Project 18: COVID 19 Reduction in Classrooms– Final Presentation

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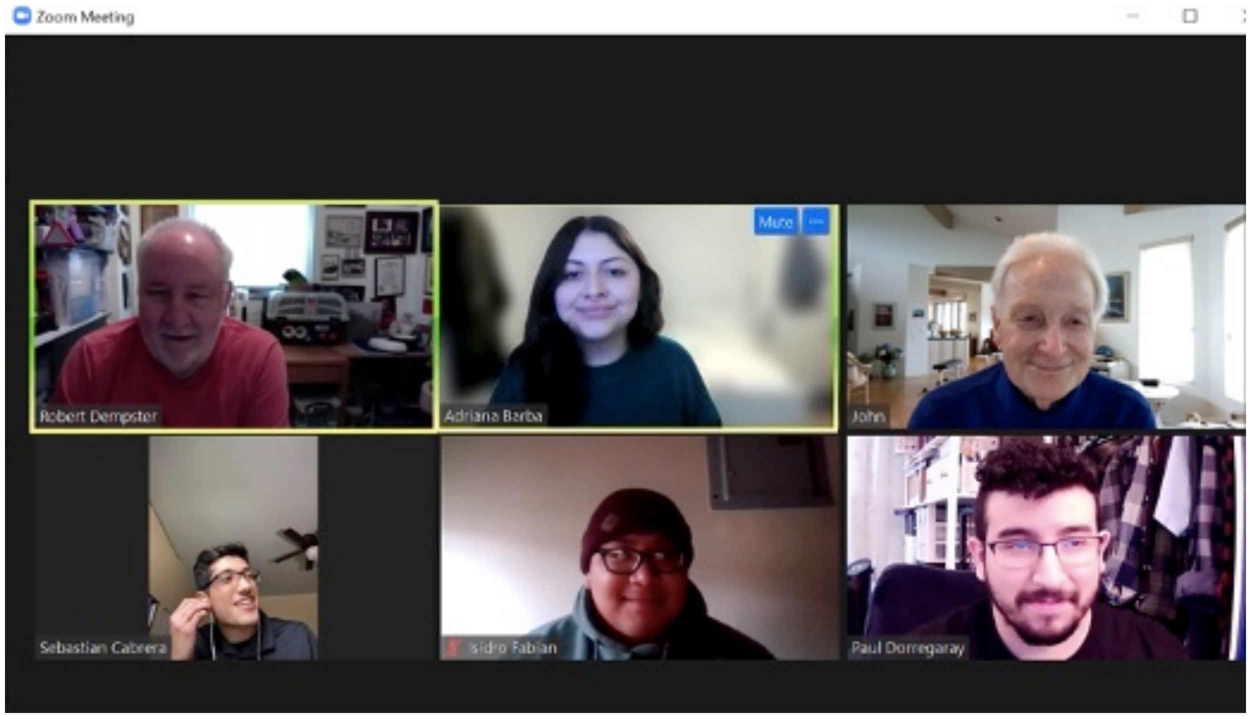

Agenda

I. Project Objective, Background, and Requirements
II. Technical Details
III. Results & Recommendations
IV. Summary

I. Project Objective & Background

Project Objective

- The purpose of this project is to design a system that reduces the COVID-19 virus density to a safer level for students.

Requirements

The Project Requirements are to:

- Significantly reduce SARS-CoV-2 particles in the air of a standard classroom area of 1000 ft^2 with a ceiling height of 9 ft.
- Remove SARS-CoV-2 particles in a classroom with an occupancy defined by the current state regulations.

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COVID-19 Background and Transmission

- The Coronavirus disease 2019 (COVID-19) is caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2).
- This disease can be transmitted from person to person by means of **droplets**, **aerosols**, and **fomites**[1]
- **Droplets** - >(5 – 10)μm in diameter[1]
- **Aerosols** - $\leq$5μm in diameter[1]
- **Fomites** - a virus-contaminated surface caused through droplets[2]
- The following slide is a visual example of these various forms of transmission.

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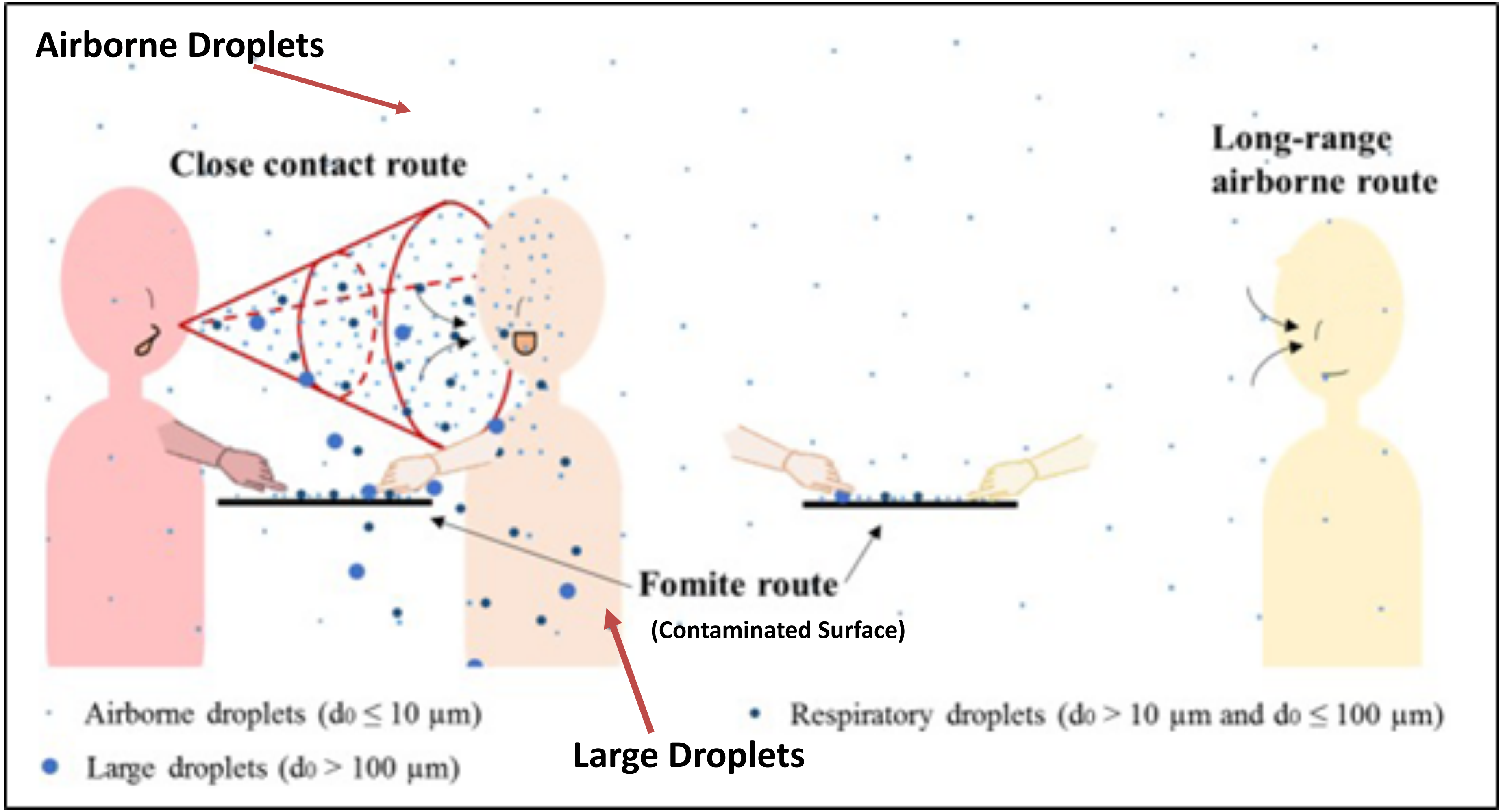

Fig. 1 – Graphic contrasting differences between droplets, fomites, and aerosol transmission[3] (**d**o being the average size of the particle)

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COVID-19 Background and Transmission

- Although droplets, aerosols, and fomites are all confirmed forms of transmission for COVID-19, a large proportion of the spread is occurring through **aerosols produced by asymptomatic individuals.[4]**
- SARS-CoV-2 particles have been found to remain as infectious aerosols in confined indoor spaces for many hours(up to 72 hours in a closed room).[1]
- The dangerous characteristic of SARS-CoV-2 is its ability to remain infectious in aerosol form.
- There are several important environmental factors that must be considered when dealing with the viability of airborne viruses[1] :
    - Temperature (Low -> increased half-life)
    - Humidity (High -> increased half-life)
    - Radiation/UV Index (Sunlight) (Low -> increased half-life)

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II. Technical Details

Probability of Viral Transmission

- Probability of infection is dependent on the Infectious Dose or viral load, which is the number of virions (complete virus) needed for likely infection
- Infection is a function of the transmission of droplets or aerosol with viral load into the lungs and deposition into the respiratory tract
- Larger droplets deposited in the upper tract of the respiratory system cause less severe infection, while smaller droplets penetrate into the lower respiratory tract and can cause severe infections[11]
- The Infection Dose for COVID-19 is not clear but is estimated to be about 1000 virions (from the original L strain)
- They key values to look at when trying to minimize the risk of infection in a classroom are given below [12]
    1. The concentration of infectious virus(C virions/m^3) in the air can be calculated with
        - C = G / Q
            - Where G is generation of virions by infectious person(virions/min)
            - Q is ventilation rate (m^3/min)
    2. An infected person with SARS-CoV-2 can generate 1000 virions/nL of expelled saliva
- In the table below, sneezes and coughs are discrete events while talking and breathing are continuous

Human Activity	Volume of Saliva	virions/min (G)
Sneeze	1 µL (1000 nL)	10^6 (1 sneeze/min = 1,001,000/min)
Cough	100 nL	10^5 (1 cough/min = 101,000/min)
Talking	10 nL/min	10^4
Breathing	1 nL/min	10^3

Table 1: Various activities or actions and the generation of airborne saliva

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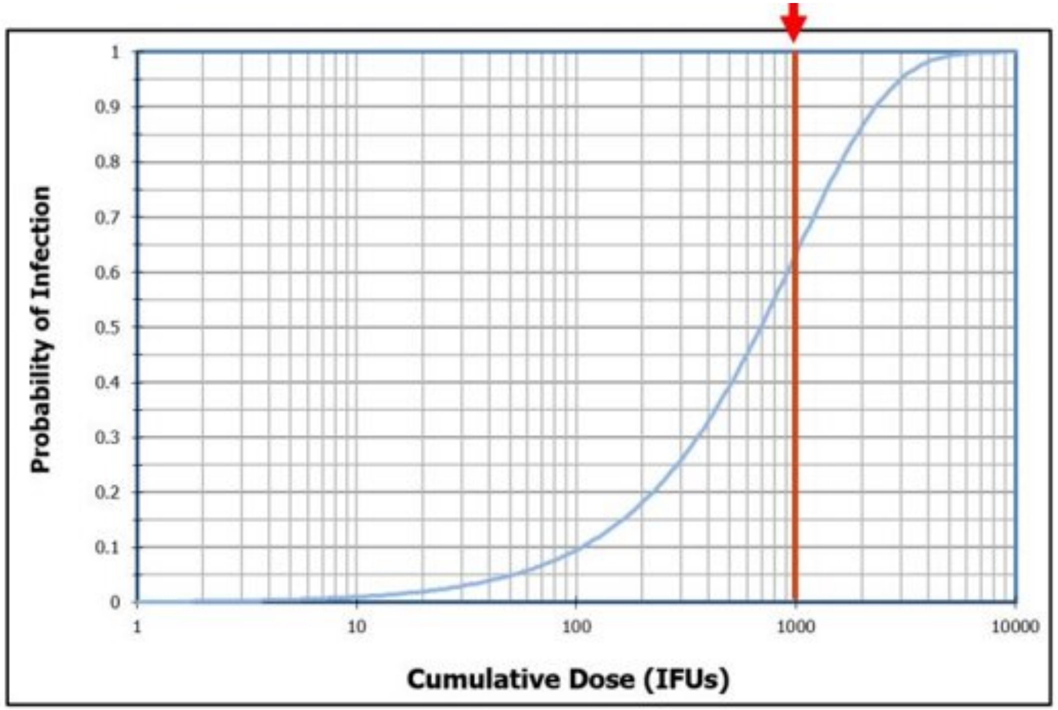
Probability of Viral Transmission

1. Air circulation and concentration of viral particles calculations:
   - Ventilation rate(m^3/min) **Q = nV**
   - Number of air changes(1/min)(**n**)
   - Volume of room(m^3)(**V**)
2. These values can be used to calculate the time(T) in minutes required to reduce the viral concentration in a room
   - $T_1 = -(V / Q) \ln (C_2 / C_1)$
   - Where C_2 is the desired lower concentration(ex 0.1 virions/m^3) and C_1 the generation of virions by infectious person
3. Exposure dose can be calculated with
   - $D = (C)(Q_{br})(t_2)$
   - Where Q_{br} is breathing rate(m^3/min) and t_2 is time exposed in minutes and **C** is initial concentration
4. This value is then used to find the probability of infection using the equation and graph:
   - Where $D_{infectious}$ is the estimated Infectious dose
   - Ex: a dose of 986 virions would have an estimated 62% chance to cause infection

- Ideally the probability of infection should be kept under 60% which is at the infectious dose that would likely cause infection of an individual

62% Probability of Infection



Graph 1 : showing 62% Probability of infection at a dose of 986 virion

- Estimate the probability of infection*

$$P(infection) = 1 - \exp\left(-\frac{D}{D_{infectious}}\right)$$

$D_{infectious}$ = infectious dose = 1000 virions (estimated; not known for SARS-CoV-2)

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Indoor CO2 Level Buildup measures possible increased COVID-19 infection

Table 2: CO2 Levels and their corresponding descriptions. [13]

Carbon Dioxide Level (ppm)	Description
250-350	Normal outdoor air level
350-1,000	Typical level found in occupied spaces with good air exchange
1,000-2,000	Level associated with complaints of drowsiness and poor air

Fig. 2: Air changes per hour and their respective levels of safety. Green being the best, red being the worst. [15]

- Carbon Dioxide (CO2) is co-exhaled with aerosols containing SARS-CoV-2. **[14]**
- Knowing this, we can associate elevated CO2 levels with possible increased COVID-19 infection.
- CO2 concentration can be measured (in ppm) to determine how well a room is ventilated, as seen in **Table 2 [13]**.

- Another factor in determining how well a room is ventilated is the amount of air changes per hour (ACH).
- Well ventilated rooms have high (5 or more) ACH. Whereas, poorly ventilated rooms may have less than 3 ACH, as observed in **Fig 2**.
- Both CO2 levels and ACH are used to monitor the air purity indoors.
- For example, a room with a high ACH (above 5), will have a low CO2 level (under 1000 ppm).

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Indoor CO2 Level Buildup measures possible increased COVID-19 infection (cont.)

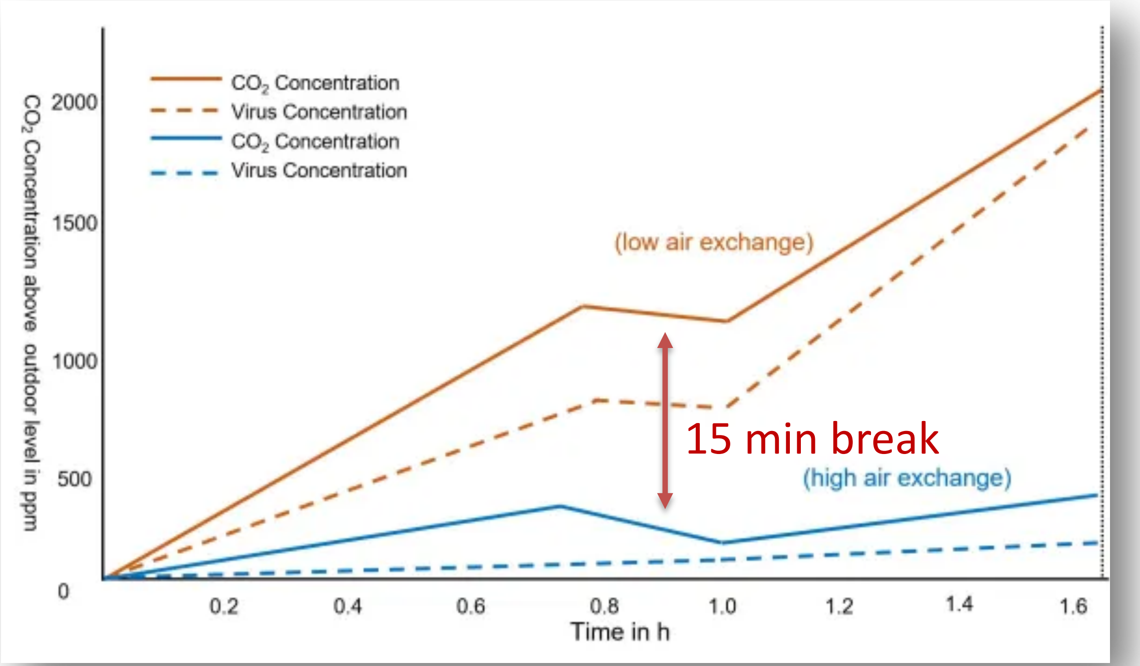

Fig. 3: The increase of the concentration of CO2 above outdoor level (450ppm) (left axis) in a classroom over the duration of two lessons with a 15 min break. The low air exchange rate being 0.5 ACH and the high air exchange rate being 4 ACH. [16]

- Poor ventilation can create a thriving habitat for long-range airborne transmission (over 6 ft) of the virus.
- The data in **Figure 3** was from a study conducted on aerosols loaded with viral particles.
- From this example, we can observe just how much of an impact ventilation rates affect aerosol viral concentration.
- We could also observe how great of an indicator CO2 is for determining the efficiency of a ventilation system.
- There are many factors that could affect the concentration of the virus at single points in the room (ex: number of infected persons, mixing ventilation rates, etc.)
- This is a scenario was conducted using ideal rates and assumptions for simplicity.

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Viability of SARS-CoV-2 based on Environmental Parameters

- Viruses in aerosols may lose or gain viability and infectivity due to environmental stress (i.e. temperature extremes, sunlight, humidity). [1]

- Research has shown that the viability of aerosolized SARS-CoV-2 can be lowered indoors by increasing the following environmental parameters: **sunlight exposure (Ultra-Violet index)**, **temperature**, and **relative humidity**[1][5][6]

- Fig. 4 breaks down what UV Index is and assists in understanding how UV Index applies to viral stability (As mentioned in following slide).

- To assist us further in understanding **aerosol viability**, we have compiled tables using data from the U.S. Dept of Homeland Security on the airborne decay of the virus on the following slide. [7]

UV index table

UV-Index Level	Exposure Category	Colour Code	Precautions
2 or less	Low		You can safely stay outdoors with minimal protection.
3 to 5	Moderate		Wear a hat, sunscreen, sunglasses or seek shady areas.
6 to 7	High		Wear a hat, sunscreen, sunglasses or seek shady areas. Stay indoors between 10am and 2pm (11-3 daylight saving time).
8 to 10	Very High		Stay indoors as much as possible, otherwise use all precautions above.

Fig. 4: UV Index chart highlighting the only applicable index for our project. [8]

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Viability of Aerosolized SARS-CoV-2 based on Environmental Parameters: Best- and Worst-Case Scenarios

Half-Life times of Aerosolized SARS-CoV-2 at UV Index: 0 (No Sunlight)

Humidity vs. Temperature	*40%*	*45%*	*50%*	*55%*	*60%*
70°F	218 min	168 min	137 min	116 min	100 min
71°F	203 min	159 min	131 min	111 min	97 min
72°F	190 min	151 min	126 min	107 min	94 min
73°F	179 min	144 min	121 min	104 min	91 min
74°F	169 min	137 min	116 min	100 min	88 min
75°F	160 min	131 min	111 min	97 min	85 min

Half-Life times of Aerosolized SARS-CoV-2 at UV Index: 2 (Some Sunlight)

Humidity vs. Temperature	*40%*	*45%*	*50%*	*55%*	*60%*
70°F	34 min	32 min	31 min	30 min	29 min
71°F	33 min	32 min	30 min	29 min	28 min
72°F	32 min	31 min	30 min	29 min	28 min
73°F	32 min	31 min	29 min	28 min	27 min
74°F	31 min	30 min	29 min	28 min	27 min
75°F	31 min	30 min	28 min	27 min	26 min

- In both tables:
  - Red indicates- Maximum half-life time
  - Yellow indicates- Moderate half-life time
  - Green indicates- Minimum half-life time
- This data will assist us to model a virus spill in a classroom if it occurs and how long it will take to safely re-enter the classroom.
- From these tables, we were able to conclude how much significance sun-generated UV plays in reducing the viability of the aerosolized virus.
- It is possible to **decrease the half-life of the virus by 70-85%** simply by allowing some sun-generated UV into a classroom.

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UV-C Trade Table Analysis

UV-C Method	Upper Air UV-C	Far UV-C
Unit Cost	Fixture ~$875-1500 Bulb : ~$75	Prototype : ~$1000+ Bulb and ballast: ~$355
Operating Costs	$22 per year electricity cost(per 25 watt fixture)	~$10 per year
Life Expectancy Bulbs	2 yrs (continuous use)	3 yrs (continuous use)
Sanitation	Upper Air UV-C uses 254nm wavelength which is the range of most effective germicidal rate	Far-UV-C at 222nm is less effective
Installation Safety Precautions	Must be installed correctly and at a specific height to be considered safe	Safe with direct contact
Ease of Use/Maint	Usage dependent on HVAC system and air flow	No intensive required since is a standalone unit
Efficacy	Effectiveness of sanitation is dependent on adequate airflow provided by HVAC system and air exchange rate	Doesn't depend on a separate system to be effective, thus can easily work conjointly with other method
Supported history of effectiveness and safety	Upper Air has been used to help reduce TB transmission in hospitals without negative side effects to patients in rooms since 1960s	Relatively new system, research is promising and shows no negative effects or damage to human cells, and is effective in killing corona-viruses in rooms

- Upper Air UV-C and Far UV-C were the two types of UVGI(Ultraviolet Germicidal Irradiation) that were looked at to inactivate, by damaging virus DNA enough to lower the propagation of infectious particles in the air.
- Upper Air UV-C is the system of germicidal irradiation that directed into the upper area of the room (7ft or higher portion) and is dependent on the air cycling by the HVAC system to work.
- Upper Air UV-C is the suggested choice for this project despite Far UV-C having more desired attributes.
- Although Far UV-C is more flexible in its application and usage Upper Air UV-C is a more readily available option.
- Upper Air UV-C also has a history of safety and usage in hospital settings and is used in conjunction with HVAC systems which complement our current design path.

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Trade Analysis Portable Air Purifiers

- Air purifiers are devices which remove contaminants from the air in a room to improve indoor air quality.
- The ACH (Air Change per Hour) and CADR (Clean Air Delivery Rate) ratings are the most important specs of an air purifier.
- Researched portable air purifiers to look for: CADR rating, which shows how effective an air purifier is.
- Project classroom size = $1000ft^2$
- CADR=600cfm

Calculating Your CADR Score

The clean air delivery rate (CADR) is the volume of filtered air that an air purifier delivers into a room. According to Association of Home Appliance Manufacturers, you should look for an air purifier that has a CADR score that's at least roughly two-thirds the size of your room's area.

Room Size (in feet)	Square Footage	Recommended CADR Score
3 x 5	15	10
5 x 6	30	20
8 x 10	80	50
10 x 12	120	80
12 x 16	192	120
12 x 18	216	140
16 x 16	256	160
16 x 20	320	200
20 x 20	400	250

CADR = [(ACH x L x W x H) / 60 min] cfm
Length(L) [ft], Width(W) [ft],Height(H) [ft]
Minute(min)

I.F

Portable Air Purifiers Trade Table

Air Purifier	Filter(s)	Coverage	Filter size	Ultraviolet light(UV)
Air Doctor ~$429	UltraHEPA: Captures: 99.95% of particles ONLY .3microns small	~ up to 900 square feet(ft^2) CADR(Clean Air Delivery Rate): ~ MAX CADR: 450 cubic feet per minute(cfm)	ULTRAHEPA ~ 17.17 x 13.86 x 2.05 inches Carbon filter ~ 16.7 x 13.2 x 1.5 inches	N/A
EnviroKlenz mobile uv air purifier ~ $899	HEPA filter: removes 99.97% impurities down to 0.3 microns	~cover up to 1000 square feet (ft^2) Maximum CADR: ~250 Cubic feet per minute(cfm)	HEPA filter: 14x14x14 EnvioKlenz-Air cartridge: 14x14	Come with 100-380nm fluorescent lamp wavelengths: 253.7nm
Coway AP-1512HH ~$249	TrueHEPA filter: catches particles just .03microns in size Captures 99.95%	~cover up to 326 square feet(ft^2) Maximum CADR:~268 cubic feet per minute (cfm)	HEPA filter: 15x13x1.5 ODOR filter: 15xx13x1.5	N/A

- Items in green are good attributes
- Items in red are bad attributes
- The EnviroKlenz mobile UV-C air purifier has green across the table.
- Enviroklenz is the only one with built in UV-C virus/bacteria killing lights
- We have chosen Enviroklenz to be the recommended air filter because it covers 1000 sq ft, has a HEPA filter and a built in UV-C light.

I.F

Filter Trade Table Analysis

Table 3: MERV Table

MERV	HVAC FILTER EFFECTIVENESS	PARTICLE SIZE EFFICIENCY IN MICRONS: Small 0.3-1.0 µm	Med. 1.0-3.0 µm	Large 3.0-10.0 µm
1	DUST/LINT, DUST MITES, POLLEN			>20%
2				>20%
3				>20%
4				>20%
5	DUST/LINT, DUST MITES, POLLEN, MOLD			Up to 20%
6				Up to 35%
7				Up to 50%
8	DUST/LINT, DUST MITES, POLLEN, MOLD, PET DANDER, BACTERIA		Up to 20%	Up to 70%
9			Up to 35%	Up to 75%
10			Up to 50%	Up to 80%
11		Up to 20%	Up to 65%	Up to 85%
12		Up to 35%	Up to 80%	Up to 90%
13	DUST/LINT, DUST MITES, POLLEN, MOLD, PET DANDER, BACTERIA, ATTACHED VIRUSES	Up to 50%	Up to 85%	Up to 90%
14		Up to 75%	Up to 90%	Up to 95%
15		Up to 85%	Up to 90%	Up to 95%
16+		Up to 95%	Up to 90%	Up to 95%

ULPA: Ultra –Low Particulate Air Filter

HEPA: High Efficiency Particulate Air Filter

- The American Society of Heat Refrigerating and Air Conditioning Engineers (ASHRAE) follows the Minimum Efficiency Reporting Value (MERV) which is a scale of 1-20 with the higher value being more efficient at air filtering. Based on MERV Ratings viruses are filtered when a filter has a MERV rating of 13-20.
- Based on Table 3 we require a minimum of MERV13 rating for either HEPA or ULPA filter to help reduce the risk of spreading airborne viruses. ASHRAE already recommends at least a MERV 13 rating for any filters used for education sites when possible.

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Filter Trade Table Analysis

Table 4: Filter Trade Table

Air Filter Type	Efficiency	Smallest Particle Filtered	MERV	Cost
ULPA	Filter has an efficiency of 99.99%, although it would be beneficial to filtration of virus particles. It would create higher air flow resistance.	Filters particles as small as 0.1 microns	Has a MERV rating of 16+	Much more expensive than other filters, $430.
HEPA	Filter efficiency of 99.97% of particles.	Works at the 99.97% efficiency for particles as small as 0.3 microns	Usual MERV Rating ranges are 13-17	Much more economical, $155

Based on Table 3 in order to filter out virus particles we require a filter with at least a MERV rating of 13. Table 4 compares the two high efficiency particulate filters that are available. It should be noted that a HEPA filter is within the range recommended by the MERV rating for filters filtering viruses.

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HVAC Parameters

The recommended parameters for hospital facilities provided by both ASHRAE and the CDC:

- No less than MERV 13 and MERV 14 preferred for systems that are not serving specialized environments that may require even higher efficiency filtration.
- Temperature 70 – 75 degrees F
- Humidity – consider maintaining 40-60% Relative Humidity.

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III. Results & Recommendations

Classroom Configurations & Dimensions

Pre-Pandemic SH Classroom Setup

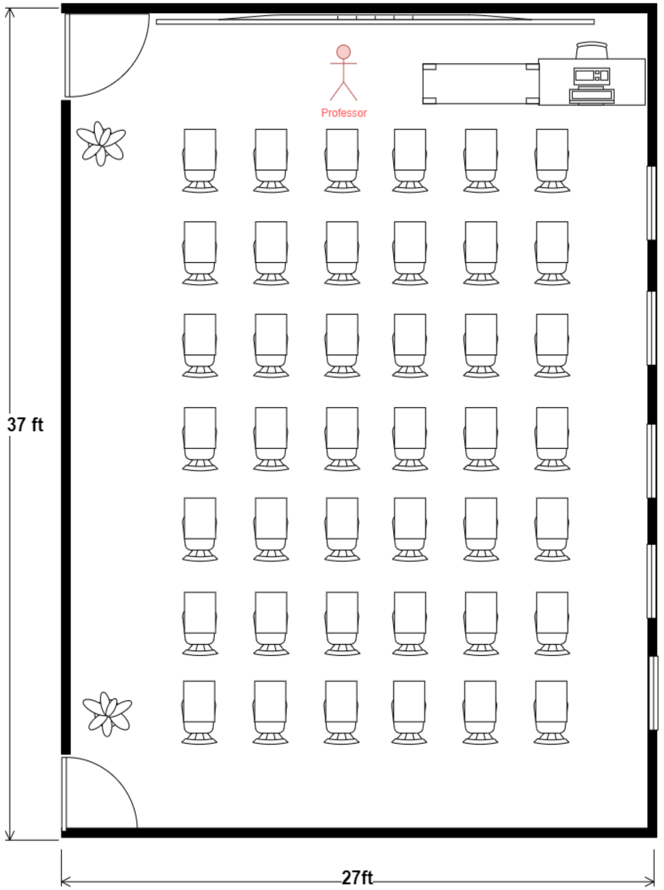

Fig. 5: Pre-pandemic Salazar Hall classroom setup, no social distancing whatsoever

- **Figure 5** shows the original configuration for a pre-pandemic Salazar Hall classroom.
- **Table 5** shows the dimensions that we gathered for the classroom.

Table 5: Information gathered from facilities services for dimensions of a CSULA SH classroom.

Dimensions of a CSULA Salazar Hall Classroom	
Width	27 ft
Length	37 ft
Height	9 ft
Area	~1000 ft^2
Maximum Occupancy	47 Students

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Pandemic-era Classroom Configurations & Dimensions

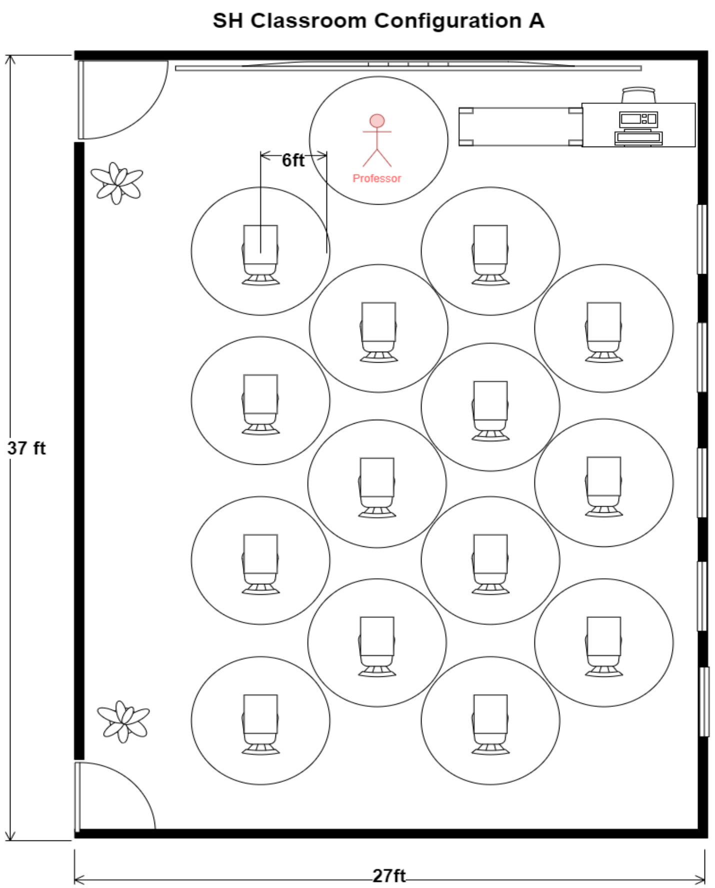

Fig. 6: Pandemic-era Salazar Hall classroom "Hex" seating arrangement with social distancing guidelines in mind. **Total students: 14**

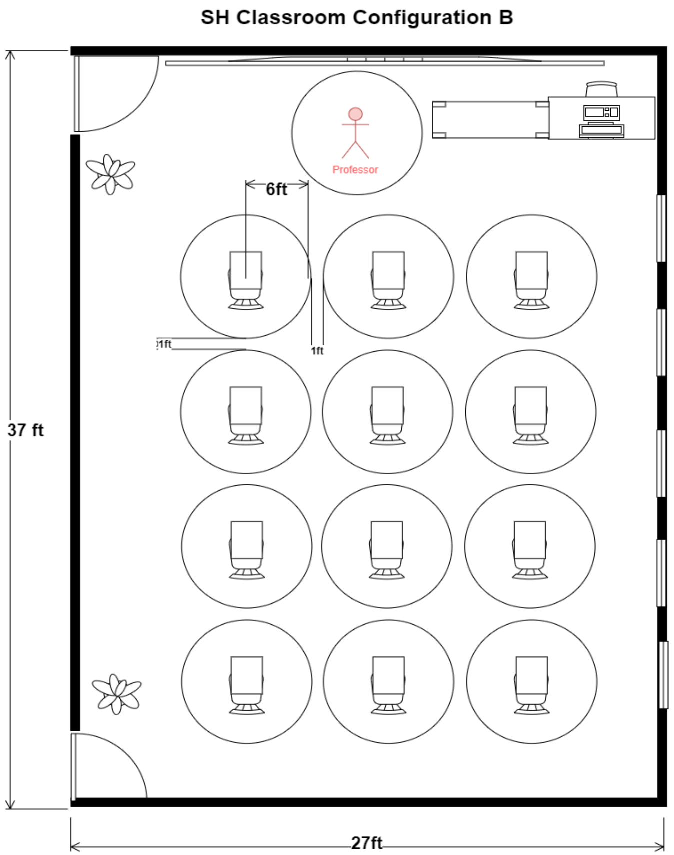

Fig. 7: Pandemic-era Salazar Hall Classroom "Grid" seating arrangement with social distancing guidelines in mind. **Total students: 12**

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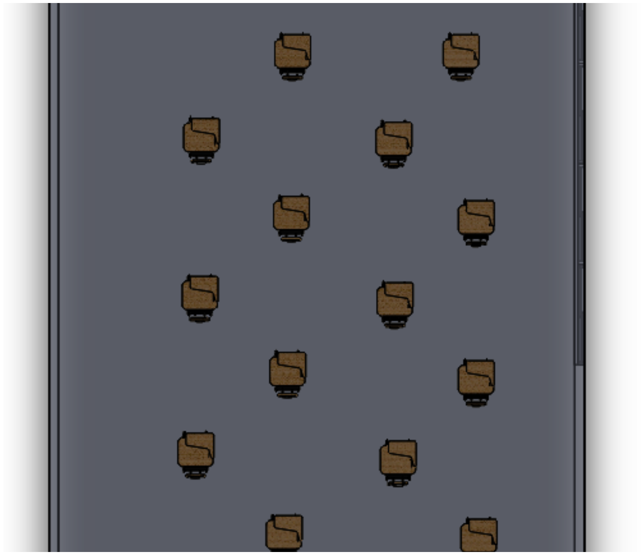
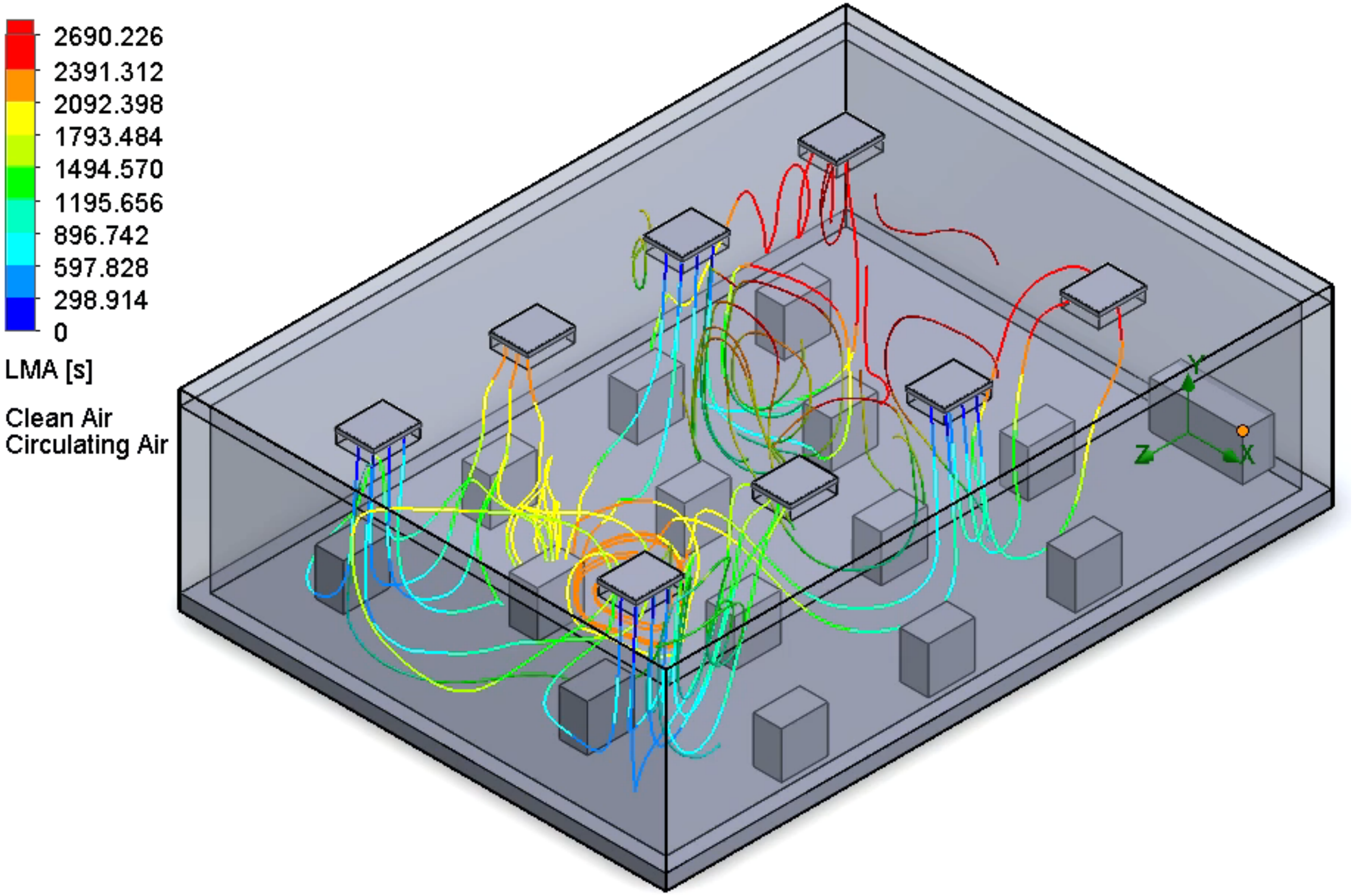
Air Flow Simulations

- Using the SolidWorks Flow Simulation Module in SolidWorks we were able to observe the Local Mean Age of Air (LMA)
- The LMA helps us evaluate the fresh air distribution inside the classroom, which is important as SARS-CoV-2 particles are present in conjunction with CO_2 particles
- Parameters used for the modeling:
    - 72^0F
    - 60% Relative Humidity

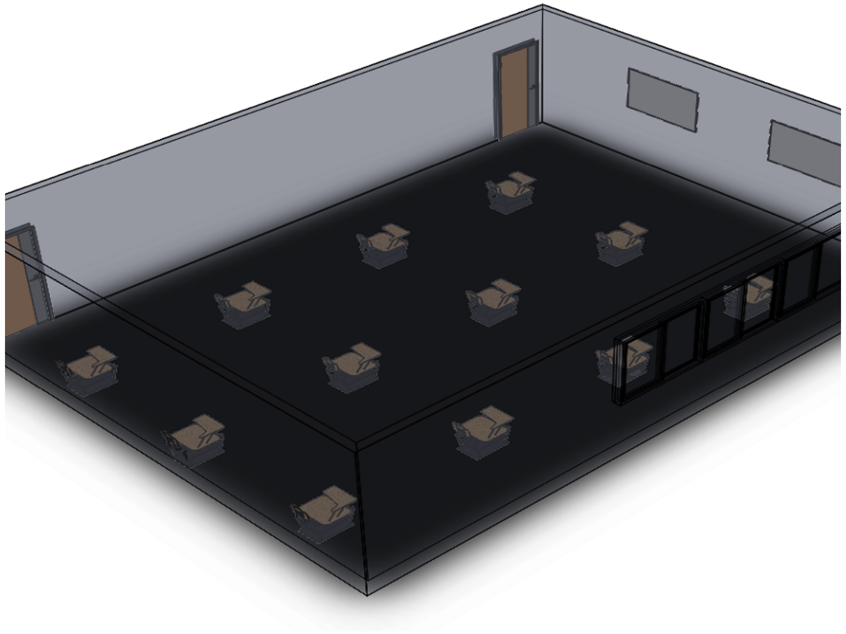
Results

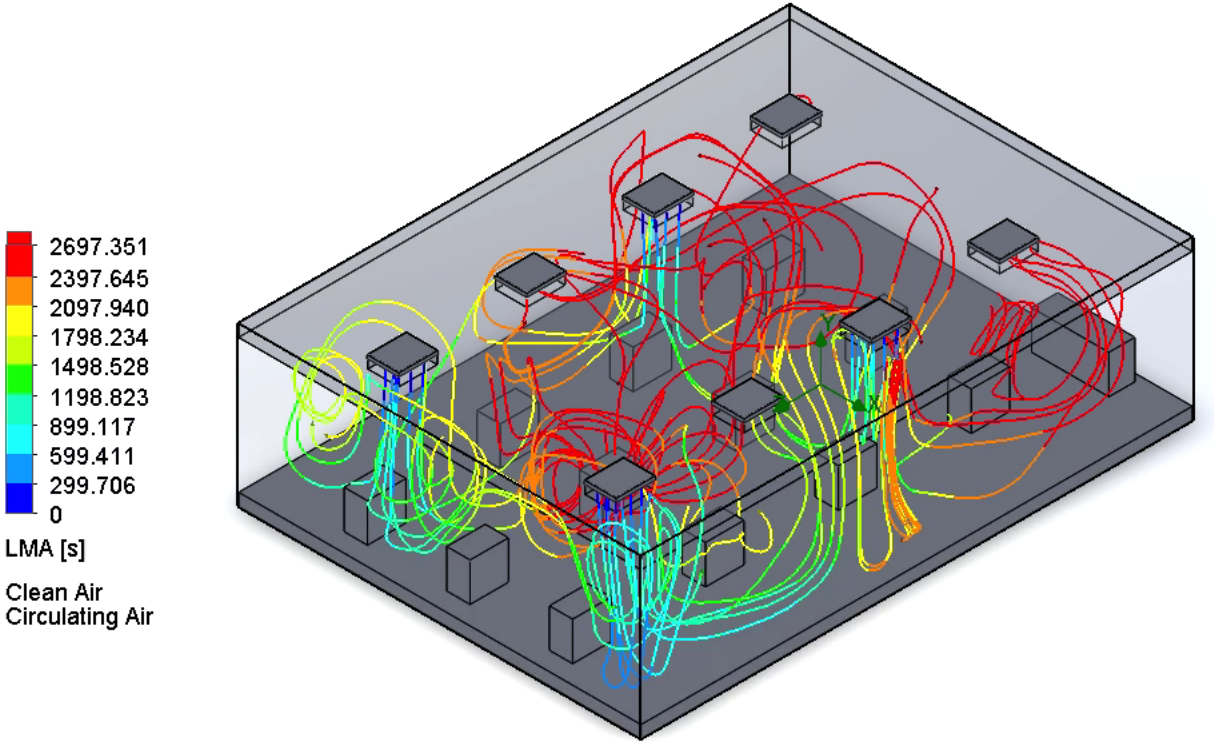


SolidWorks Model of Configuration A



Results





SolidWorks Model of Configuration
B

Classroom Specific Recommendations

- Install an inexpensive real-time CO_2 monitoring device to determine indoor CO_2 levels and ensure suitable ventilation rates.
- Installation of UV-C lights in classrooms such as Upper Air UV-C fixtures help to reduce the infection rate from airborne pathogens such as COVID-19
- Use of Hexagonal Configuration as it allows better air ventilation.
- Use a portable HEPA filter in locations where the air is stagnant in order to enhance the air flow.
- Sanitizing of high touch areas throughout the day

General COVID-19 Recommendations

Certain guidelines and recommendations that will help limit the probability of infection and improve the safety of staff and students include:

- Face Masks should be required to be worn while on campus. Standardized guidelines will establish what is an acceptable type of mask that when worn properly, offers adequate protection.
- Testing for COVID-19 should be requested of students and staff returning to campus with negative results, at most 2 weeks before returning.
- Having staff and students preform a Health Questionnaire before arriving to campus
- Quick methods of COVID-19 testing should be made available and encouraged for students and staff to limit outbreak occurrence.
- Proper personal hygiene encouraged, such as wipes and hand sanitizers.
- Require staff and students to get vaccinated before returning to school.

IV. Summary

Summary of what has been accomplished this year

- We studied the many forms of transmission for COVID-19 and how the virus is affected by its surrounding environment.
- We conducted trade studies including UV-C, Filters, and Portable Air Purifiers.
- We created two possible socially distanced classroom configurations for a CSULA Salazar Hall classroom and conducted SolidWorks modeling to determine the air flow for each configuration.
- We provided classroom specific and general recommendations to curb the spread of COVID-19 in the classroom.

Future tasks to make this design viable for the classroom

- Perform tests using real-life data to record how effective each classroom configuration is.
- Conduct a cost-analysis on the upgrades required to retrofit each classroom.
- Ensure faculty and students are vaccinated before returning to the classroom.
- Continue enforcing CDC guidelines for the COVID-19 pandemic.

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