

**Ventilation Assessment and Recommendations for Safer Schools,
Restaurants, Bars, and All Other Spaces**

Background Theory and Instructions

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Introduction

This Ventilation Assessment and Recommendations document is for those trying to determine what they need to do to make their spaces more safe from infections. It is the result of research on COVID-19 from a systems perspective that started in March 2020. It is because of that research that the ventilation story broke in 2020. Other engineers and scientists were signing petitions but this research published numbers that no one could refute.

The research eventually resulted in system architecture solutions to mitigate and eliminate the COVID-19 virus. It was found that the problem is massive within small enclosed spaces, problematic in large spaces, and extremely rare in outdoor spaces. It was also found that the technology exists, is relatively low cost, and is part of the system solution in elite settings. The problem is a social problem where the technology and system solutions must find their way into all facilities especially schools, airports, airplanes, bars, restaurants, etc. where large numbers of people congregate and where the facilities are not properly maintained and use the available technologies to mitigate and eliminate contagions from the air.

This document will allow owner operators of buildings to assess their current level of virus mitigation levels in their buildings and provide information on how to increase the virus mitigation levels.

A word about the term guidelines before we move into the details. Throughout the COVID-19 disaster the term “guidelines” was used. That is an inappropriate term used to engage in management damage control. Engineers work from specifications that are testable and must be followed or the design is rejected. This document is based on the engineering method. It is not a guideline document. You either follow what is in this document or you are not compliant with the engineering needed to assess and improve your building virus mitigation levels.

A book was produced that includes the 2020 COVID-19 research published on a website 2020 and additional systems engineering content: [COVID-19 A Systems Perspective](#). This is a textbook that provides the raw information for findings that resulted in this Ventilation Assessment and Recommendations document.

Approach

The approach that is used to make your building safer from all airborne contagions is to first determine the current condition of the building and compare it with a virus mitigation scale that was developed with the COVID-19 research from a systems perspective.

The scale is based on how often the air is changed in a room. This is called air changes per hour (ACH) or air update changes (AUC). It is assumed that recirculated air is filtered and is clean just like outside air; so the terms ACH and AUC are interchangeable.

When a building assessment is performed a Virus Mitigation Certificate of Occupancy is posted in each room and for the building as a whole.

Once the current condition of the building is known then either nothing needs to be done or various upgrades can be performed as suggested in this document.

Virus Mitigation Scale

These are the engineering requirements and Contagion Mitigation Levels (CML) to assess a building and issue a Contagion Mitigation Certificate (CMC) for a building. Likely technologies are also offered to suggest how a particular CML is achieved.

Table 1 Virus Mitigation Scale

Level	State	AUC	AUC Range	Infection Risk Window Time	Airborne Contagion Mitigation System Building Condition	Likely Technologies
6	Green	120	120+	30 sec	Approaches outside ventilation conditions	Exhaust fans previously used to remove smoke filled public spaces
5	Green	50-100	50-120	1.2 min	Similar to operating room without PPE conditions in all public affected spaces	Large HVAC system + UV and or other Open windows + open doors + large fans
4	Yellow	24	24-50	2.5 min	Similar to WHO patient room airborne precautions in all public affected spaces	Small HVAC system + UV and or other Large HVAC system Open windows
3	Yellow	10-24	10-24	6 min	Similar to WHO patient room airborne precautions in most public spaces but not all	Small HVAC system + UV and or other or Large HVAC system
2	Orange	4	4-10	15 min	Marginal mitigation	Medium HVAC system (usually heater + cooling)
1	Red	1	1-4	1 hour	No mitigation, School data suggests infection happens	Small HVAC system (usually heater only)
0	Red	0	0-1	full time	No ventilation	No windows, no mechanical, no UV, no other

The following justification is offered for the CML State colors.

- **Green.** The system analysis in 2020 suggested that the living scenarios need an AUC of 50-100 and that 120+ is possible. This level tolerates mask failures such as when eating or not being worn for 1 hour. Some analysis suggests a face mask may not be needed.
- **Yellow.** Patient room visits are limited. If the time changes to a continuous stay then the risk increases. The 2020 system analysis empirical data showed that ground transportation systems are not an infection source with this AUC range, however the time is limited.

- **Orange.** This is marginal mitigation. It is what exists in most of the infrastructure today. The current infrastructure was never designed to mitigate airborne contagions. When different living scenarios are analyzed there are different levels of probability of infection. The problem is massive in small enclosed spaces, problematic in large spaces, rare in outdoor spaces.
- **Red.** We know that an AUC of 1 leads to infection. We also know that there are some infrastructure spaces where the AUC is zero.

An infected person will exhale an infection load in a very small amount of time. A cough or sneeze is orders of magnitude worse. The lower the infection risk window time, the lower the risk of infection, and the greater the mitigation level. A Level-6 certificate is the most effective indication of contagion mitigation.

When trying to understand contagions, the problem is best viewed from the perspective of how long a contagion might remain in the affected space. The Heating Ventilation and Cooling (HVAC) fan cubic feet per minute (CFM) performance metric is useful for understanding the buildup of CO₂ in a space, but not for contagion mitigation. The CFM must be coupled with the associated physical space and the AUC determined.

As part of the certification, all the ventilation CFM and physical volume data needs to be gathered to determine the AUC in each space and clearly documented. Additional information that affects the AUC is also gathered such as other mitigation technologies (natural ventilation, fans, UV, room sanitizers, etc.) and large space mitigation factors. This is captured in a site survey. This information then needs to be examined and the appropriate certification level applied to the Contagion Mitigation Certificate of Occupancy.

The AUC and CML correlations are for small indoor spaces because that is the basis of all the research data and standards. We know from empirical data that the infection rate is much lower in large indoor spaces than small indoor spaces. Modeling using the Well-Riley equation confirms this finding. This is because the large volume dilutes the virus more than the small volume and so there is less need to exchange the air.

For large indoor spaces there is additional large space mitigation that is treated as a factor that affects the final AUC level that is then used for the CML correlation. This is called the LS-AUC and it is captured in the site survey. The Well-Riley equation is used to determine this additional large space mitigation and increase the AUC that is then used to determine the CML for large indoor spaces. Basically the large building mitigation factor adjusts the AUC so that an appropriate CML correlation is performed for the large indoor spaces.

Just because a design, resulting implementation, and actual test results may yield a rating above Level 0 it does not mean that the building operates at its suggested Level. The systems could be turned off or disabled. This is especially of concern in public buildings like bars and restaurants where there is no large central maintenance organization responsible for the facility. In these buildings the certification level is drastically affected because the CML is zero when the HVAC system is not running.

One strategy is to apply a simple set of rules that modify the certification level with a ceiling cap based on the ability to bypass or mismanage the systems. The other strategy is to offer two separate certification levels, one for the equipment CML and one for the controls CML. The Contagion Mitigation Certification Level (CMCL) criteria in either case is:

Table 2 Contagion Mitigation Levels Based on Building Management

Max Possible Cert Level Max CMCL	System Operation	Risk of System Compromise	Comments
6	Fully automated with alarms	Very Low six 9s five	State of the art office building and schools
4	Fully automated	Very Low three 9s five	Office building, large schools, large retail stores
3	Manually controlled by onsite dedicated maintenance staff	Low 1%	Office building and large schools
0	Manually controlled by building users	Very High 50%	Bars, restaurants, clubhouses, retail stores

Individual certificates need to be placed in each room and then an overall building certificate in the main lobby needs to be placed in clear public view without any special access.

A building may have several Level-6 rooms but the building itself may be a Level-1 building based on a worst case finding in a portion of the building where the public may gather. The building operators can either accept the Level-1 certificate, close off the area, or upgrade that area of the building.

This is not a popular analysis finding and suggestion for a path forward. However, we have been in COVID-19 disaster mode for over a year.

Welcome to the 21st century of deadly airborne contagions.

Technologies to Boost Certification Levels

Once the certification process starts the findings will identify possible areas for improvement. The improvements may be associated with building procedures or with building systems. The following identifies technologies with the implied products and systems that can be used to boost building certification levels.

In the 2020 system analysis, various technologies were identified to mitigate contagions. The analysis identified Photocatalytic Oxidation air cleaning (PCO) but focused on the HVAC systems, Fans, Natural Ventilation, Ceiling Level UV-C lights, and Far UV-222 lights because they have the longest proven history of operation going back 80 years.

A Heating Ventilation and Cooling (HVAC) system uses fans that produce air in terms of cubic feet per minute (cu-ft). Once the fan cu-ft per minute is coupled with the size of the space serviced by the fan, then the AUC can be calculated. This an example:

Fan Size 300 cu-ft per min
Room Size 60x60x10 feet = 36,000 cu-ft
300 cu-ft per min X 60 min = 36,000 cu-ft per hour
AUC = Fan Size / Room Size = 36,000/36,000 = 1

Room Size 30x30x10 feet = 9,000 cu-ft
AUC = Fan Size / Room Size = 36,000/9,000 = 4

To increase the AUC from 1 to 4, the ventilation needs to increase by 4 times. This can happen with the addition of 4 fans or an upgraded fan that is 1200 cu-ft per min.

When dealing with systems that do not use air changes to mitigate a contagion, studies have been performed to determine the Equivalent AUC and they are specified as eAUC. For example, ceiling level UV-C systems can have an eAUC = 24 according to various studies and claims from CDC related documentation. Far UV-222 systems are new and the current conservative estimates are 4 eAUC but because its actions are a function of distance and power density it may be possible to achieve much larger eAUC ratings.

A Photocatalytic oxidation air cleaning (PCO) system bathes a space in molecules that destroy pathogens. It is assumed that it takes several minutes for the space to be filled with the molecules but once initiated the kill rate is assumed to be continuous as long as the device is in operation. If the kill rate is at 3 minutes then the effective AUC or eAUC = 20. No studies were located to add more information and provide a better understanding of these systems from an eAUC perspective. There are details such as the production rate of the molecules. For example, one product has an air processing rate of 300 CFM maximum, but if the molecules stay airborne then once initialized the coverage may be for the entire physical space for 100% of the time. As always there are engineering details associated with system sizing and resulting performance.

Each space is unique and some technologies are more appropriate for a particular space than others. The solution needs to be a system integration solution providing the most effective system. The available technologies to boost certification levels are:

Table 3 Technologies to Boost Certification

Technology	Possible AUC	Source	Comments
Typical HAVC system	4	Current standards	Only when on
Special HAVC system	60	Current standards	Only when on
Fans	100	Analysis	Only when on
Open Windows	37	WHO	Only when open
Ceiling Level UV-C	24	CDC	Continuous airborne eAUC
Far UV-222	4+	Columbia University	Continuous airborne and surface, eAUC is much higher but needs to be validated with more analysis
PCO	20	Active Pure	Continuous airborne and surface eAUC

Technology	Possible AUC	Source	Comments
Outside space	3600	Analysis	Continuous full space operation

Building Assessment Procedure

The procedure to assess the Contagion Mitigation Level (CML) of a building is to start with a site survey that examines the building design and then verifies the claimed design numbers by performing ventilation tests. Once the site survey is completed, calculations are performed and questions are answered. The result will be a CML that is used to fill out a Contagion Mitigation Certificate (CMC). The CMC is then posted in each room and at the building entrance for the building as a whole.

These are the steps for a small owner operator. Large buildings have staff that know what to do and they will follow their own procedures.

Procedure:

1. All HVAC systems have the fan size noted on the HVAC system as either a standalone number or encoded in the model number of the HVAC system.
2. Measure each room including the ceiling height to determine the cubic feet.
3. Calculate the AUC = Fan Size / Room Size for each room.
4. Remember to multiply the fan cubic feet per minute by 60 to get the cubic feet per hour.
5. There may be multiple zones. Do each zone separately.
6. Use the Virus Mitigation Scale to assign the CML to each area. Use a spreadsheet.
7. Proceed to the Assessment questions.

Note: As part of the assessment it is assumed that the HVAC system fan is on 100% of the time that the public is present and that the filters are properly maintained. If at anytime the HVAC fans are off and or the filters are not maintained the CML is automatically a Level 0.

Site Survey Spreadsheet

The following example is provided for a spreadsheet that is to be populated with the site survey data. In the case of a restaurant or bar, a spreadsheet is probably not needed. Outside air or properly filtered air can be treated as equivalent. Some systems will use a large amount of fresh air and it needs to be added to the filtered air.

Table 4 Site Survey Spreadsheet Example

1 Classroom ID / Area ID Number					6 Square Footage					11 AUC				
2 Classroom / Area Type supplied					7 Square Footage Occupancy (SqFt / 44)					12 Cert Level				
3 Mechanical System Clean Air CFM					8 Max Occupancy per Room					13 Mitigation AUC				
4 Mechanical System Occupancy (CFM/15)					9 Type of Unit					14 Mitigation Cert Level				
5 PCO Unit Installed					10 cu-ft 8 ft ceiling									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
-	Auditorium	2,417	161		3,234	73	73	Air Handling Unit	25,872	6	2	6	2	
-	Gym/Cafeteria	322	21		3,432	78	21	Air Handling Unit	27,456	1	0	1	0	

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1 Classroom ID / Area ID Number 2 Classroom / Area Type supplied 3 Mechanical System Clean Air CFM 4 Mechanical System Occupancy (CFM/15) 5 PCO Unit Installed					6 Square Footage 7 Square Footage Occupancy (SqFt / 44) 8 Max Occupancy per Room 9 Type of Unit 10 cu-ft 8 ft ceiling				11 AUC 12 Cert Level 13 Mitigation AUC 14 Mitigation Cert Level				
1	2	3	4	5	6	7	8	9	10	11	12	13	14
-	Main Office	161	10		468	10	10	Unit Ventilator	3,744	3	1	3	1
-	Faculty Room	0	0		104	2	0	Unit Ventilator	832	0	0	0	0
100	Classroom	452	30		960	21	21	Unit Ventilator	7,680	4	1	4	1
101	Classroom	409	27		960	21	21	Unit Ventilator	7,680	3	1	3	1
102	Classroom	125	8	Yes	782	17	17	Unit Ventilator	6,256	1	1	21	3
103	Classroom	485	32		1,470	33	32	Unit Ventilator	11,760	2	1	2	1

Site Survey Questions

The following example is provided as an example of site survey questions.

1. Is each room measured in real time for ventilation rates and if there is a drop an alarm is activated? If yes the building management CML is 6.
2. Is each room measured in real time for ventilation rates? If yes the building management CML is 4.
3. Is the HVAC system manually controlled by onsite dedicated maintenance staff? If yes the CML is 3.
4. Is the HVAC system Manually controlled by building users? If yes the CML is 0.

Healthy Infrastructure

The Philadelphia Water Works was the first water treatment facility in the United States. It was a model for all future water works to follow in the New World. People would flock from around the planet to see this facility which combined engineering and art to solve a massive problem of safe water for the inhabitants of Philadelphia. It was born of necessity as the people decided they would not tolerate yet another yellow fever outbreak. The Museum sits on top of the original water reservoir that provided the city with water.

As Philadelphia grew the reservoir and Water Works could no longer meet the needs of the city and new projects eventually replaced this once great technological and artistic achievement. It stopped operations in 1909.

When I took the picture I knew nothing of the Water Works or its history. Like many things in our world it was invisible to me, until now. I only knew of its beauty in a very urban landscape setting. And so it is with all our infrastructure. There is massive science and engineering behind it that keeps us safe and healthy when it is properly designed, implemented, maintained and operated each and every day.



Figure 1 Philadelphia Art Museum and Water Works

A post vaccine world implies that everyone has received a vaccine against the COVID-19 virus but we know that will not happen. In the USA some will refuse the vaccine. In many countries the poor will not have access to the vaccine. The idea of a post vaccine world also suggests that we can return to the pre-COVID world but we know that is not the case. The contagion and its variants will be in the environment for decades. This is not unlike the situation that existed in the early part of the last century where there were deadly contagions that were part of normal life. It was not until multiple technologies were introduced in multiple systems that there was a decline in many deadly contagions in the USA and other parts of the world. These technologies and systems were embedded in:

- Clean water systems
- Proper sewer systems
- Proper waste removal sanitation systems
- Proper housing and removal of high density tenement housing with no ventilation
- Forced air HVAC systems
- Effective use of ceiling level UV-C ventilation systems
- Use of contagion resistant materials (furniture, table surfaces, building materials, etc.)
- Use of contagion resistant high touch surfaces (railings, door fixtures, toilet fixtures, etc.)

Appendix A

Contagion Mitigation Certification Examples

Philadelphia School District

The Philadelphia School District performed a site survey of their schools and published the findings on the school district website. Each school is captured in a separate tab in the spreadsheet. There are 220 tabs suggesting that there are 220 schools that were surveyed. Each row represents a space in the school with an appropriate name that conveys the space use. There are over 12,000 rooms.

The spreadsheet was converted to a single tab spreadsheet so that all the spaces in all the schools could be easily analyzed for AUC and Contagion Mitigation Level (CML). The CML is the number used for the Contagion Mitigation Certification Level (CMCL).

The pre-contagion mitigation results are as follows. [[Certification Spreadsheet](#)]

Table 5 Contagion Mitigation Certificate Before Upgrades

Room Ratings			Overall District Rating			
AUC Range	Cert Level CMCL	Number of Rooms	AUC Range	Cert Level	Building Average AUC	Building Cert Level CMCL
120+	6	1	120+	6		
50-100	5	25	50-100	5		
24	4	73	24	4		
10 to 24	3	462	10 to 24	3		
4 to 10	2	2574	4 to 10	2		
1 to 4	1	4554	1 to 4	1	3.8	1
0 - 1	0	2476	0 - 1	0		

The overall District Rating is 1 Red before contagion mitigation.

The post contagion mitigation results are as follows.

This school district moved from Level 1 Red to Level 2 Orange.

We also see that a large number of rooms moved from Level 1 Red to higher levels with a significant jump into Level 3 Yellow.

The Level 3 category is approaching hospital room airborne contagion mitigation levels.

Table 6 Contagion Mitigation Certificate After Upgrades

Room Ratings			Overall District Rating			
AUC Range	Cert Level CMCL	Number of Rooms	AUC Range	Cert Level	Building Average AUC	Building Cert Level CMCL
120+	6	1	120+	6		
50-100	5	25	50-100	5		
24	4	101	24	4		
10 to 24	3	2935	10 to 24	3		
4 to 10	2	2547	4 to 10	2	7.7	2
1 to 4	1	4166	1 to 4	1		
0 - 1	0	1721	0 - 1	0		

There was 1 room that was rated at Level 6 and 25 rooms rated at Level 5. They are as follows:

Table 7 Contagion Mitigation Certificate Levels per Room

Space	AUC	Certification Level CMCL	Comments
Classrooms	64	5	
Classrooms	70	5	
Classrooms	76	5	
Autobody	73	5	
Sheet Metal	50	5	
Warehouse Classroom	114	5	
Factory Lab	69	5	
Offices	327	6	Thomas Edison High School - Offices is the row label
Janitor Close and Storage Rooms	82	5	
CAFE	70	5	
Classroom	57	5	
Gym	57	5	
Asist Prince	117	5	
Classroom	72	5	
Office	73	5	
Classroom	79	5	
1st Flr Kitchen	68	5	
Exercise	105	5	
Storage	105	5	
Boiler Rm.	118	5	
Classrooms	60	5	
Nurses	59	5	

Space	AUC	Certification Level CMCL	Comments
Kitchen	51	5	
Kitchen	53	5	
MEDIA LAB B	71	5	
Gym- Weight Room A	51	5	

The Philadelphia School District purchased 2000+ Active Pure systems. For this analysis it is assumed that the Active Pure systems have an eAUC = 20. This is similar to a ceiling level UV-C system. Again eAUC of 20 for the Active Pure system is based only on some broad assumptions in this analysis and the number may be significantly smaller. However for this analysis the best case is selected. In both instances, UV-C or PCO, the costs are approximately the same, \$1500 retail price per unit. It is unclear what the negotiated prices might be for a large purchase like the Philadelphia School District.

What If Analysis

A What If Analysis can be performed using the Philadelphia School District site survey. The site survey provided data to calculate the AUC, CML, and CMCL. The data shows that the school district purchased 2500 PCO like systems to help with classroom ventilation. This allowed the school district to move from a CMCL of 1 to 2 and it moved 2000+ rooms into CMCL 3. This analysis increases the number of PCO like systems to determine its impact on the overall school district CMCL rating. The analysis is approximate and is based on the total district cubic feet, AUC, and number of rooms. This results in a slightly different AUC number than when the individual room AUCs are calculated. This is an artifact of the site survey data where in some instances cubic feet is provided but no ventilation number is provided. Regardless the results are similar and what is desired is a What If Analysis to determine the effect of adding more mitigation technology units. The results are as follows.

For the analysis the following data was used:

Table 8 Site Survey Summary Data

eAUC / PCO	20	Assumption based on vendor claims
Total cu-ft	92,871,681	site survey data
Total HVAC CFM	4,337,033	site survey data
Total HVAC AUC	38,489	site survey data

The analysis results are:

Table 9 Contagion Mitigation Certificate Levels Possible

Num PCO Units	Total eAUC	Total AUC	AUC	CML CMCL	Cost	PCO / Room	Comments
0	0	38,489	3.0	1			
2503	50,060	88,549	6.9	2	\$3,754,500	0.19	From site survey.

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Num PCO Units	Total eAUC	Total AUC	AUC	CML CMCL	Cost	PCO / Room	Comments
4503	90,060	128,549	10.0	3	\$6,754,500	0.35	If the technology complements the HVAC system then the system quickly jumps to CML 3
6503	130,060	168,549	13.1	3	\$9,754,500	0.51	This does not impact the overall rating for the school district but it continue to the number of rooms to the next CML level.
8503	170,060	208,549	16.2	3	\$12,754,500	0.66	
10503	210,060	248,549	19.4	3	\$15,754,500	0.82	
12503	250,060	288,549	22.5	3	\$18,754,500	0.97	
14503	290,060	328,549	25.6	4	\$21,754,500	1.13	It is unclear if over dosing the space with the PCO technology is an issue.
16503	330,060	368,549	28.7	4	\$24,754,500	1.29	Eventually the HVAC system becomes irrelevant
18503	370,060	408,549	31.8	4	\$27,754,500	1.44	Multiple units per room is probably not appropriate for most technologies. What needs to happen is the either other additional technologies are added into the system or the technology performance is increased. For example, instead of HVAC + PCO move to HVAC + PCO + UV but there may be compatibility issues that need to be understood.
20503	410,060	448,549	34.9	4	\$30,754,500	1.60	
22503	450,060	488,549	38.0	4	\$33,754,500	1.75	
24503	490,060	528,549	41.2	4	\$36,754,500	1.91	
26503	530,060	568,549	44.3	4	\$39,754,500	2.06	
28503	570,060	608,549	47.4	4	\$42,754,500	2.22	
30503	610,060	648,549	50.5	5	\$45,754,500	2.38	
32503	650,060	688,549	53.6	5	\$48,754,500	2.53	
34503	690,060	728,549	56.7	5	\$51,754,500	2.69	
36503	730,060	768,549	59.8	5	\$54,754,500	2.84	
38503	770,060	808,549	63.0	5	\$57,754,500	3.00	
40503	810,060	848,549	66.1	5	\$60,754,500	3.15	
42503	850,060	888,549	69.2	5	\$63,754,500	3.31	
44503	890,060	928,549	72.3	5	\$66,754,500	3.47	
46503	930,060	968,549	75.4	5	\$69,754,500	3.62	
48503	970,060	1,008,549	78.5	5	\$72,754,500	3.78	
50503	1,010,060	1,048,549	81.6	5	\$75,754,500	3.93	

Num PCO Units	Total eAUC	Total AUC	AUC	CML CMCL	Cost	PCO / Room	Comments
52503	1,050,060	1,088,549	84.8	5	\$78,754,500	4.09	
54503	1,090,060	1,128,549	87.9	5	\$81,754,500	4.24	
56503	1,130,060	1,168,549	91.0	5	\$84,754,500	4.40	
58503	1,170,060	1,208,549	94.1	5	\$87,754,500	4.56	
60503	1,210,060	1,248,549	97.2	5	\$90,754,500	4.71	
62503	1,250,060	1,288,549	100.3	5	\$93,754,500	4.87	
64503	1,290,060	1,328,549	103.5	5	\$96,754,500	5.02	
66503	1,330,060	1,368,549	106.6	5	\$99,754,500	5.18	
68503	1,370,060	1,408,549	109.7	5	\$102,754,500	5.33	
70503	1,410,060	1,448,549	112.8	5	\$105,754,500	5.49	
72503	1,450,060	1,488,549	115.9	5	\$108,754,500	5.65	
74503	1,490,060	1,528,549	119.0	5	\$111,754,500	5.80	
76503	1,530,060	1,568,549	122.1	6	\$114,754,500	5.96	The point of the What If Analysis was to determine what it would take for the system to reach a CML of 6.

If the technology complements the HVAC system then the system quickly jumps to CML 3. It is unclear if over dosing the space with the PCO technology is an issue. Eventually the HVAC system becomes irrelevant. Multiple units per room is probably not appropriate for most technologies. What needs to happen is either other additional complementary technologies are added into the system or the individual technology performance is increased. For example, instead of HVAC + PCO move to HVAC + PCO + UV or HVAC + PCO + Fans with filtration ([Classroom & Other Designs](#)) or HVAC + PCO + [Negative pressure per person systems](#) but there may be compatibility issues that need to be undersold.

Other Buildings Based On Existing Standards

The starting point for Contagion Mitigation Certification Level assessments is to examine the current standards. The standards do not reflect the actual building design and implementation but they are a starting point for what the best case expected results might be after the assessment.

There is a spreadsheet with several hundred Area Types (Rooms) identified with various AUC standard numbers that are expected to be used in the design of a physical space. [[spreadsheet ACH CML](#)]

The Certification Levels below are based on the Max AUC standard from the various sources in the spreadsheet. [[spreadsheet ACH CML](#)]

Table 10 Contagion Mitigation Certificates With Current Standards

Area	AUC min	AUC max	Source	Cert Level CMCL
Hospital Trauma room	15	-	CDC	3 yellow

Area	AUC min	AUC max	Source	Cert Level CMCL
Hospital room airborne precautions	24	-	WHO	4 yellow
Hospital operating room	25	-		4 yellow
Hospital rooms	6	10	EPA	2 orange
Restaurants	8	12	EPA	2 orange
Restaurants	8	20	NCI	3 yellow
Restaurants	15	20	wiki	3 yellow
Bar	15	30	Greencheck	4 yellow
Bar	15	20	NCI	3 yellow
Bar	15	20	wiki	3 yellow
School Classroom	4	12	EPA	3 yellow
Auditorium	8	15	EPA	3 yellow
Assembly Hall	6	8	EPA	2 orange
Classroom (Art)	16	20	EPA	3 yellow
Malls	6	10	EPA	2 orange
Office	8	30	Greencheck	4 yellow
Engine Room	20	60	Greencheck	5 green
Kitchen	12	60	Greencheck	5 green
Kitchen	7	8	NCI	2 orange
Kitchen	14	18	NCI	3 yellow
Kitchens (commercial)	15	30	EPA	4 yellow
Retail	6	10	NCI, wiki, EPA	2 orange
Laboratory	12	30	Greencheck	4 yellow
Laboratory	6	12	wiki	3 yellow
Club Houses	20	30	EPA	4 yellow
Theatres	8	15	EPA	3 yellow

There are no design standards that would result in a Level 0 or 1 Red condition as long as the lower limits of the standard were not picked for the design. Some of the design standards are Level 5 Green.

Just because a design, resulting implementation, and actual test results may yield a rating above Level 0 it does not mean that the building operates at its suggested Level. The systems could be turned off or disabled. This is especially of concern in public buildings like bars and restaurants where there is no large central maintenance organization responsible for the facility. In these buildings the certification level is drastically affected because the CML is zero when the HVAC system is not running. One strategy is to apply a simple set of rules that modify the certification level with a ceiling cap based on the ability to bypass or mismanage the systems. The other strategy is to offer two separate certification levels, one for the equipment CML and one for the controls CML. In either case the criteria might be:

Table 11 Contagion Mitigation Levels Based on Building Management

Max Possible Cert Level Max CMCL	System Operation	Risk of System Compromise	Comments
6	Fully automated with alarms	Very Low six 9s five	State of the art office

Max Possible Cert Level Max CMCL	System Operation	Risk of System Compromise	Comments
			building and schools
4	Fully automated	Very Low three 9s five	Office building, large schools, large retail stores
3	Manually controlled by onsite dedicated maintenance staff	Low 1%	Office building and large schools
0	Manually controlled by building users	Very High 50%	Bars, restaurants, clubhouses, retail stores

An approach to capture this information in a certificate, that is physically posted in the building, is to provide the building Contagion Mitigation Level when the system is on and the Contagion Mitigation Level when the system is off (because of the high risk of system compromise). This can be accomplished with two separate certification ratings on the same physical certificate document: Contagion Mitigation Level and Contagion Mitigation Controls. The following are examples:

Table 12 Example Certificate 1:

Building	Contagion Mitigation Level	Contagion Mitigation Controls
Bar and Restaurant	Level 5 GREEN	Level 0 RED

Table 13 Example Certificate 2:

Building	Contagion Mitigation Level	Contagion Mitigation Controls
Large Retail Store	Level 5 GREEN	Level 4 Yellow

Table 14 Example Certificate 3:

Building	Contagion Mitigation Level	Contagion Mitigation Controls
State of the art School	Level 5 GREEN	Level 6 Green

Notice that Certificate 3 has a higher rating for the controls than the general Contagion Mitigation Level. This suggest that the school still has the possibility of adding higher levels of system performance to mitigate airborne contagions.

Product Certification Testing Strategies

The purpose of this Product Certification Testing Strategy is to test and evaluate various products and systems for airborne contagion mitigation. The goal is to provide a common engineering metric that can be used in the design of effective airborne contagion mitigation systems. Most of the studies in the past 50 years are associated with Air Update Rates (AUC) or Air Changes Per Hour (ACH). There is a difference between the two where one represents the introduction of fresh air. For this test and evaluation platform there will be no introduction of fresh air. This will allow solutions other than HVAC systems and Fans to be evaluated like UV systems, PCO systems, and others systems that do not use air exchange as part of the mitigation mechanism.

The test approach is to use a controlled Known Test Bed (KTB) or gold standard and then a Target Test Bed (TTB) containing the product and or system under test. The approach is to use 2 separate clean rooms and feed them from a single airborne contagion source using a Y-pipe. The purpose of the Y-pipe is to ensure that each test bed receives the same amount of airborne contagion. Petri dishes are to be uniformly distributed in the same locations after the clean rooms are initiated to an ISO-3 level condition. The recommended locations are on the walls and in the spaces 3 feet apart at the 3, 6, and 8 foot levels. The size of each test bed is recommended to be a real world setting of 30 x 30 x 10 feet or 9,000 cubic feet. Each test bed is to use identical construction, materials, and configurations. The test beds are to be a minimum of ISO-3 or FED-STD-209E Class 1 rooms.

Table 15 ISO-14644-1 and FED-STD-209E

ISO-14644-1	ISO-ACH	FED-STD-209E	FED-ACH
ISO-1			
ISO-2			
ISO-3	360-540	Class-1	
ISO-4	300-540	Class-10	
ISO-5	240-480	Class-1,000	
ISO-6	150-240	Class-10,000	
ISO-7	60-90	Class-100,000	
ISO-8	5-48	Class-1,000,000	
ISO-9		Room Air	

The following are the broad test steps to certify products and subsystems for contagion mitigation.

1. Place the product or system to be tested in the TTB.
2. Initialize the KTB and TTB to an ISO-3 level environment for one hour to ensure similar relatively low contagion levels in each test bed.
3. Place Petri dishes spaced 3 feet apart at the 3, 6, and 8 foot levels.
4. Scrub the KTB and TTB to an ISO-3 level environment for 10 minutes to remove any contamination introduced during test setup.
5. Simultaneously turn on the KTB and TTB mitigation systems starting with a KTB ACH of 1.
6. Turn on the contagion source within 10 seconds of turning on the KTB and TTB mitigation systems.
7. Run the test chambers for 1 hour.

8. Turn off the contagion source.
9. Turn off the KTB and TTB mitigation systems within 10 seconds of turning off the contagion source.
10. Run the test for the following ACH levels: 1, 4, 10, 20 (product claim), 24, 37 (open windows), 50, 60, 100 (fans level), 120, other above 120 if needed
11. Allow the cultures to grow for 24 hours or more if needed.
12. Perform a culture count and compare the KTB with the TTB findings.
13. Where the culture counts are the same for the KTB and TTB, that is the resulting eAUC rating for the product or system under test.
14. Repeat the test a minimum of 3 times.
15. Repeat all tests with the ACH levels running in both the KTB and TTB to determine the results of an integrated solution using HVAC ACH mitigation plus the product or system under test.
16. Perform sensitivity and boundary analysis to provide the final eAUC rating for the product or system under test and the combined eAUC + ACH levels.
17. Report both the standalone eAUC and the combined ACH + eAUC

It is expected that eventually high levels of ACH for an integrated solution that uses an HVAC system will make most products or systems under test ineffective. For example high levels of ACH will prevent a ceiling level UV system from acting on contaminated air. That is why both test conditions must be performed: (1) the first is just the product and system under test and (2) the second is the product or system under test with an operating HAVC system in the same room.

The contagion must be as close to the contagion that is the current threat. In the case of a virus this requires live subjects like test mice. However, various bacteria in a Petri dish may be a good indicator of what to expect for a viral contagion. For a bacteria / viral calibration testing, mice in small cages can be used in place of the Petri dishes during early test and evaluation efforts.

The above proposed Product Certification Testing Strategy is a path forward that industry can handle and it will allow people to make proper engineering based choices when performing the system analysis and integration of contagion mitigation systems.

References:

1. COVID-19 A Systems Perspective, Walter Sobkiw, 2021, ISBN 9780983253044, hardback.

Appendix B Site Survey Forms and Certificates

The following forms are to be used to conduct a site survey of the facility. The forms include gathering the following:

- Rooms Site Survey
- HVAC System Site Survey

Once the data is collected an assessment form is provided. Once the assessment is completed a blank certificate form is provided. It is to be completed and signed by the site survey inspector. The assessment and certificate forms are:

- Contagion Mitigation Level Assessment
- Building Management Assessment
- Room Contagion Mitigation Certificate Details
- Building Contagion Mitigation Certificate Details
- Room Contagion Mitigation Certificate
- Building Contagion Mitigation Certificate

Room Site Survey

Number _____ Room Name _____

Length _____ Width _____ Height _____ Cubic Feet _____

1. If the room ventilation is Natural Ventilation using windows:Number of Windows _____ Fully Open ☐ Yes ☐ No Not Blocked ☐ Yes ☐ NoIf Windows are open Door is Fully Open ☐ Yes ☐ No Not Blocked ☐ Yes ☐ No

If windows are open AUC is 4 if the door is open and not blocked or there is other cross ventilation AUC is 37. If windows are closed or blocked w-AUC = 0.

w-AUC _____

2. If the room ventilation uses Exhaust Fans:

Number of Exhaust Fans _____

Intake vents Fully Open ☐ Yes ☐ No Not Blocked ☐ Yes ☐ No

Total Exhaust Fans CFM _____

If the room is serviced by exhaust fans the $AUC = \text{Fan CFM} / \text{Room Cubic Feet}$

f-AUC _____

3. If the room ventilation uses Forced Air System:Is the Room Serviced By a Forced Air Heating System ☐ Yes ☐ NoIs the Room Serviced By a Forced Air Heating and Cooling System ☐ Yes ☐ NoIs there a Fan On option on the HVAC system ☐ Yes ☐ NoNumber of Exhaust Vents _____ Fully Open ☐ Yes ☐ No Not Blocked ☐ Yes ☐ NoNumber of Intake Vents _____ Fully Open ☐ Yes ☐ No Not Blocked ☐ Yes ☐ NoVisual Streamers on all Ventilation Vents ☐ Yes ☐ No

If there was a room Ventilation Test performed: Total Room CFM _____

AUC = Test CFM / Room Cubic Feet

t-AUC _____

Transfer a-AUC from the HVAC Site Survey Form

a-AUC _____

Note: If a test was performed and it deviates from the HVAC survey then an analysis must be performed to determine the source of the difference. For example there could be mechanical dampers that are closed or leaking ducts.

When t-AUC is available then h-AUC = t-AUC; otherwise h-AUC = a-AUC.

h-AUC _____

4. If the room ventilation uses UV-C System:

Number of UV-C Fixtures _____ Model _____

Total Watts _____ (eAUC typically 24) **eAUC** _____

Public View On/Off Indicators ☐ Yes ☐ No Automated Alarms ☐ Yes ☐ No

5. If the room ventilation uses Far UV System:

Number of Far UV Fixtures _____ Model _____

Total Watts _____ (eAUC typically 4) **eAUC** _____

Public View On/Off Indicators ☐ Yes ☐ No Automated Alarms ☐ Yes ☐ No

6. If the room ventilation uses Room Air Sanitizer System:

Number of Air Sanitizers _____ Model _____

Total CFM _____

s-AUC = CFM X 60 / Room Cubic Feet **s-AUC** _____

Public View On / Off Indicators ☐ Yes ☐ No Automated Alarms ☐ Yes ☐ No

7. If the room ventilation uses Room Photocatalytic Oxidizer or other System:

Number of Units _____ Model _____

Rooms Site Survey Form

Claimed effective ep-AUC _____ Test Authority _____

Total CFM _____

p-AUC = CFM X 60 / Room Cubic Feet or ep-AUC **p-AUC** _____

Public View On / Off Indicators ☐ Yes ☐ No Automated Alarms ☐ Yes ☐ No

8. Full Room AUC assessment:

Total AUC = h-AUC + e-AUC + s-AUC + p-AUC (Forced air systems) or

Total AUC = w-AUC + e-AUC + s-AUC + p-AUC (Natural ventilation systems) or

Total AUC = f-AUC + e-AUC + s-AUC + p-AUC (Exhaust Fans ventilation systems)

Massive w-AUC or f-AUC will reduces all other AUC levels and make them ineffective.

Total AUC _____

9. Large Space Mitigation:

If AUC is greater than 4 there is a Large Space Mitigation factor that will increase the Final AUC. Use the following factors to calculate the Final AUC.

Cubic Feet	Large Space Mitigation Factor	<p>If Total AUC is less than 4: Final AUC = Total AUC Else: Final AUC = Total AUC X Large Space Mitigation Factor</p>
400,000	<input type="radio"/> 7.75	
300,000	<input type="radio"/> 5.94	
200,000	<input type="radio"/> 4.14	
100,000	<input type="radio"/> 2.35	
50,000	<input type="radio"/> 1.49	
20,000	<input type="radio"/> 1.06	
< 20,000	<input type="radio"/> 1.00	

LS Factor _____

Final AUC _____

10. Additional site survey data:

Room Occupancy Sign Posted ☐ Yes ☐ No Occupancy Number _____

Public Present During Site Survey ☐ Yes ☐ No

Data Entered Directly Into Computer ☐ Yes ☐ No

Printout Attached To This Form ☐ Yes ☐ No

11. Contagion Mitigation Level (CML) Assessment

Using the Contagion Mitigation Level Assessment Form enter the following information:

Note: Large spaces have a factor that increases the AUC to account for dilution.

LS Factor ____ AUC _____ CML ____ Color _____

Transfer this information to the Room Contagion Mitigation Certificate.

12. Notes and Observations:

Inspector Signature _____ Date _____

HVAC System Site Survey**Forced Air Heating System** ☐ Yes ☐ No**Forced Air Heating and Cooling System** ☐ Yes ☐ No**HVAC Zone Name** _____**HVAC Model Number** _____**HVAC Fan Size in Cubic Feet Per Minute (CFM)** _____

Physically examine unit to find fan size or examine model number and cross reference to find the fan size. Do not trust the HVAC maintainer or original design documentation.

Number of Rooms Serviced by this Zone _____**Total Cubic Feet Serviced By This Zone** _____

Identify each room by Room Survey Number and add the individual cubic feet to find the total cubic feet. List Room Survey Numbers:

HVAC Zone a-AUC _____

If there is no Fan On option on the HVAC system enter 0. System must operate 100% of the time when the public is present not just when it is providing heating or cooling. If there is a Fan On option the AUC is the HVAC Fan Size in Cubic Feet Per Minute (CFM) X 60 minutes divided by Total Cubic Feet Serviced By This Zone. The a-AUC = $CFM \times 60 / \text{Cubic Feet}$. Go back and enter the a-AUC into the associated Room Site Survey Forms.

Automated Alarms ☐ Yes ☐ No**Manual Dampers in Ducts** ☐ Yes ☐ No**Thermostat Control** ☐ Facility Maintainers ☐ Users (do not check if locked)**Thermostat Locks Removed** ☐ Yes ☐ No**Visible Vent Manually Controlled** ☐ Yes ☐ No**System Fans on 100% of the time 24/7** ☐ Yes ☐ No**System Fans on 100% of the time when public is present** ☐ Yes ☐ No**Notes and Observations:****Inspector Signature** _____ **Date** _____

Contagion Mitigation Level and Building Management Assessment

Contagion Mitigation Level Assessment

The Contagion Mitigation Level (CML) assessment is performed by examining the final AUC for each room and comparing it to the CML Scale. The scale is as follows.

Table 16 Contagion Mitigation Level Scale

CML Scale	State	Final AUC	AUC Range	Infection Risk Window Time	Airborne Contagion Mitigation System Building Condition	Likely Technologies
6	Green	120	120+	30 sec	Approaches outside ventilation conditions	Exhaust fans previously used to remove smoke filled public spaces
5	Green	50-100	50-120	1.2 min	Similar to operating room without PPE conditions in all public affected spaces	Large HVAC system + UV and or other Open windows + open doors + large fans
4	Yellow	24	24-50	2.5 min	Similar to WHO patient room airborne precautions in all public affected spaces	Small HVAC system + UV and or other Large HVAC system Open windows
3	Yellow	10-24	10-24	6 min	Similar to WHO patient room airborne precautions in most public spaces but not all	Small HVAC system + UV and or other or Large HVAC system
2	Orange	4	4-10	15 min	Marginal mitigation	Medium HVAC system (usually heater + cooling)
1	Red	1	1-4	1 hour	No mitigation, School data suggests infection happens	Small HVAC system (usually heater only)
0	Red	0	0-1	full time	No ventilation	No windows, no mechanical, no UV, no other

Go back to each room assessment and enter the appropriate Level and Color based on the Final AUC. Once all the sheets are completed find the maximum and minimum AUC and CML assessment for the building and enter the data here:

Max AUC _____

Min AUC _____

Max CML _____

Min CML _____

Max CML Color _____

Min CML Color _____

Transfer this information to the Room and Building Contagion Mitigation Certificate.

Contagion Mitigation Level and Building Management Assessment

Building Management Assessment

Once the ventilation assessment results are complete the Building Management Assessment needs to be performed. A system only works if it is running. Most systems are turned off. A series of questions were asked during the site survey that will be used to determine the building management results.

CML Rating	State	System Operation	Compromise Risk
6	Green	Fully automated with alarms	Lowest
4	Yellow	Fully automated	Very Low
3	Yellow	Manually controlled by onsite dedicated maintenance staff	Low
0	Red	Manually controlled by building users	Very High

Examples based on the site survey questions:

If windows are used and they are blocked or not opening the CML = 0.

If Exhaust Fans are used and there are no visual streamers on the intake then the CML = 0

If Exhaust Fans are used but they are manually controlled by building users the CML = 0.

If Exhaust Fans are used the level can increase based on the system operation criteria in the table.

If an HVAC system is used and there is no Fan On option the CML = 0

If an HVAC system is used and the exhaust or intake vents are blocked the CML = 0

If an HVAC system is used and there are no visual streamers on all vents the CML = 0.

If an HVAC system is used and there are Automated Alarms the CML = 6

If an HVAC system is used and there are manual dampers in ducts the CML = 0 until locked in place and tamper protected.

If an HVAC system has Thermostat Controls that can be accessed by users the CML = 0

If an HVAC system Thermostat Control Lock has been removed the CML = 0

If an HVAC system vents are Visible and can be Manually Controlled the CML = 0.

If there is a UV-C system and the public can access the On/Off switches the CML = 0.

If there is a UV-C system and there are Automated Alarms the CML = 6.

If there is a Far UV system and the public can access the On/Off switches the CML = 0.

If there is a Far UV system and there are Automated Alarms the CML = 6.

Room Contagion Mitigation Certificate Details (Office Access)

Room Contagion Mitigation Certificate Details

CML Rating	State	AUC Range	Risk Window	Airborne Contagion Mitigation System Building Condition	Room place X
6	Green	120+	30 sec	Approaches outside ventilation conditions	
5	Green	50-120	1.2 min	Similar to operating room without PPE conditions	
4	Yellow	24-50	2.5 min	Similar to WHO patient room airborne precautions	
3	Yellow	10-24	6 min	Similar to WHO patient room airborne precautions	
2	Orange	4-10	15 min	Marginal mitigation	
1	Red	1-4	1 hour	No mitigation, data suggests infection happens	
0	Red	0-1	full time	No ventilation, infection happens	

AUC _____

Large Space Factor _____

CML _____

Color _____

Room Operational Management Assessment

CML Rating	State	System Operation	Compromise Risk	Room place X
6	Green	Fully automated with alarms	Lowest	
4	Yellow	Fully automated	Very Low	
3	Yellow	Manually controlled by onsite dedicated maintenance staff	Low	
0	Red	Manually controlled by building users	Very High	

CML _____

Color _____

Final Building CML rating (lowest value from above)

CML _____

Color _____

Self Inspection Signature

Date

Independent Inspector Signature

Date

Government Inspector Signature

Date

Only one signature is needed others are optional



Contagion Mitigation Level and Building Management Assessment (Office Access)

Building Contagion Mitigation Certificate Details

CML Rating	State	AUC Range	Risk Window	Airborne Contagion Mitigation System Building Condition	# of Rooms
6	Green	120+	30 sec	Approaches outside ventilation conditions	
5	Green	50-120	1.2 min	Similar to operating room without PPE conditions	
4	Yellow	24-50	2.5 min	Similar to WHO patient room airborne precautions	
3	Yellow	10-24	6 min	Similar to WHO patient room airborne precautions	
2	Orange	4-10	15 min	Marginal mitigation	
1	Red	1-4	1 hour	No mitigation, data suggests infection happens	
0	Red	0-1	full time	No ventilation, infection happens	

Max AUC _____

Min AUC _____

Max CML _____

Min CML _____

Max CML Color _____

Min CML Color _____

Building Operational Management Assessment

CML Rating	State	System Operation	Compromise Risk	# of Rooms
6	Green	Fully automated with alarms	Lowest	
4	Yellow	Fully automated	Very Low	
3	Yellow	Manually controlled onsite dedicated maintenance staff	Low	
0	Red	Manually controlled by building users	Very High	

CML _____

Color _____

Final Building CML rating (lowest value from above)

CML _____

Color _____

Self Inspection Signature

Date

Independent Inspector Signature

Date

Government Inspector Signature

Date

Only one signature is needed others are optional



Room Contagion Mitigation Certificate (Posted in Room)

Room Contagion Mitigation Certificate

Building Owner Operator:

Building Name:

Building Address:

Room Name:

Room Number:

Equipment Level

CML Rating	State	Room
6	Green	
5	Green	
4	Yellow	
3	Yellow	
2	Orange	
1	Red	
0	Red	

Place only one X

Controls Level

CML Rating	State	Room
6	Green	
4	Yellow	
3	Yellow	
0	Red	

Place only one X

CML - Contagion Mitigation Level.
Level 6 is best Level 0 is worst.

The Contagion Mitigation Certificate details are available in the office.

Signature

Date

☐ Self Inspection ☐ Independent Inspector ☐ Government Inspector (check one)



Building Contagion Mitigation Certificate (Posted in Lobby)

Building Contagion Mitigation Certificate

Building Owner Operator:

Building Name:

Building Address:

Number of Rooms:

Equipment Level

CML Rating	State	Building
6	Green	
5	Green	
4	Yellow	
3	Yellow	
2	Orange	
1	Red	
0	Red	

Place X or room count
in each applicable Level

Controls Level

CML Rating	State	Building
6	Green	
4	Yellow	
3	Yellow	
0	Red	

Place X or room count
in each applicable Level

CML - Contagion Mitigation Level.
Level 6 is best Level 0 is worst.

The Contagion Mitigation Certificate details are available in the office.

Signature

Date

☐ Self Inspection ☐ Independent Inspector ☐ Government Inspector (check one)

License Key: _____

LICENSE AGREEMENT

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