Commissioning reduces the likelihood of unintended consequences of making changes to how systems operate.
4. If one or more of the systems are deemed to be inadequate, commissioning will provide the basis for making informed and intelligent decisions about next steps to improve those systems.
5. The cost for commissioning is money well spent because it will prevent building operators from spending money on things that add little value and instead, help them focus attention on things that will make a real difference.

Additional resources:

- AICARR- Decision Tree: Protocol for risk reduction of SARS-CoV2-19 Diffusion With the Aid of Existing Air Conditioning and Ventilation Systems
- Air filtration and COVID-19: Indoor air quality expert explains how to keep you and your building safe: Interview with Professor Jeffrey Seigel, University of Toronto
- The Path to COVID-19 Recovery: How To Improve Indoor Air Quality When Re- Opening K-12 Schools. Univ Calif Davis.

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VANZELM ENGINEERS

APPENDIX 4

Field Survey Findings

Field Survey Findings

08-12-2020 through 08-14-2020

Auditors: Joshua Klein and Bob Marra

Please refer to each school's "Unit Map" in appendix 1 for unit designations. Some units in the field do not have a tag, or their designation did not make sense with their location.

General Comments Applicable to Both Schools

- General Comment: Rooftop condensing units for split air-conditioning systems (AC/CU) have exposed refrigerant piping where the insulation has been completely deteriorated by the sun. All of these refrigerant tubes should be reinsulated and coated with UV-resistant materials. These will conserve energy by limiting losses through exposed piping and will help avoid the piping breaking causing loss of refrigerant charge in the system.
- General Comment: We recommend splash pads or blocks to be placed below all RTU condensate drains to prevent any damage
- General Comment: All outside air bird screen or pollen wire filters should be cleaned/replaced
- General Comment: All dampers on shafts should be greased to prevent burning out actuators or snapping jackshafts.
- General Comment: Condensate trap heights are important to allow for the condensate pans to drain. The installation of these traps depends on the static pressure at the condensate section of the unit while running, which can vary significantly depending on if the unit is a blow-through (positive pressure) or draw-through (negative pressure) configuration. It was common to find drain pans with sitting water in them and only a small amount of water coming out of the drain, which indicates improper trap heights. Most units at the schools are draw-through, so the outlet of the traps needs to be much lower than the inlet. A thorough review of these should be conducted.
- General Comment: Most units that have two sets of filters have 2" MERV 8 filters protecting 4" MERV 8 filters. This increases the pressure drop across the filter rack with minimal effect on the improvement of indoor air quality, since the downstream filters will not pick up much more out of the air that the upstream ones have. For these units, it would be easy to only replace the 4" MERV 8s with MERV 13s.

Fairfield Warde High School

- Servery: Many upper windows for the kitchen near RTU-B-3 are cracked/not sealing against the frame properly. A compromised building envelope leads to thermal losses and potential indoor air quality concerns.
- General Comment: The fan squirrel cage in any unit with one is generally dirty
- General Comment: Many filter racks at Warde are distorted / have screws along the length that catch the filters as they are moved in or out, causing some damage upon changeout. We observed many filters found with damage from this but were installed anyway. We recommend straightening the racks and fixing bypasses created in this way, especially before installing costlier MERV 13 filters.
- The A-wing Plymovent EF guy-wires are not affixed to the roof anymore.
- RTU-A-1
  - The filters are dirty. Two filters have fallen out of the rack
  - The filter section lower door handle is broken in the shut position
  - The unit interior is dirty
  - The coil is dirty
- RTU-A-2
  - The unit interior is dirty
  - The coil is dirty
  - The dampers need to be lubricated
  - The filters are very dirty and are being pulled out of the racks.
  - The condenser coils need to be combed to straighten the fins
  - The supply air duct insulation seams are coming undone near the steam coil. There appear to be some sections where the duct is leaking, as evidenced by the insulation ballooning. With the insulation damaged, water could get into the ductwork in these locations, so it should be patched wherever possible.
- RTU-A-3
  - There was excessive water found in the filter section of the unit. Some debris and paper was sitting in the water; these should be removed.
  - The condenser fans are imbalanced
  - The condenser coils need to be combed to straighten the fins
- RTU-A-4
  - The unit was running but the DX cooling was not operating. We would have expected it to, given the conditions.
- RTU-A-5
  - For the unit serving the Black Box Theater, the unit nameplate tags this unit at RTU-A-2, but that designation is taken by another unit. The previous list had this unit as "AC-E-5" but this building section is still A. For this report, the unit is designated as "RTU-A-5".
  - The fan belt is missing
  - The fan bearing is destroyed and needs to be replaced
  - Piping insulation in the unit is damaged
- RTU-A-6
  - For the unit serving Technical Education, the unit nameplate tags this unit at RTU-A-3, but that designation is taken by another unit. The previous list had this unit as "AC-E-6" but this building section is still A. For this report, the unit is designated as "RTU-A-6".

  - Based on the filters, it looks like this unit has not run at all since the previous filter change on 5/4/2020. While it is likely that the unit has had little to no occupancy load due to COVID-19, most units were found to operate some during this time.
- RTU-A-7
  - For the unit serving the Early Childhood Center, the unit nameplate tags this unit at RTU-A-1, but that designation is taken by another unit. The previous list had this unit as "AC-E-7" but this building section is still A. For this report, the unit is designated as "RTU-A-7".
  - The coil is dirty
  - The condensate pan is dirty and needs to be cleaned out
  - We found this unit running in 100% return air recirculation.
  - With the positioning of the ductwork and piping for this unit, access is impossible without stepping on one or the other. This has led to the insulation being crushed, which compromised both the vapor barrier and the effectiveness of the insulation. Additionally, the ductwork itself seems to have been damaged. Repairing the damaged insulation and installing a permanent means of accessing this unit are recommended to prevent future damage.
  - Piping insulation inside of the unit is damaged
  - The programming module was found within the unit control cabinet, plugged into the convenience receptacle on the exterior of the unit with an extension cord. Upon discussion with the facilities staff, they informed us that unit does not receive a cooling signal command from the control system. Whenever cooling is desired, somebody needs to go to the roof and manually enable it. This manual enable only lasts for 75 minutes when it would need to be re-enabled. This is not something that would have been corrected with the controller upgrade by ALC, so further investigation should be done.
- RTU-B-1
  - The unit was found off
- RTU-B-2
  - This unit was operating with much higher airflow than expected compared to RTU-B-1 and 3.
  - The top filters were found installed facing the wrong direction. We faced them correctly.
- RTU-B-3
  - Debris was found inside of the unit
  - Some of the control relays appear to have burned out and should be changed
- RTU-C-1
  - The unit was found not running, and it seems that it hasn't run in a while.
  - The condenser coil need cleaning
- RTU-C-2
  - Access to this unit is precarious. Recommend installing a permanent stair/ladder to safely traverse over the solar panel electrical conduit.
- RTU-C-3
  - The 2" pre-filters are dirty
  - The coil is slightly dirty
- RTU-E-1
  - The filters are very dirty, and some have been pulled out of the frame. The broken filters were removed, and facilities was informed.
- RTU-E-2

    - The filters were very dirty
- RTU-E-5
    - The filters were very dirty
- RTU-E-6
    - Unit nameplate is missing, could not confirm model/serial
    - Filters are extremely dirty and wet
    - The unit interior is dirty
    - The coil is dirty
    - The condensate pan is dirty and needs to be cleaned out
- RTU-E-8
    - The condenser coil should be cleaned
    - The fan belt is incredibly loose and is whipping around on the pulleys, though it has not yet fallen off.
- HV-D-1
    - The unit returns air from the mechanical space that it is in (Small Gym MER South). By code, this is not allowed since it will have adverse effects on the indoor air quality. The return air must be ducted to the space or a section of the building where all of the materials are plenum-rated.
- HV-D-3
    - The coil is coated with dust, pollen, and debris; this requires a full cleaning.
    - The unit returns air from the mechanical space that it is in (Small Gym MER South). By code, this is not allowed since it will have adverse effects on the indoor air quality. The return air must be ducted to the space or a section of the building where all of the materials are plenum-rated.
- RTU-F-1
    - The mixed air damper jackshaft is bent, possibly from over torqueing. Dampers should be greased, and the jackshaft replace.
    - The unit interior is very dirty. We observed large sections of rust and corrosion inside the cabinets particularly near the condensate pans.
    - The DX cooling was not running at the time of inspection, but we would have expected it to be given the conditions.
    - The supply fan belt is loose
    - The supply fan is imbalanced
- RTU-F-2
    - The supply fan belt is loose
    - The supply fan is imbalanced
- RTU-F-4
    - The damper actuator linkage was detached, and the damper were found locked in place at approximately 90% return air position.
    - The supply fan belt is loose
    - The supply fan is imbalanced
- RTU-H-6
    - This unit was found above the auditorium with no nameplate and only the label "AC-H-6" painted on the side. It is assumed to not be needed since RTU-AUD now serves the auditorium.
- RTU-L-1

  - The coil and the coil section of the unit are dirty
  - The condensate pan is dirty and needs to be cleaned out
- RTU-L-2
  - The coil is dirty
  - The condensate pan is dirty and needs to be cleaned out
- RTU-L-4
  - This unit is mounted directly on the roof without some sort of structural/acoustic base. It is one of the smaller units, but this is still not advised.
- RTU-L-6
  - Filters are very dirty and damaged ones were pulled out from the frames. The damaged filters were removed, and facilities was notified.
  - The supply fan belt is loose
  - The coil is dirty
- RTU-L-8
  - Unit is operating much quieter than expected compared to similar units.
- RTU-L-9
  - The coil is dirty
  - The mixed air damper shaft is disconnected from the actuator at the linkage
  - The unit was found off, but the outside air damper remained at 100% open. This should be closed whenever the unit is off, but it is unclear if the damper is stuck or if this is a sequence issue.
- RTU-L-10
  - Unit was not running at the time of inspection
- RTU-L-11
  - This MagicAire unit, located on the L roof, does not have an actual designation.
  - Facilities staff informed us that this unit was never operational from the beginning, and it has been abandoned in place.
- RTU-M-1
  - There is no safe access to this unit. Planks are used to bridge the gap between the nearby roof and the unit itself
- RTU-W-1
  - The duct insulation vapor barrier is compromised where it connects to the unit. This should be sealed to prevent damage to the insulation.
  - Both the supply and return fan belts are loose and are rubbing
  - Wasps have infested the unit exterior; we advise caution when nearby
  - The filters are dirty
- RTU-W-2
  - The coil is dirty and has bugs on the entering side
- RTU-W-3
  - The supply fan squirrel cage is wobbling, and the belt is slightly loose
  - There is too much bypass in the filter rack
  - The condenser fans are imbalanced, causing excessive rattling
- RTU-W-4
  - There is too much bypass in the filter rack
  - The condenser fans are imbalanced, causing excessive rattling
- RTU-W-5

  - The dampers are dirty and require lubrication
  - The interior of the unit is dirty
  - The coil is dirty
  - The condenser coils are dirty and need to be combed to straighten the fins
  - We found the outside air wire filter laying on the ground
  - There is too much bypass in the filter rack
  - This unit, and similar units, have packaged economizer control. This means that commands from the building automation system will not necessarily be able to open the outside air dampers if additional ventilation is desired when the unit controller decides that conditions are not favorable to do so. As part of improvements for increasing ventilation, the controls system should be reviewed, and devices/wiring should be adjusted to accommodate these commands.
- RTU-W-6
  - The condenser fans are imbalanced, causing excessive rattling
  - The filters seem to be slightly oversized. The door of the unit crushes the filter when closed and forms small bypasses.
- RTU-W-7
  - Wasps have infested the unit exterior; we advise caution when nearby
  - The supply fan belts are loose
  - The coil is dirty
- RTU-W-8
  - The filters seem to be slightly oversized. The door of the unit crushes the filter when closed and forms small bypasses.
  - The duct insulation vapor barrier is compromised where it connects to the unit. This should be sealed to prevent damage to the insulation.
  - The condensate trap is not the right height for a draw-through configuration, causing too little condensate to drain out.
- RTU-W-9
  - This MagicAire unit, located on the W roof, does not have an actual designation.
  - Facilities staff informed us that this unit was never operational from the beginning, and it has been abandoned in place.

Fairfield Ludlowe High School

- The Sanyo C3032 Condensing unit near RTU-7 is Inoperative with a condenser fan removed
- Condensate from RTU-5 and nearby units pools on this section of the roof despite the nearby roof drain.
- HV-1
  - Exhaust Fan (serves art/sculpture rooms 006 and 007 along the eastern section of the school) does not have a VFD and was drawing a stiff negative in room 006. We found all dampers (OA, RA, and EA) 100% open indicating either no software interlock limitations to prevent this or any combination have failed/become stuck open. There is no transfer ductwork between the two art rooms, so HV-1 supplies OA to 007 but takes nothing back, so room 006 returns/exhausts two rooms-worth of air.
  - The filters that are installed in this unit seem to be a downgrade of what was once there based on the notes made on the unit in permanent marker, which indicate it once had MERV 13 filters.
  - The filters are dirty
- HV-2
  - The energy recovery wheels are very dirty and are coated with debris (there are two staggered wheels in this unit), indicating that the filters might have been compromised at one point while the unit was running (they were dirty but intact during the site visit). The dirt appears on both sides. The wheel will need to be thoroughly cleaned.
  - Some of the sheet metal in the exhaust fan section is breaking apart. It is rattling around with the doors closed, and after enough time this could possibly break off completely, causing damage to the exhaust fans.
- HV-3
  - The outside air hood is missing a bolt on the northern side, which is causing it to slump in towards the unit; it looks like it might have rusted away based on the streaks. This scrapes against the unit exterior but also slightly reduces the free area for outside air to enter into the unit.
  - The mixed air temperature sensor only covers the bottom half of the unit. Since outside air enters from the upper section, this will not provide an accurate reading.
- HV-4
  - The filters are dirty
  - The condensate pan is dirty and needs to be cleaned out. Additionally, it has standing water in it indicating improper trap height.
  - A ladder was found stored inside the post-coil section of the unit. This would consistently expose the ladder to water and is not advised as a storage location.
  - The mixed air temperature sensor between the filters and the cooling coil was not affixed to anything in the unit and was able to be pulled out. This should be restrung for adequate coverage.
  - The post-coil temperature sensor is loose
  - There are signs of rust/corrosion around the bell mouth fan inlet, likely from the condensate being drawn through from not draining properly
- HV-5
  - Could not access the auxiliary gym duplex suspended units. Would require a lift.

   - The filters for this system are very dirty. Unfortunately, this is the most difficult unit to access, and since it does recirculate a lot of air in a high activity zone it would definitely need the MERV 13 filters.
- HV-6
   - It does not appear that this unit has operated since at least the previous filter change on 01/20/2020. Classes were still in session in January, so it is not clear why the filters would be so clean.
   - The unit was found off at the time of inspection
   - The condensate drain trap is broken
   - This unit has a refrigerant coil but no compressor. If this unit runs, the dead coil will only provide a restriction to the airflow.
- HV-7
   - The return air section below the damper assembly is not properly sealed
   - The external duct insulation vapor barrier is compromised and should be repaired to protect the insulation and ductwork
   - The unit was found off and does not appear to have run at least since the last filter change on 05/21/2020.
- MUA-1
   - The piping insulation inside the unit is damaged and the copper piping is showing signs of significant corrosion.
- MUA-2
   - The unit interior shows signs of rust/corrosion
- MUA-3
   - The piping insulation inside the unit is damaged
   - The unit interior shows signs of rust/corrosion
- AHU-15
   - Access to units AHU-15, 16, 17, and 18 is difficult in general and the mechanical space they are in is not well cleaned.
   - ductwork insulation falling apart, missing insulation on large sections of OA ductwork
   - Dirt and debris found within the unit up against the coil
- AHU-16
   - Filters are dirty
   - Coil is dirty
   - Fan belt is loose
   - ductwork insulation falling apart, missing insulation on large sections of OA ductwork
- AHU-17
   - Filters are dirty
   - The coil is dirty
   - Dirt and debris inside of unit and fan squirrel cage has debris/insulation on it
   - Fan belt is loose
   - ductwork insulation falling apart, missing insulation on large sections of OA ductwork
- AHU-18
   - The filters are dirty
   - The coil is dirty
   - The unit interior is dirty
   - ductwork insulation falling apart, missing insulation on large sections of OA ductwork

- RTU-1R1
  - Note: This is the only unit with natural gas for heat.
  - This unit has an energy recovery wheel which is not common among the units at these schools (HV-2 also has a wheel). While the outside air filters for the wheel section only need to be MERV 8, it is important to keep them clean or risk causing damage to the wheel, requiring extensive cleaning or replacement.
  - The supply air filters air dirty
  - The unit interior is dirty and is showing some signs of corrosion
  - The mixed air temperature sensor is wrapped around either a metal pipe or piece of conduit. This arrangement does not provide sufficient coverage.
- RTU-1
  - The condensate drain trap is broken and the part attached to the unit was found turned upward, which not allow for any condensate to leave through the outlet.
  - The condensate pan section of the unit appears to be damaged on the underside and water was seen leaking out. This is pooling under the unit and is showing signs of bio-growth on the roof surface.
  - The unit was running with the outside air damper at 0% open.
- RTU-2
  - The condenser coils should be combed to straighten out the fins
  - The cooling coil has significant damage to the fins and needs cleaning in general. A large area of fins on the north side of the coil have been pressed down or scraped. Further investigation would be required to determine the effect on unit performance. This coil might need to be replace if the damage cannot be corrected.
  - The filters are dirty
  - The return air section beneath the damper assembly is not properly sealed
- RTU-3
  - The condensate pan is dirty and has a carboard box soaking in the water collected there. That should be removed.
  - The unit was found running but the filters appear perfectly clean. The last change was 05/21/2020 as indicated on the filters. Even in an empty building this is not expected, especially compared to some of the other unit filter conditions.
- RTU-4
  - Refrigerant coil piping resting in condensate pan, which has standing water while the unit is running, causing corrosion and rust to the refrigerant tubes.
  - Condensate is not draining fast enough, which could indicate the trap is not the correct height (should have a greater difference in height for a draw-through unit).
  - The piping insulation in the control section is damaged
- RTU-5
  - Nameplate tag mislabeled as "RTU-6"
  - MERV 13 filters lasts changed 01/01/2016
  - Some of the filter rack clips meant to hold the 2” pre-filters are missing. Two of the filters had fallen out of the racks because of this. In addition to needing to be replaced from being dirty, these filter rack clips should be repaired.
  - The unit interior shows signs of some corrosion
- RTU-6
  - The refrigerant coil is dirty, and some small sections of the coil’s fins show damage. These should be combed out if possible.

- The compressors were running but no condensate was being produced (unexpected for conditions, which could indicate improper refrigerant charge)
- RTU-7
  - The piping in the control section is uninsulated
  - The unit was found powered off with a large, filled plastic bag occupying the fan section. It looks like it contains piping insulation
- RTU-8
  - The condensate trap heights are incorrect, which is causing water to pool in the drain pan. So much water has collected that the supply fan is drawing some of it up and injecting it into the airstream, increasing humidity.
- RTU-9
  - MERV 13 filters last changed 02/01/2018
  - Both sets of filters are dirty
  - The return fan belt is loose
  - The Cooling coil is dirty
  - Drain pan needs to be cleaned out
- RTU-10
  - MERV 13 filters last changed 02/01/2018
- RTU-11
  - The condensate trap fitting was pulled apart causing condensate pan overflow and leaking out of bottom of unit. We pushed it back together
  - The condensate drain trap height is suspected to be too little for this unit configuration
  - The Refrigerant Coil Iced up indicating possible low on charge.
  - There are some signs of structural rust
  - The condenser coils should be combed to straighten out the fins
- RTU-12
  - Exhaust air lower backdraft damper hinge cap is broken, causing the blade to come off
  - The filters are dirty
  - The condenser coils should be combed to straighten out the fins
- RTU-13
  - The unit has a minimum outside air damper position of 0%
  - The filters are dirty
  - The unit interior shows signs of rust/corrosion, particularly around the outside air damper section
- RTU-14
  - There are some signs of structural rust on the top of the fan section, and water was seen pooling within an indentation
  - The condenser coils should be combed to straighten out the fins
  - The condensate drain trap height is suspected to be too little for this unit configuration
- AC-4
  - During the visit it was very hot and humid out. The power exhaust was found operating and the outside air damper at 100%, utilizing full mechanical cooling rather than any recirculation
- DOA-1
  - The MERV 13 VariCel filters have never been changed since 2016 and the frames have melted from the heat coming off of the steam coil.