Campus Sunrise –
Preparing Facilities HVAC Systems

Executive Summary

Campus Sunrise - Preparing Facilities HVAC Systems Work Group (Work Group) was charged to advise Facilities Management on ventilation strategies for University buildings amid challenges posed by the COVID-19 pandemic. The main objective is to recommend operational changes for heating, ventilating, and air conditioning (HVAC) systems in University facilities to reduce the risk of aerosol transmission while pandemic conditions persist.

The Work Group's efforts are to be focused on instructional spaces, open office spaces, housing, dining, libraries and other indoor spaces used by large groups for extended periods.

Additional space types including housing (sleeping rooms), conference rooms, corridors, toilet spaces, and private office spaces are not considered large group settings and are excluded from the Work Group scope. It is expected that ventilation systems serving these space types will continue to operate normally. CDC guidelines should be followed in non-large group settings including social distancing, face coverings, and enhanced sanitation practices (where appropriate). Note that reducing airborne transmission rates in residence hall sleeping areas will be very difficult.

Laboratory and clinical spaces were not a focus of the Work Group scope due to the different code requirements for those spaces which exceeds the CDC and ASHRAE guidance related to COVID-19 risk. Laboratory spaces are generally ventilated with 100% outside air which will typically be at least double the rates found in the spaces that are included in the Work Group scope. It is expected that laboratory managers will develop plans for maintaining social distancing and issue guidance to lab personnel regarding the use of face covering. Clinic spaces are governed by health care codes that directly address infectious disease and hazardous aerosol control. Clinic managers should follow current codes and best practices for airborne infectious disease management.

The three major transmission paths that are known or assumed for SARS-COV-2 (the virus that causes the COVID-19 disease) are

1. Direct person-to-person via large droplets;
2. Transmission via contact with contaminated surfaces;
3. Transmission via infectious aerosols (airborne).

The direct and surface transmission pathways are currently assumed to be the major mechanisms driving the spread of SARS-COV-2 but the risk of airborne transmission is considered sufficient enough that mitigation steps are recommended. If a significant airborne transmission path does exist, the highest risk of infection is to persons in the room where the infectious aerosols are created. A second possibility is that infectious aerosols can be moved from one room to another via the HVAC system. Infectious material being moved from one space via the HVAC system and causing an infection in a different space has not been documented and is not likely. HVAC operation can reduce the risk of SARS-

COV-2 transmission by limiting the concentration of airborne infectious material in a space through dilution (ventilation). In addition, HVAC operation can reduce the risk of transferring infectious material from room to room via building ductwork (filtration). Note that HVAC operation cannot significantly impact large droplet or surface contamination transmission paths.

The Centers for Disease Control (CDC) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) have issued guidance for operating HVAC systems while pandemic conditions exist. The Work Group has reviewed this guidance and developed a list of strategies that can reduce the potential for airborne transmission of SARS-COV-2 in University facilities. The Work Group identified a subset of these strategies as representing the Baseline HVAC Performance Expectations. The Work Group believes that the baseline subset meets the intent of the CDC and ASHRAE guidance.

For fall semester 2020 the Work Group recommends implementing the Baseline HVAC Performance Expectation strategies. In addition to the Baseline strategies, the outdoor air ventilation rates should be increased by as much as the systems can provide.

The list of recommended strategies for fall 2020 is shown below:

General Recommendations

- Reduce the number of group activities to the greatest extent possible
- Move group activities outdoors whenever possible
- Implement health screening to limit the number of contagious people within groups
- Universal face covering requirement to limit the amount of airborne pathogens

HVAC Specific Recommendations

- Operate ventilation systems continuously
- Provide at no less than design minimum ventilation
- Disable demand control ventilation
- Increase the outdoor ventilation beyond the design minimum as much as possible
- Open windows in naturally ventilated rooms when used for group activities

The implementation phase will include assessing the required minimum baseline ventilation rates for each space and recording the actual ventilation rates once the outdoor air percentages have been increased at the air handlers.

Fall semester tends to have mild weather so the systems will generally have enough capacity to increase the amount of outdoor ventilation air by a significant amount (up to 100% outdoor air in many cases). In addition, the cost of increasing the ventilation rate and operating hours during fall semester is modest compared to winter or summer. Significantly increasing the outdoor air ventilation reduces the amount of recirculated air which justifies not pursuing high first cost strategies like enhanced filtration and ultraviolet disinfection systems.

The Work Group anticipates that there could be significant changes to the CDC and ASHRAE guidance by the fall as the airborne transmission path is better understood. There is a reasonable expectation that the guidance related to the airborne pathway will be relaxed as more data is analyzed. The Work Group will update the recommendations at the end of October to help with decisions about what mitigation strategies to pursue for winter break and spring semester 2021.

Introduction

Campus Sunrise - Preparing Facilities HVAC Systems Work Group (Work Group) was charged by AVP Bill Paulus on May 19, 2020 to advise Facilities Management leadership on ventilation strategies for University buildings amid challenges posed by the COVID-19 pandemic. The Work Group's main objective is to recommend operational changes to heating, ventilating, and air conditioning (HVAC) systems to reduce the risk of aerosol transmission of SARS-COV-2 (the virus that causes the disease COVID-19) in University facilities. Recommendations shall be based on guidance provided by the Centers for Disease Control (CDC), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), and other relevant authorities.

At present there are three documented or assumed transmission pathways for SARS-COV-2:

1. Direct person-to-person transmission via large droplets (expelled into the air through regular breathing, coughing, sneezing, etc.)
2. Surface transmission via touching contaminated surfaces and then transferring the pathogen to the nose, mouth, or eyes
3. Airborne transmission via aerosols that are contaminated with the virus.

Direct transmission appears to be the dominant method of transmitting the virus with surface contact a secondary but still important pathway. This Work Group is focused only on airborne transmission because the HVAC system does not have a significant impact on either large droplet or surface transmission.

Research into the transmission of SARS-COV-2 via small particles (aerosols) in ongoing and currently there is little direct evidence to indicate whether airborne transmission is significant. However, because airborne transmission does occur with other similar pathogens the Working group is operating under the assumption that airborne transmission of SARS-COV02 is possible, though that transmission pathway is less significant than direct transmission via large droplets.

The Work Group Goals:

1. Interpret the current government recommendations and industry best practices and determine how they should be applied to University HVAC systems and space types.
2. Develop a list of recommended HVAC operational strategies that align with current government recommendations and industry best practices. The Work Group will identify which strategies are required and represent the minimum performance expected for group activities. The Work Group will identify which strategies represent opportunities to enhance HVAC performance above the minimum level.
3. Identify facilities that:
    a. Currently meet the minimum performance guidelines or that can meet the guidelines with minor adjustments
    b. Currently do not meet the minimum performance guidelines and that may require significant adjustments or restrictions to perform at the minimum acceptable level.
    c. Currently do not meet the minimum performance guidelines and where meeting the minimum acceptable level is likely not practical in the near term.

The Work Group’s recommendations are to be focused on the following space types.

- Instruction Spaces (Classrooms)
- Open Office areas and support spaces
- Housing Common Spaces (University operated)
- Dining spaces
- Libraries
- Other spaces used by large groups for extended periods

Additional space types including housing (sleeping rooms), conference rooms, corridors, toilet spaces, and private office spaces are not considered large group settings and are excluded from the Work Group scope. It is expected that ventilation systems serving these space types will continue to operate normally. CDC guidelines should be followed in non-large group settings including social distancing, face coverings, and enhanced sanitation practices (where appropriate).

Laboratory and clinical spaces were not a focus of the Work Group scope due to the different code requirements for those spaces which exceeds the CDC and ASHRAE guidance related to COVID-19 risk. Laboratory spaces are generally ventilated with 100% outside air which will typically be at least double the rates found in the spaces that are included in the Work Group scope. It is expected that laboratory managers will develop plans for maintaining social distancing and issue guidance to lab personnel regarding the use of face covering. Clinic spaces are governed by health care codes that directly address infectious disease and hazardous aerosol control. Clinic managers should follow current codes and best practices for airborne infectious disease management.

Background

ASHRAE and the CDC have both issued guidance regarding the operation of HVAC systems during an active pandemic. The ASHRAE and CDC guidance for HVAC systems are essentially identical and the CDC references the ASHRAE guidance on HVAC systems. The Work Group recommendations are based on ASHRAE guidance unless otherwise noted.

There are two aspects of airborne transmission that HVAC enhancements can impact: room-level particulate concentration and particulate transport via the HVAC system. Explanations of both are provided below:

> **Room-level Particulate Concentration**. The concentration of small particles (infectious or otherwise) that can remain airborne for an extended time inside a given space. These particulates can be reduced by the HVAC system if the air supplied to the space has a lower concentration of particles than the existing room air. Introducing clean air to the space will dilute the small particles and reduce the concentration over time. Clean air is typically defined as outdoor air but any air source that has low concentrations of particulates is equally effective.
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> **Particulate Transport via HVAC**. Small airborne particles recirculated into the HVAC system return ductwork from one space and then introduced to other spaces by that same HVAC system. Strategies for reducing the distribution of potentially harmful particles from one space to other spaces via the HVAC system include: reducing or eliminating recirculation; filtering out the particles at the room or air handler; or disinfecting the particles prior to recirculation.

A person becomes infected when they come in contact with a sufficient amount of a particular pathogen. This amount is called the infectious dose. When exposure is less than the infectious dose a person's immune system is able to destroy the pathogens before an infection can occur. When exposure is higher than the infectious dose the immune system cannot destroy enough of the pathogens before the pathogen becomes established in the body causing an infection. For airborne pathogens the number of infectious particles encountered (e.g. breathed in) depends on the concentration of particles in the air, the amount of time spent in the space, and the rate at which air is consumed. The HVAC system can impact only the concentration of particles in the air. The infectious dose for SARS-COV-2 is unknown so no "safe" exposure can be determined at this time.

Presently, there is little evidence (due to absence of studies and verified confirmed transmissions) that airborne transmission within a room is significant compared to direct large droplet person-to-person transmission. However, being in a room with infectious aerosols present clearly poses at least some risk of infection.

ASHRAE has issued the following statements regarding airborne transmission:

- 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.
- Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus 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.

While being in a room where infectious aerosols are generated (e.g. infected person sneezes, coughs, sings, talks, etc.) clearly poses at least some risk there appears to be less evidence to suggest that an HVAC system can move enough infectious particles from one space and cause infections in another space. Prominent ASHRAE members have provided comments to various media outlets regarding the role of HVAC systems in the spread of SARS-COV-2 within a building including the following:

> "What we've been able to learn so far is there's no evidence that contaminated air taken from one space and put through an air conditioning system into another space has been found to cause infections," quoted on May 18, by Bill Bahnfleth, Chair of the ASHRAE Epidemic Task Force by CBS news

Taken together, the above statements from ASHRAE can be summarized as follows:

1. Airborne transmission of SARS-COV-2 is likely and steps to limit exposure should be taken.
2. HVAC system operation can reduce exposure to airborne pathogens and therefore reduce the chance of transmission.
3. The filtration and ventilation provided by HVAC systems can reduce exposure to airborne pathogens and HVAC system should continue to operate.
4. It is unlikely that an HVAC system can transport SARS-COV-2 infected particles from one space to another in sufficient concentration to cause infection. There is no evidence so far that this has occurred.

The CDC and ASHRAE have made specific recommendations concerning the operation of HVAC equipment while pandemic conditions persist. The CDC and ASHRAE guidance shown below is taken from the respective websites:

CDC Guidance - Maintaining a healthy work environment

Consider improving the engineering controls using the building ventilation system. This may include some or all the following activities:

- Increase ventilation rates.
- Ensure ventilation systems operate properly and provide acceptable indoor air quality for the current occupancy level for each space.
- Increase outdoor air ventilation, using caution in highly polluted areas. With a lower occupancy level in the building, this increases the effective dilution ventilation per person.
- Disable demand-controlled ventilation (DCV).
- Further open minimum outdoor air dampers (as high as 100%) to reduce or eliminate recirculation. In mild weather, this will not affect thermal comfort or humidity. However, this may be difficult to do in cold or hot weather.
- Improve central air filtration to the MERV-13 or the highest compatible with the filter rack, and seal edges of the filter to limit bypass.

- Check filters to ensure they are within service life and appropriately installed. Keep systems running longer hours, 24/7 if possible, to enhance air exchanges in the building space.

ASHRAE Guidance (based on ASHRAE Journal article Guidance for Building Operations During the COVID-19 Pandemic)

- Increase outdoor air ventilation (use caution in highly polluted areas); with a lower population in the building, this increases the effective dilution ventilation per person.
- Disable demand-controlled ventilation (DCV).
- Further open minimum outdoor air dampers, as high as 100%, thus eliminating recirculation (in the mild weather season, this need not affect thermal comfort or humidity, but clearly becomes more difficult in extreme weather).
- Improve central air filtration to the MERV-13 or the highest compatible with the filter rack, and seal edges of the filter12 to limit bypass.
- Keep systems running longer hours, if possible 24/7, to enhance the two actions above.
- Consider portable room air cleaners with HEPA filters.
- Consider UVGI (ultraviolet germicidal irradiation), protecting occupants from radiation, particularly in high-risk spaces such as waiting rooms, prisons, and shelters.

Analysis

In summary, ASHRAE guidance is to increase outdoor air ventilation rates as much as practical, increase outdoor air percentage to 100% when possible (even if that means losing some humidity control) to reduce or eliminate recirculation of room air, improve filtration as much as possible depending on the system capabilities (MERV 13 or higher when possible), and keep systems running longer both pre and post occupancy. They also recommend UVGI disinfection at the air handling unit (AHU) and using room level filter units, but those recommendations seem more for specific applications than for the general HVAC systems considered by the Work Group. The CDC has the same recommendations but adds increasing the total room ventilation rate (not just outdoor air) in addition to increasing outdoor air ventilation rates.

The recommended HVAC measures intended to mitigate the potential spread of SARS-COV-2 can be grouped into four basic categories: Baseline Ventilation, Increased Dilution, Enhanced Filtration, and Local Room Air Treatment. A discussion of the recommended HVAC measures, by category, follows.

Baseline Ventilation

The HVAC system serving any given space controls airborne contaminants (infectious or otherwise) by introducing clean air to the space and removing the contaminated air. The ability of the HVAC system to remove contaminants depends on a variety of factors including the rate of clean air delivery (measured in cubic feet per minute or CFM) and for how long that air is delivered. Typically, only the portion of the air supplied to the space that is outdoor air is considered "clean" and able to provide dilution. This assumption is not strictly true for normal building contaminants (e.g. CO2, odors, dust, etc.) and multizone AHUs because the recirculated air often contains lower concentrations of contaminates than a given room and is therefore able to dilute the room concentration. The expectation is that most spaces will have very low concentrations of infectious aerosols (no infected people in those spaces) and the recirculated air will also have very low concentrations. However, the guidance from ASHRAE considers outdoor air as the only source of dilution in a space. This results in a more conservative approach and the Work Group takes the same approach.

ASHRAE recommends that all buildings should continue to operate with design ventilation rates. In addition, ASHRAE recommends that designers continue to meet the requirements of ASHRAE standard 62.1 for new buildings. In other words, ASHRAE is suggesting that the current ASHRAE 62.1 ventilation rates are still the proper starting point for building ventilation, pandemic conditions or not. ASHRAE also recommend disabling demand control ventilation (DCV) if it is used. DCV is intended to reduce ventilation levels below the prescriptive levels given in ASHRAE 62.1 in response to low occupancy conditions. ASHRAE's apparent intent is to have buildings operate at <u>no less than</u> the ASHRAE 62.1 prescriptive minimum outdoor air ventilation rates while pandemic conditions persist.

The CDC recommends increasing overall ventilation rates (not just the outdoor air percentage) when possible. This would involve increasing the total supply and return flow for the spaces. The rationale appears to be that by increasing the total airflow rates any infectious aerosols will be more quickly distributed throughout the room where they can be removed by the HVAC system. In addition, the room will also receive more outdoor as the total supply airflow rate is increased. For variable air volume (VAV) systems, increasing the room airflow rates can typically be done by changing the airflow setpoints via the building automation system (BAS). For constant volume systems, increasing the ventilation rates may require extensive manual rebalancing of the system. The maximum practical ventilation rate will depend on available AHU fan horsepower, VAV box size, ductwork size and layout, noise sensitivity, etc. Each space is different and there is no reasonable way to predict what the potential percentage increase in room ventilation rates will be campus wide. The large number of spaces on campus makes altering airflows in all or even most spaces impractical. Increased room ventilation rates are best reserved for spaces that present the highest risk of airborne transmission. Candidates include spaces that are densely occupied where people spend significant time and where social distancing and mask usage is difficult. There is no obvious benefit to increasing total airflow rates in single zone systems. This will increase the air velocity in the space but will not impact dilution of contaminates.

Increased Dilution

ASHRAE recommends increasing the outdoor air percentage at the AHU to the maximum level that the AHU can accommodate, up to 100% when possible. Typically, this will result in rooms operating above the ASHRAE 62.1 minimum outdoor air ventilation rate. Increasing outdoor air ventilation is easier to accomplish than increasing the overall room ventilation because the adjustments are typically made at the AHU. The AHUs that would be adjusted number in the hundreds compared to potentially thousands of spaces. Most, though not all AHUs on campus are capable of full economizer mode (using outdoor air to provide cooling) so increasing the outdoor air percentage is typically not a problem during mild weather. During more extreme weather, the limiting factor is the capacity of the heating and cooling coils in the AHU. When cold or warm and humid outdoor air conditions exist, it may not be possible to provide 100% outdoor to some buildings without a significant loss of indoor temperature or humidity control. In addition, there is also a central system limit that will apply at the campus level. During extreme weather, the ability of campus heating and cooling utilities to serve 100% outdoor air loads needs to be considered. Central utilities may be capacity limited (boilers, chillers, etc.) or distribution limited (pumps, pipe sizes, etc.) and the limits may change based on maintenance schedules or equipment failures.

ASHRAE[1] recommends that buildings be "flushed" to reduce the level of airborne contaminants by 95% compared to the levels at the beginning of the flush. See Appendix D – Ventilation Calculations for details. The recommendation explicitly applies to pre- and post-occupancy periods for buildings that operate with the ventilation scheduled off during unoccupied periods. The CDC and ASHRAE also recommend operating buildings longer, even 24/7 if possible, to maximize the removal of potentially infectious airborne material. There is no significant limit to building operating hours during mild weather. In the summer cooling season, the load on campus utilities is typically lower at night and the outdoor conditions tend to be less extreme so it is likely that 24/7 operation can be achieved without running into system capacity limitations. Winter operation poses some challenges as extreme cold weather typically occurs at night. In the winter, outdoor air percentages may have to be reduced during unoccupied hours to limit the load on the central heating utilities.

Enhanced Filtration

[1] ASHRAE website. https://www.ashrae.org/technical-resources/building-readiness#epidemic Technical Resources, Building Readiness, Ventilation Control Section

Airborne contaminants are removed from the space via the return or exhaust ductwork. Some contaminants may be able to pass through the air handler and be returned to occupied spaces in systems that use recirculated air such as those supporting most offices and classrooms. ASHRAE recommends enhanced filtration to remove more particulates from the airstream before it is returned to the spaces for systems that use recirculated air. Filters with MERV-13 efficiency are recommended. Better filtration usually requires additional fan horsepower and not all HVAC systems will be capable of operating with MERV-13 filtration. Also, enhanced filters may not fit in the existing AHU filter racks.

Increasing the outdoor air percentage reduces the percentage of return air which reduces the amount of potentially infectious contaminates that can be recirculated. For systems that are operating with 100% outdoor air the risk of recirculated contaminants is essentially eliminated and enhanced filtration provides no additional contaminant reduction. Note that ASHRAE focuses significant attention on the potential role of energy recovery devices, particularly energy wheels in allowing cross contamination which allows recirculated air to leak into the supply air and be returned to the occupied spaces. The University has energy wheels operating on campus, but the concerns raised by ASHRAE largely do not apply to the designs used on campus. The amount of unintended recirculation for campus energy recovery systems is likely the same order of magnitude as that associated with leaking AHU dampers and does not appear to be a significant concern. Enhanced filtration is best applied to systems where the outdoor air percentage is low and cannot be increased.

For systems that cannot operate with improved filtration (or as an additional enhancement for systems that can) ASHRAE encourages the use of UVGI disinfection systems. The UVGI system is typically installed inside the AHU. Depending on the application the UVGI lamps can be located before or after the heating and cooling coils and can also be installed in the distribution ductwork. The UVGI lamps produce UV light at wavelengths that can destroy viruses like SARS-COV-2. For dealing with potentially infectious particles in the recirculated airstream the UVGI system usefulness is reduced as the percentage of outdoor air and the filtration efficiency is increased. UVGI is perhaps most appropriate when applied in lieu of filtration or outdoor air enhancements or for situations with a very low tolerance for risk.

Local Room Air Treatment

Local air cleaners that use highly efficient filters (such as MERV-13 and HEPA) and/or UVGI systems are part of the ASHRAE guidance. They are most appropriate for applications with low levels of ventilation or high occupant density or both. Local air cleaners could also be useful in spaces that expect to see high levels of contaminants like clinic waiting areas. The local devices could be similar to fan coil units (where air is circulated through the cleaner via ductwork) or they could stand alone systems that sit in the room.

Recommendations

Based on current CDC, ASHRAE, and other guidance and due to the significant uncertainty regarding how SARS-COV-2 is transmitted the Work Group recommends that the University take steps to limit the concentration of potentially infectious aerosols in University facilities. The recommendations are organized into the 5-step risk mitigation hierarchy that is used by the National Institute for Occupational Safety and Health (NIOSH). This hierarchy groups mitigation strategies into levels based on effectiveness with level 1 (Elimination) the most effective and level 5 (PPE) the least effective. See Appendix C – Mitigation Hierarchy for a more detailed discussion of the risk mitigation hierarchy. Table 1 shows the airborne transmission mitigation strategies the Work Group has identified. The last column in the table indicates whether the strategy is based on guidance from ASHRAE, guidance from the CDC or based on the expertise of the Work Group. A more detailed discussion of the strategies listed in Table 1 follows.

Table 1. Airborne Transmission Mitigation Strategies

1.0	Elimination		
	1.1	**Reduce the number of group activities**	**Work Group**
	1.2	**Move group activities outdoors**	**Work Group**
	1.3	**Health screening**	**Work Group**
2.0	Substitution		
	2.1	**Universal face covering requirement**	**Work Group**
3.0	Engineering Controls		
	3.1	**Operate ventilation systems continuously**	**ASHRAE**
	3.2	**Provide at least design minimum ventilation**	**ASHRAE**
	3.3	**Disable demand control ventilation**	**ASHRAE**
	3.4	Increase the outdoor ventilation	ASHRAE
	3.5	Improve filtration to MERV-13	ASHRAE
	3.6	Install UVGI systems	ASHRAE
	3.7	**Open windows in naturally ventilated rooms**	**ASHRAE**
	3.8	Increase total room ventilation	CDC
4.0	Administrative Controls		
	4.1	Schedule dwell time between group activities	Work Group
	4.2	Schedule for maximum HVAC diversity	Work Group
	4.3	Limit duration of group activities	Work Group
5.0	Personal Protective Equipment (PPE)		
	5.1	Use N95 or better mask	Work Group

Strategy Description / Discussion

1.0 **Elimination**. The hazard is present when infectious aerosols are generated in a space and that space is occupied by one or more uninfected persons.

1.1. Reduce the number of group activities. The risk of virus transmission is highest when large groups share a space. Without groups, the risk of airborne transmission approaches zero. Maximize remote interactions (online meetings and classes, food deliveries or grab-and-go, work from home, etc.) and schedule in person interactions (classes, meetings, dine in meals, etc.) only when absolutely necessary.

1.2. Move group activities outdoors whenever practical. Airborne transmission in outdoor settings is unlikely due to high ventilation rates and corresponding low aerosol concentrations. Note that direct transmission is still a concern in outdoor settings and should be controlled by adhering to social distancing guidelines.

1.3. Use health screening (e.g. temperature checks) to reduce the number of infected individuals entering a space.

2.0 **Substitution**. The hazard is an infectious person generating infectious aerosols in a space that is shared by uninfected people.

2.1. Require universal face coverings in rooms used for group activities. Face coverings can reduce the amount of infectious material that a contagious person emits into the air. This in turn will reduce the concentration of infectious material in the room air. Note that the intent is not to protect the wearer of the face covering but to limit an infected person's ability to create infectious aerosols.

3.0 **Engineering Controls**. The hazard is infectious aerosols in rooms used for group activities.

3.1. Operate ventilation systems continuously. This is a CDC/ASHRAE recommendation intended to maximize the ability of the HVAC system to dilute and remove potentially infectious aerosols from a building.

3.2. Provide outdoor air ventilation to all spaces used for group activities at no less than the prescribed minimum ventilation rates given in ASHRAE 62.1-2019 Table 6-1. This is how the Work Group interprets the guidance from CDC/ASHRAE regarding minimum ventilation rates. Setting a single standard for all spaces eliminates the need to investigate the code requirements in force when each space was constructed or remodeled. Most University spaces were constructed or remodeled under some version of ASHRAE 62.1 and the 2019 revision generally requires less outdoor air than previous versions. Expectations are that the majority of spaces used for group activities are either already meeting the ASHRAE 62.1 minimum ventilation rates or can meet them with relative ease. Verifying space ventilation rates will require some effort given the large total number of spaces.

3.3. Disable demand control ventilation (DCV) and occupancy sensor ventilation control. This is a CDC/ASHRAE recommendation. Operate ventilation system at no less than the design minimum ventilation rates regardless of occupancy.

3.4. Increase the outdoor ventilation above the design minimum rates subject to system capacity limitations. The intent is to maximize the ability of the HVAC system to remove aerosols from the building which will in turn minimize the concentration of those aerosols in the rooms. System capacity limits are highly dependent on outdoor air conditions. For fall semester (September through the end of November) the weather conditions are typically mild, and it is likely that the percentage of outside air can be increased significantly above the ASHRAE 62.1 levels for the majority of University HVAC systems.

3.5. Improve filtration to MERV-13 in select applications. Filtration should be enhanced for HVAC systems that utilize high percentages of recirculated air and serve spaces populated with high at-risk individuals. CDC/ASHRAE guidance recommends broadly enhancing filtration to MERV-13 subject to HVAC system capacity limits. The intent is to limit the amount of potentially infectious aerosols that are distributed from one space to another via the HVAC system. The Work Group recommends a much narrower interpretation of this guidance given the lack of evidence that a significant risk exists.[2]

3.6. Install UVGI systems for specialty applications only. Possible applications include systems that have high percentages of recirculated air, cannot use enhanced filtration, and serve at risk groups. Very few of these applications exist for space types considered by the Work Group.[2]

3.7. Open all windows in naturally ventilated spaces when used for group activities. Windows should be opened at least 2 hours before occupancy and remain open at least two hours after occupancy. Because natural ventilation rates are highly dependent on outdoor conditions (wind, temperature, etc.) consider using local box fans to increase the amount of air exchange in the room.

3.8. Increase total room ventilation rates in select applications only. CDC recommends increasing the total room ventilation rates (not just outdoor air ventilation rates). Increasing total ventilation rates can improve mixing within a space which can reduce the concentration of particles near a source more quickly. It can also help dilute the overall room concentration by mixing more air with other spaces served by the AHU. Increasing total room ventilation rates may be considered for spaces that cannot meet the minimum outdoor ventilation rate target (3.2) but is likely not practical for widespread implementation.

4.0 **Administrative Controls**. The hazard is infectious aerosol concentrations at the room level.

4.1. Schedule group activities to allow time for the HVAC system to reduce the level of aerosol contaminants before another group uses a space. Reduce the chance of infectious aerosols generated during one group activity infecting persons participating in a subsequent group activity. Spaces should be “purged” between uses to reduce aerosols by 95% before the next group occupies the space. Note that systems with high outdoor air ventilation rates or enhanced filtration will require little or no purge time between space uses. Systems with lower outdoor air ventilation and without enhanced filtration will require longer purge times.

4.2. Schedule spaces for group activities to maximize HVAC system diversity. For buildings with multiple air handling systems, room schedules should be designed to minimize the number of active rooms served by any single AHU. For example, if a building has three AHUs and needs three simultaneously occupied rooms it is better to have one room served by each AHU rather than a single AHU serving three rooms.

4.3. Limit the time groups of people are together indoors. The chance of a person encountering an infectious dose of an airborne pathogen is related to the time spent in a space. Engage in group activities only when no practical alternative exists and then limit the time the group is together as much as possible.

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[2] Measures such as enhanced filtration or UVGI systems should be treated as lower priority than room ventilation until there is at least some documented cases where aerosols infected with SARS-COV-2 generated in one space were transported to another space via the HVAC system and caused an infection

5.0 **Personal Protective Equipment (PPE)**. The hazard is infectious aerosols in the breathing zone.

5.1. Use N95 or better mask or respirator for high risk populations. CDC does not recommend the use of healthcare grade masks (e.g. N95) by the general public due in part to concerns about availability. However, these devices do appear provide protection if fitted and used properly and persons at high risk for infection or complications related to COVID-19 may wish to use them. Cloth face coverings that are recommended for the general population may provide some protection from airborne pathogens but likely not enough to be considered effective PPE.

Recommendations – Fall Semester 2020

There is no way of designating spaces as safe or unsafe with respect to airborne transmission of SARS-COV-2. Further, there isn't a way to quantify the risk since we do not know the infectious dose of SARS-COV-2 and we have no practical way to measure the airborne concentration of the pathogen even if the infectious dose was known. While we cannot designate a space as safe or unsafe, we can judge whether the HVAC system serving a space is capable of effectively diluting and removing airborne particles. The Work Group has identified eight of the strategies included in Table 1 (shown in **bold**) that should be implemented in all spaces used for group activities.

Strategies 1.1, 1.2, 1.3, and 2.1 represent the most effective approach to limiting airborne transmission (and transmission in general). They are obvious and not HVAC specific. The remaining four strategies, 3.1, 3.2, 3.3, and 3.7 are HVAC specific. These eight strategies comprise what the Work Group considers the Baseline HVAC Performance Expectations for group activities. Spaces that achieve baseline performance can be expected to provide reasonable control of airborne contaminants and are broadly in conformance with the intent of the CDC and ASHRAE guidance for HVAC system operation.

In addition to meeting the baseline performance, the Work Group recommends that the University also implement strategy 3.4 (increase outdoor air ventilation beyond design minimum) for the fall semester. Group activities for fall semester begin on September 8 and run through Thanksgiving before the University switches back to online-only classes. The roughly 10 week on-campus period occurs when outdoor conditions are typically mild and most HVAC systems on campus are already operating in economizer mode. Implementing strategy 3.4 during this time period will have only a modest impact on energy cost and the central utility systems should have ample capacity to serve the increased load.

In summary, the Work Group recommends implementing the strategies shown in Table 2 before a space is scheduled for group activities during fall semester.

Table 2. Fall 2020 Recommendations

1.0	Elimination		
	1.1	**Reduce the number of group activities**	**Work Group**
	1.2	**Move group activities outdoors**	**Work Group**
	1.3	**Health screening**	**Work Group**
2.0	Substitution		
	2.1	**Universal face covering requirement**	**Work Group**
3.0	Engineering Controls		
	3.1	**Operate ventilation systems continuously**	**ASHRAE**
	3.2	**Provide at least design minimum ventilation**	**ASHRAE**
	3.3	**Disable demand control ventilation**	**ASHRAE**
	3.4	Increase the outdoor ventilation	ASHRAE
	3.7	**Open windows in naturally ventilated rooms**	**ASHRAE**
4.0	Administrative Controls		
5.0	Personal Protective Equipment (PPE)		

For spaces that cannot comply with these recommendations there may be other strategies that will adequately mitigate risk (e.g. filtration, reduced frequency of use, etc.) or the space should not be used.

Recommendations – After Fall Semester 2020

The Work Group expects the guidance from the CDC, ASHRAE, and other groups to change over time. In particular, if the evidence of a significant airborne transmission risk continues to be weak (for in-room) or non-existing (for transport via HVAC systems) then most of the engineering controls listed in Table 1 will likely be scaled back or abandoned. Of course, the opposite could also be true but at present all the available evidence and published research points to HVAC systems as having a minor role (positive or negative) in the transmission of SARS-COV-2.

There are approximately 10 weeks between Thanksgiving and the expected start of in-person classes for spring semester 2021. The Work Group will issue updated recommendations at the end of October 2020 to help make decisions for winter break and spring semester. This will provide enough time to implement items like enhanced filtration should there be a need. Winter break also provides time to return systems to normal operating mode prior to spring semester if appropriate based on updated guidance and information.

Implementation – Fall Semester 2020

An outline for implementation of the Work Group engineering controls recommendations is provided below. Recommendations other than engineering controls would be implemented prior to the start of fall semester.

Near term (July)

- Schedule all HVAC systems to operate 24/7
- Disable DCV and occupancy sensor control for all systems where group activities are planned

Medium term (July through the start of fall semester)

- Assess the current ventilation rates in spaces used for group activities. Perform engineering calculations to identify spaces that comply with the minimum ventilation rate target, spaces that can comply with minor adjustments, and spaces where compliance will require significant adjustments. Verify the HVAC operations are consistent with the engineering calculations.
- Identify spaces that comply with the recommendations. For naturally ventilated spaces confirm that all windows open properly. These spaces are then considered acceptable for use with group activities.
- Identify spaces that require additional work to comply with the minimum recommendations. Create a plan for adequately mitigating the risk from airborne pathogens or choose to not use the space for group activities.
- Increase outdoor ventilation rates beyond the minimum targets per CDC/ASHRAE

Long term (until pandemic conditions end)

- Identify AHUs where enhanced filtration can have a significant impact on the risk of airborne transmission. Perform engineering calculations to determine which AHUs can operate with enhanced filtration and determine which, if any, AHU filters will be enhanced.
- Identify AHUs where UVGI systems may be appropriate.
- Continue to review updated guidance from CDC/ASHRAE and other sources as more is learned about the risk of airborne transmission. Recommend changes to the mitigation strategies based on the updated information.

Appendix A – Work Group Charge Statement

The Work Group's directive is to provide a HVAC system operational guideline for use while SARS-COV-2 (the virus that causes the disease COVID-19) pandemic conditions exist. Work Group recommendations would then be implemented as applicable across the Twin Cities campus by Energy Management and Facility Management District teams.

The Work Group's main objective is to determine if the University should make operational changes to our heating, ventilating, and air conditioning (HVAC) systems with the intention to reduce the risk of aerosol transmission of SARS-COV-2 (the virus that causes the disease COVID-19) in University facilities for the return of students to campus for 2020 Fall semester.

Appendix B – Work Group Members

The Work Group consisted of the following members:

- Bill Paulus, AVP Facilities Management
- Katharine Bonneson, AVP University Health and Safety
- David Pui, Regents Professor, Director, Center for Filtration Research
- Chenxing Pei, Ph.D. student
- Nelson Hard, UDS Contract Administration
- David Hutton, Senior Director, District Operations
- Rob Tunell, District Team leader
- Nate Ryan, District Team leader
- Mike Buck, Department of Environmental Health and Safety
- Mike Maurer, Department of Environmental Health and Safety
- Neil Carlson, Department of Environmental Health and Safety
- James Hilgendorf, Building Codes
- Jared Ellingson, Building Codes
- Mark Rossi, Building Codes
- David Danforth, Crookston
- David Walberg, Duluth
- John Rashid, Duluth
- Bradley Gibson, Morris
- Bryan Herrmann, Morris
- Erick Van Meter, Director Energy Management
- Jeff Davis AD Energy Management
- Jay Denny, Energy Management
- Jay Amundson, Energy Management

Appendix C – Mitigation Hierarchy

The Work Group scope is focused on HVAC systems which can only impact the airborne transmission of a virus. The contribution of airborne transmission to the overall transmission rate for SARS-COV-2 is not well understood but all indications are that the airborne pathway is much less important than direct transmission person to person via large droplets. Since the Work Group is part of a larger effort to recommend ways to reduce the risk of infection within University facilities it is worth discussing how mitigating the airborne transmission pathway fits within an overall infectious disease control strategy.

For this discussion we will employ the 5-step risk mitigation hierarchy that is used by the National Institute for Occupational Safety and Health (NIOSH). This hierarchy is often used to help guide risk mitigation efforts when dealing with chemical and biological hazards in labs and industry. The steps are shown in Figure 1.

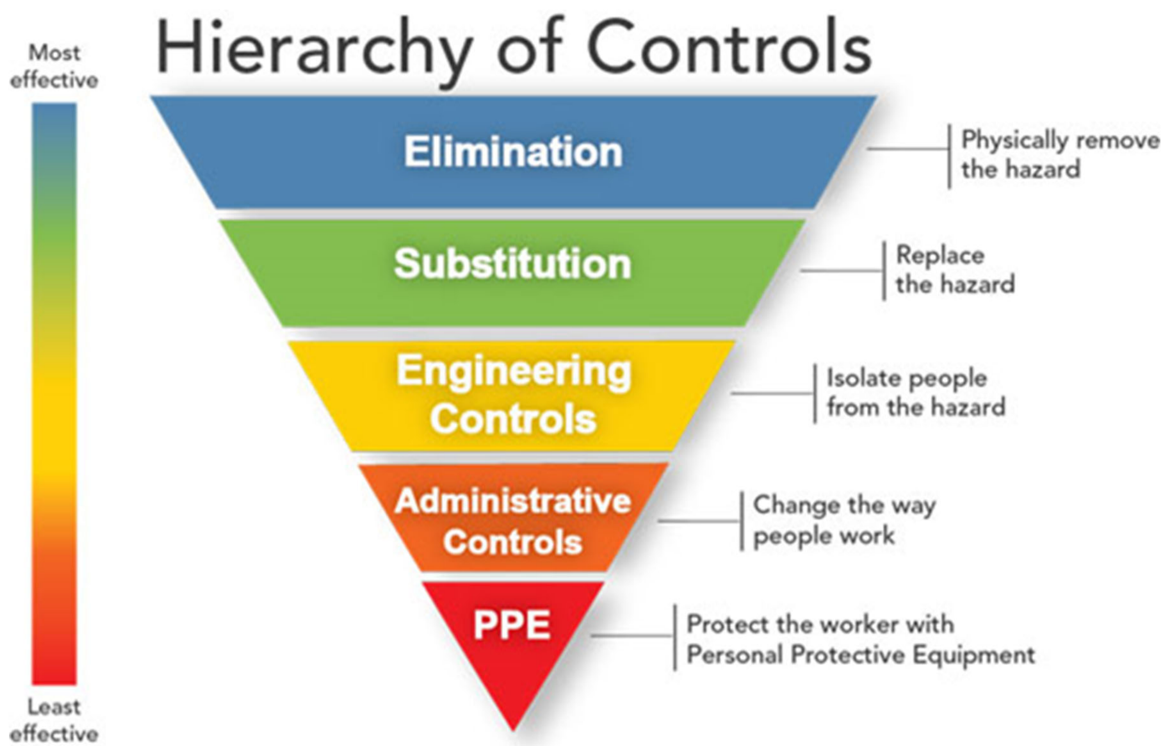


Figure 1

Examples of controls that can be applied to reduce the risk of virus transmission are shown in Table 1. Most of the Work Group scope is contained in the Engineering Controls entry in the Airborne Transmission pathway. If we take a more holistic approach to risk reduction we would work from the top left of the table (Direct Transmission pathway, Elimination controls) towards the lower right of the table (Airborne pathway, PPE). For example, the upper left box in Table 1 shows that the most effective risk mitigation strategy would be to keep infected people out of the facility (health screening) or to populate the building with people who are immune to SARS-COV-2 (vaccine). Those steps are either out of our control or likely not practical so the next best mitigation strategy would be to find a lower risk substitute for the hazard. In this case the substitution involves finding ways to make it harder for infected people to spread the virus, in effect creating a less infectious form of the virus. The obvious strategy is 100% face covering 100% of the time combined with social distancing. The face covering reduces the amount of infectious material that enters the room and limits the distance that material can travel. Note that face coverings should also reduce the total amount of aerosols that enter the room from infected people.

Table 1	Pathway		
Control	Direct Transmission	Surface Contact	Airborne Transmission
Elimination	Health Screening Vaccine	Disinfect	Health Screening
Substitution	Face Covering Social Distancing		Face Covering
Engineering	Physical Barriers	Select cleanable surfaces	Ventilation Filtration UVGI
Administrative	Stay home when sick	Stay home when sick	Stay home when sick Room Scheduling
PPE	N95 Masks Hand Hygiene	Gloves Hand Hygiene	N95 Masks

After face coverings and social distancing have been fully implemented the next level to consider is engineering control. For direct transmission this will include physical barriers to intercept large droplets when face coverings and social distancing is either not sufficient or can't be maintained. Examples might include Plexiglas barriers at cash registers or plastic dividers between rows of seats in a lecture hall. For the airborne pathway, the engineering controls are the ventilation, filtration, and disinfection systems discussed in the Work Group report.

Administrative controls are limited to encouraging people to stay home when sick, restricting the occupant density to help with social distancing, and scheduling events to minimize overlap in common spaces. Note that work from home and similar policies could be considered administrative controls but for this discussion they are treated as elimination or substitution controls because they are essentially a re-design of the work flow and are more durable than typical administrative controls.

The final control is PPE. Outside of health care facilities and a few other specialty applications there isn't an effective PPE strategy available. N95 masks and goggles should be effective at protecting an individual but current guidance discourages the use of N95 masks due to persistent shortages. In addition, the protection offered by N95 masks or similar respiratory protection is dependent on the fit. Even if N95 masks were widely available for the general public it is difficult to train everyone to use them properly. Even a poorly fitted N95 will act as a useful face covering but it may not provide much protection for the wearer themselves.

The list below includes examples of controls that could be considered as part of a holistic approach to reducing the risk of SARS-COV-2 transmission:

- Require face coverings for all labs, classrooms, residence halls, and common spaces. Resident rooms and individual offices would be exempt, but masks would be required if an office was used for a meeting.
- Posting signage with CDC guidelines in common areas, bathrooms, learning spaces, and conference rooms
- Demarcating travel patterns within the building's public and private space. Provide physical barriers when one-way travel is not possible.
- Limiting classroom and conference room capacity
- Greater emphasis on cleaning high-touch surfaces, including doorknobs and elevator buttons
- Providing disinfectant wipes and hand sanitizer stations in the lobbies
- Making new seating arrangements
- Installing shields between desks that face each other
- Requiring employees and guests to check their temperature upon arrival

Appendix D – Ventilation Calculations

The following is excerpted from the ASHRAE website https://www.ashrae.org/technical-resources/building-readiness#epidemic

The intent is to ensure that while the building is operating your ventilation schedule should assist in removing bioburden during, pre-, and post- occupancy of the building. Flush the building for a duration sufficient to reduce concentration of airborne infectious particles by 95% . For a well-mixed space, this would require 3 air changes of outside air as detailed in the calculation methodology.

In lieu of calculating the air change rate, pre- and post-occupancy flushing periods of 2 hours (for a total of 4 hours) may be used since this should be sufficient for most systems meeting minimum ventilation standards.

So for each mode, the control would be as follows:

- *Occupied: bring in the most outside air that the systems can accommodate as described above*
- *Pre- and Post-: The general method is to operate the systems in Occupied Mode for "x" hours prior to, and after, daily occupancy. Use the calculation to determine "x".*

Ventilation Control: Flushing Air Changes Calculations for Well-Mixed Spaces

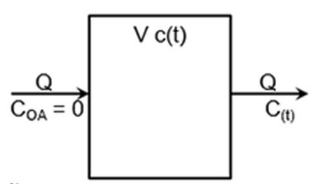
1 ACH = $c / C_0 = \exp^{-1} = 0.368$

3 ACH = $c / C_0 = \exp^{-3} = 0.050$

Therefor, 3 ACH results in the removal of 95% of the contaminants in the space for a well mixed system

During time T, contaminant in the space is equal to

Flow in – Flow out



$V * dC = (QC_{OA} - Qc) * dt$
$V * dC = -Qc * dt$
$dC / dt = -Q / V * c$
$dc / dt = -ACH * c$
$dc / c = -ACH$
$\ln c \; (c \to C_0) = -ACH * t \; (t \to 0)$
$\ln c - \ln C_0 = -ACH * t$
$\ln c / C_0 = -ACH * t$
$c / C_0 = \exp(-ACH * t)$

Assumptions:

- V = Volume
- Q = OA Flowrate
- c = space concentration
- $C(t=0) = C_0$
- $C_{OA} = 0$
- Q = constant
- $d = \triangle$

The calculations used to determine how much air is required to "flush" a building and reduce the contaminate level by 95% can be used to compare the ventilation rates in various spaces. For example, to achieve a 95% reduction in aerosol contaminants in one hour a classroom would need to operate at the prescriptive ASHRAE 62.1 ventilation rates (around 3 ACH). For applications with lower occupant density achieving a 95% reduction in one hour could require a ventilation rate that exceeds the ASHRAE 62.1 prescriptive minimums. By setting a minimum contaminant dilution rate (e.g. 95% per hour) the required ventilation rate can be calculated for each space.

Appendix E – Long Term Considerations

The SARS-COV-2 pandemic is placing severe stress on all University systems, including HVAC systems. The Work Group is focused on how best to improve safety for building occupants in the short term but there will also be lessons learned that can help guide longer term planning for the design and operation of campus facilities.

The University, as with all organizations, will have to decide how to plan for the next pandemic, one that may involve a pathogen that is more readily transmitted via airborne particles. Based on what we learn from the current pandemic how should University buildings generally, and HVAC systems in particular, be configured to best operate during the next pandemic?

The Work Group believes that the University must review the impact of the pandemic on operations and the Design Standards should be revised to help mitigate that impact where deemed appropriate. Examples of the types of questions that should be asked are listed below.

Capital Project HVAC Design Standards Questions

- Filtration Level. Should the University mandate MERV-13 for all AHUs? Note that the industry was already moving towards this level of filtration prior to the pandemic.
- Disinfection Systems. Should UVGI be specified for new AHUs going forward? Should AHUs be UVGI-ready so they can be easily retrofitted in the future?
- Ventilation. Should all AHUs be capable of 100% OA?
- Zoning. Should buildings be zoned such that it is easy to divert ventilation capacity to high priority spaces (e.g. classrooms)?
- Space Ventilation. Should higher risk spaces (e.g. large group spaces) be designed with enhanced ventilation capacity? Is there a more effective system layout that can better limit the concentration of airborne pathogens?
- Operating Modes. Should new buildings be designed and tested to operate in a “pandemic mode”? Should all buildings have a written plan for how they can be operated to minimize the potential for airborne infectious disease transmission?

Appendix F – Residential Life Considerations

The primary focus of the Work Group is on instructional spaces and other group settings where the occupants tend to enter the space, stay for a short time (60-90 minutes), and then exit. For much of the campus population (students, visitors, faculty, and staff) this will be the typical experience, short duration group activities followed by extended periods of relative isolation or at least the opportunity to isolate.

For students living on campus in University operated residence halls the situation is somewhat different. Those students will likely go from a group activity such as an in-person class and then return home to a different group setting. It is important to note that residence halls operate differently than the other spaces considered by the Work Group and will likely present significant challenges to airborne infection control. The following is a list of considerations specific to residence halls:

- Exposure time is an important variable in the rate of airborne transmission. Student's "dwell time" in a residence hall will far exceed the time spent in other group settings.
- Residence halls are open 24/7. They cannot be managed as easily as a classroom or office area.
- The population density profile in residence halls will peak during mealtimes and times when classes are not scheduled. If study spaces outside the residence halls are unavailable or study group activities are curtailed, then the population density of the residence halls will likely increase.
- HVAC system serving residence halls will likely not have much spare capacity. Normally these systems are designed to provide just the minimum code required ventilation and ventilation rates cannot be easily increased. Some residence halls have no mechanical ventilation in portions of the facility and rely on operable windows to provide the necessary ventilation. Those windows are typically controlled by the occupants and if they are not open then ventilation rates may be very low.
- Social distancing is difficult to maintain in sleeping spaces, common restrooms/showers, hallways, elevators, stairways, etc. Sleeping areas are especially challenging due to the long duration of continuous occupancy. Reducing airborne transmission rates in sleeping areas will be very difficult.

Appendix G – Implementation Procedure

Implementation of these recommendations should follow the procedures outlined below. The procedures are written specifically for classrooms but procedures for other space types would be similar. Note that there are approximately 800 spaces on campus that are designated as classrooms.

1. Obtain or create a list of spaces to be reviewed.
2. Perform an engineering analysis of the current ventilation rate for each space. The analysis will be based on design documentation and current BAS data (where available). The outcome of the analysis is to create a spreadsheet that provides a preliminary indication on whether a space complies or does not comply with the minimum ventilation standard.
3. Confirm the spaces that appear to comply are compliant in practice. This may include some on-site measurements to confirm the percentage of outside air delivered by the AHUs or spot checks of airflow readings in the spaces. Once a space ventilation rate has been confirmed the space will be deemed compliant.
4. Where the engineering analysis shows a space is likely not compliant with the minimum ventilation standard then investigate and assess what would be required to make the space compliant. Decisions about which spaces to make compliant will be made based on a variety of factors that could include the relative difficultly of achieving compliant, the relative need for the space, the practicality of using other measures to achieve compliance, etc. This will be an iterative process with the result of identifying which of the non-compliant spaces will be made compliant and how that will be done.
5. Perform an engineering analysis of the AHUs that serve the spaces identified in item 1. The analysis will focus on the heating, cooling, and fan capacity of the AHUs. The outcome will be an estimate of how much additional outdoor air the AHU can provide before the heating or cooling capacity is exceeded. In addition, the current filtration level will be identified and the practicality of improving the filtration to MERV-13 will be assessed.
6. Adjust the HVAC systems serving the non-compliant spaces per the assessment and investigation outlined in item 4.
7. Increase the outdoor air ventilation for all AHUs serving the identified spaces subject to the limits identified in item 5. Develop a plan for how to deal with extreme weather events if the increased outdoor air ventilation will cause the central utility loads to increase beyond capacity.
8. Identify AHUs where improved filter efficiency will be most useful. High percentage of recirculated air is one criteria that could be used to identify candidates for filtration upgrades.
9. Identify spaces that are either non-compliant or have a high likelihood of seeing airborne infectious agents. Assess whether local air treatment (filtration, UVGI, etc.) is appropriate for those spaces. For spaces where local air treatment is effective and the space is needed procure, install, and test the treatment devices.
10. Change AHU and VAV box schedules for 24/7 operation. Disable local occupancy sensor control of space ventilation. Disable any demand control ventilation sequences.
11. Document the changes to the spaces and AHUs and create a plan for returning the systems to normal once pandemic conditions no longer exist.