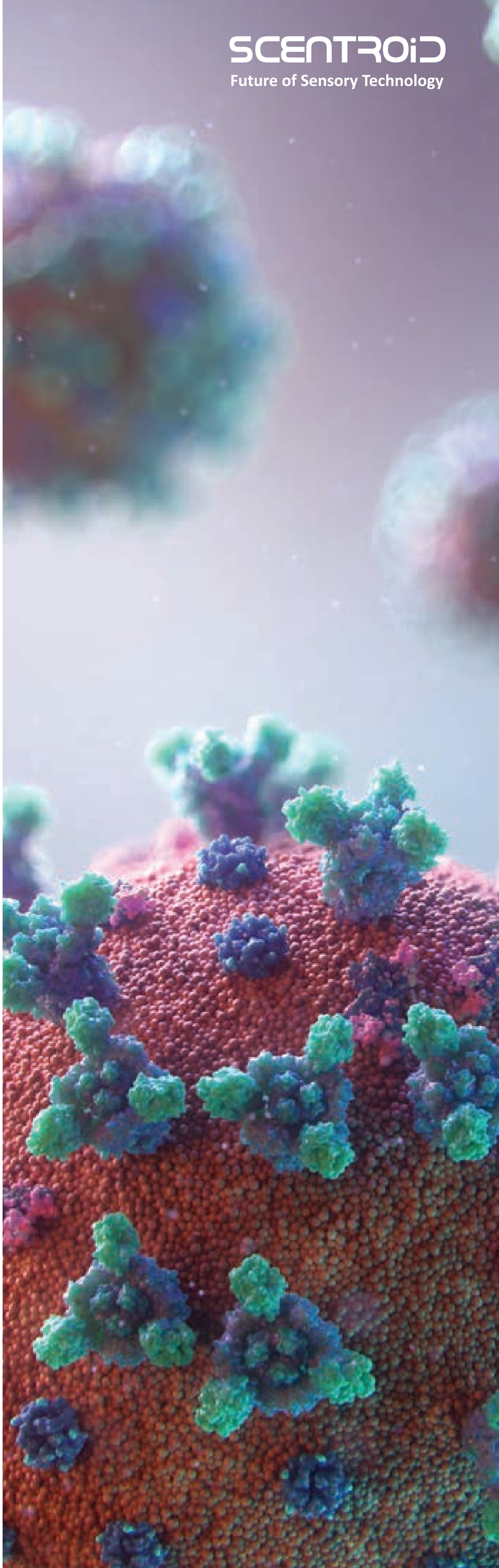
Viral
Transmission Score (VTS)

Airborne Viral Transmission Monitoring

Future of Sensory Technology



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Introduction to Ambient Air Quality Monitoring

Ambient air monitoring is the act of performing a long-term assessment of surrounding air to measure the quantity and types of pollutants present. These assessments are typically completed for various reasons including:

1. Determining the threat level of a space and the extent of pollution
2. Providing accurate air pollution data to the public in a timely manner
3. Supporting the implementation of air quality standards
4. Evaluate the overall effectiveness of mitigation strategies
5. Map and study air quality trends
6. Provide data to create air quality models
7. To support a hypothesis or research problem

There are several sensor varieties available along with ambient air monitoring instruments to measure a specific pollutant in any given space, whether indoors or outdoors. The technology must also be developed with several factors in mind, including what the uses of the data may be, the investment costs of the equipment, operational costs, reliability, and the overall ease of operation.

Determining which locations to use is an essential component for any successful air quality monitoring project. For the purpose of this program, we are going to assume measurements are utilized to support human health objectives. According to the EPA, a typical individual, on average, spends approximately 90 percent of their time indoors[1]. In addition to this, inadequately maintained heating, ventilation, humidity, and pressure could all contribute to health and safety concerns[2]. For this, monitoring stations are required in highly centralized population centers, and areas with more than one occupant within an enclosed space.

[1] https://www.epa.gov/report-environment/indoor-air-quality
[2] https://www.ccohs.ca/oshanswers/chemicals/iaq_intro.htm

Viral Transmission Monitoring Background

Viral disease transmission occurs mostly in indoor spaces where groups of individuals assemble. This is especially true of known airborne viruses such as COVID-19 and SARS. Several factors have aided in the transmission of the virus from one individual to the next when both are present in the same enclosed air space. These factors include occupancy to air volume ratio, occupancy to fresh air intake, relative humidity, temperature, and fine particulate concentration in the air. Both public and private establishments can significantly reduce the chances of viral transmission among the occupants by optimizing these parameters through better building and HVAC design as well as control of occupancy loading.

There are currently no instruments on the market that will provide a thorough analysis of viral transmission monitoring. All previously developed systems focus only on detection of an infectious person or a specific virus within a monitored environment. This does not consider any of the parameters that would aid in the transmission of the infection from one person to the next within the monitored space.

SCENTROID
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What Is Viral Transmission Monitoring?

Scentroid has created a system that will measure several air quality parameters based on scientific studies that associate environmental parameters with the movement and transmission of viruses such as COVID. Within the context of ambient air quality monitoring, devices with a specific sensor load out can be placed in key locations to track pertinent ambient air quality data.

To be able to fully assess the quality of an indoor space for viral transmission, a single numerical value known as our Viral Transmission Score (VTS), is required. VTS will analyze each of the factors mentioned within this paper and determine their combined affect. The single numerical number would correlate with the probability of transmission of airborne viruses between occupants, if any occupants were contagious. This viral transmission score can aid in:

1. Determination of 2 occupancy load in real-time
2. Providing an alarm for highly contagious environments
3. Allowing regulators to set limits to force establishments to improve HVAC/building design.

An algorithm represents this numerical value within a scale of 1-10. A low number will indicate a lower transmission rate of COVID, and a high number indicates a higher transmission rate.

1-5 ideal/low
5-8 Moderate
8-10 Critical

Creating the VTS Formula: Fundamentals

Water Droplets vs COVID-19 Transmission

COVID-19 transmission has been linked by the transferring of water droplets generated through a cough, sneeze, or even simply as speech between two bodies in proximity. According to the Journal of New England Medicine, 1 minute of loud speaking can generate at least 1000 virion containing droplet nuclei with the potential to remain airborne for more than 8 minutes.[3] Measured airborne particles at the point of creation were larger than 12 μm in diameter and diminished to 4 μm towards the end of their life cycle. In addition, the water contained in respiratory droplets evaporated rapidly, leaving microscopic particles called aerosols that moved for long distances through indoor air currents.

According to Stokes law, the terminal velocity of a falling droplet scales as the square of its diameter.[4] As the size of the droplet slowly decays over time, the rate of fall also diminishes, allowing for the particles to travel freely through the air. In areas of high air movement (not necessarily high circulation, as air intake systems may not be performing optimally), it can be expected that water droplets will rapidly move and transfer from person to person, contributing to viral transmission.

With regards to droplets in air, both volume and count increase with varying loudness of voice, vocal vibrations, and the presence of sneezing and coughing. Thus, in an environment of stagnant air, droplets will persist as a slowly descending cloud emanating from an individual's mouth, with an overall rate of descent being controlled by the dehydration of a speech droplet.

[3] https://www.nejm.org/doi/full/10.1056/NEJMc2007800?query=featured_home
[4] https://www.pnas.org/content/117/22/11875
[5] https://www.pnas.org/content/117/22/11875

According to the National Library of Medicine For COVID-19, "with an oral fluid average virus RNA load of 7×10^6 copies per milliliter (maximum of 2.35×10^9 copies per milliliter), the probability that a 50-μm-diameter droplet, prior to dehydration, contains at least one virion is 37%. For a 10-μm droplet, this probability drops to 0.37%, and the probability that it contains more than one virion, if generated from a homogeneous distribution of oral fluid, is negligible"[6]

These findings imply that airborne droplets pose significant risks for human-to-human viral transmission for respiratory illnesses such as COVID-19, influenza, and measles. By establishing a standardized monitoring system, it is possible to investigate these droplets at varying sizes, accommodating the principles of dehydration decay, and determine the overall concentration of droplets in any given space. This serves as the first measurement in our Viral Transmission Score formula algorithm.

Relative Humidity, Temperature, and the Effects on Viral Survival Rates

With seasonal changes, noticeable differences between the spread and transmission of COVID-19 were identified. Through an attempt to discover the reasons behind this phenomenon, teams of researchers conducted systematic reviews of the transmission of respiratory illnesses (including COVID-19) and the effects of varying weather factors.[7] Assessing a COVID risk factor through relative humidity and temperature variances must be considered upon determining a standardized Viral Transmission Score formula (VTS).

In a clinical study, high temperature and humidity, together, displayed a combined diminishing effect of corona-viruses. The opposite weather conditions were shown to support a prolonged survival time of the virus on surfaces, further facilitating the transmission and susceptibility of the viral agent.[8] Increased temperatures and increased humidity are frequently connected to a reduction of the transmission of respiratory viruses. This is due to the virus being more stable in cold temperatures, and respiratory droplets remain in suspension for longer periods of time in drier air.[9] These climates are also capable of compromising a host's immunity, further making them more susceptible to the virus.[10]

As viruses can be carried on varying water droplet sizes, the quantity of droplets found in ambient air could change based on several factors. Analyzing temperature and humidity is key to creating an accurate representation of the number of viral agents present.

With that in mind, initial studies have revealed that maintaining a humidity range of 40-60% within an indoor space could slow the spread of COVID-19. We also understand that warm and wet climates assist with a reduction in the spread of COVID-19. However, as per the Public Library of Science, these variables alone could not explain most of the variability in disease transmission.[11] Several other factors must be calculated to quantify and produce an accurate VTS.

[6] https://pubmed.ncbi.nlm.nih.gov/32235945/

[7] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0238339

[8] https://www.hindawi.com/journals/av/2011/734690/

[9] https://jvi.asm.org/content/88/14/7692

[10] https://www.pnas.org/content/116/22/10905

[11] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0238339

Particulate Matter and Its relationship to COVID

A positive correlation has been observed between the spread of COVID-19 and increased air pollution. Small particles act as a potential carrier through air, conveying the virus and increasing its spread.

An analysis proposed by the New England Journal of Medicine has fully investigated the stability of COVID in an aerosol and on surfaces. Within their study, they determined the half-life of a COVID molecule on common airborne surfaces such of plastic, steel, cardboard, and copper. Despite some being a less hospitable environment for the virus, COVID on all four aerosols remained for 3 hours, slowly reducing infectious capabilities over time.[12] The study indicated that the virus could persist on surfaces for days and in aerosols for hours.

Water droplet transmission tends to be short range due to size, weight, and travel distances prior to falling to the ground. However, this is different than an aerosol-based transmission, which is a suspension of solid particles within a gas phase. These particles range in size between 0.001 and 100 μm. Small sediment particles are easily manipulated by air flow to effectively complete long-distance transmission.

Particulate matter is known to have an inverse reaction to our lungs by creating inflammation at varying contact points. The rise in inflammation may increase the severity of the virus in heavily polluted areas. This is due to the virus binding to enzyme receptors. Upon binding, the enzyme releases an anti-inflammatory peptide[13] and is over-expressed due to it being inflamed from frequent PM exposure. This further increases the probability of COVID taking hold within a host body.

Air quality indoors has been found to be significantly more health hazardous than air quality outdoors. According to the EPA, the levels of indoor air pollution might often be 2 to 5 times higher than outdoor levels. In certain cases, with regards to poor ventilation and air circulation, these levels might exceed 100 times of those found outdoors.[14]

Thus, persons within closed spaces who are frequently exposed to higher levels of ambient air pollution are more likely to contract COVID-19 or other airborne respiratory illnesses. These developments are an essential starting point to determining the overall risk and connections between COVID-19 and PM pollution, serving as an essential component in viral hazard calculation.

[12] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7121658/

[13] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7345938/

[14] https://www.epa.gov/indoor-air-quality-iaq/inside-story-guide-indoor-air-quality

CO2 Being Used as a Risk Proxy for Indoor Spaces

Approximately 90% of our time is spent indoors, according to the Environmental Protection Agency.[15] As we spend the most time in an indoor environment, air volumes are limited and aerosols carrying viruses may easily accumulate. Combating indoor COVID transmission is a subject of high interest, and it is key to mitigating the negative impacts of a pandemic on a society/economy. Practical methods of monitoring and limiting indoor transmission is needed.

Indoor CO2 levels can be used as a practical proxy of respiratory infectious disease transmission and risks.[16] Even though COVID-19 can travel on both aerosols and particulate matter, this correlation is unnecessary for viral hazard tracking without factoring in a viral host.

As pathogen-containing aerosols are exhaled by those infected, tracking CO2 changes in the air can be used to justify potential viral transmission hazards. As ambient CO2 levels are stable, an excess of CO2 is a common indicator of exhalation. Measuring indoor CO2 concentration fluctuations can often serve as a powerful indicator of infection risk. Through careful analysis of the quantity of occupants, average exhalation rates, ventilation protocols, and a potential (or lack thereof) of an external CO2 source, a rudimentary formula can be derived.[17]

However, varying functions may require varying formulas. The breathing rate of an individual performing intense physical activities changes dramatically from individuals at rest. Thus, a single recommendation of CO2 thresholds cannot be used, as the formula must be flexible to accommodate for many environments/situations. To effectively assess an indoor space, advanced sensors such as occupant traffic, or high accuracy CO2 tracking to determine occupants and/or occupant activities may be required.

Therefore, a thorough guideline can be created for indoor CO2 concentrations which can be used to further develop a formula for Viral Transmission Monitoring.

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[15] https://www.epa.gov/report-environment/indoor-air-quality

[16] https://pubmed.ncbi.nlm.nih.gov/12950586/

[17] https://www.medrxiv.org/content/10.1101/2020.09.09.20191676v1.full.pdf

Building Effective Equipment to Process Raw Data & VTS

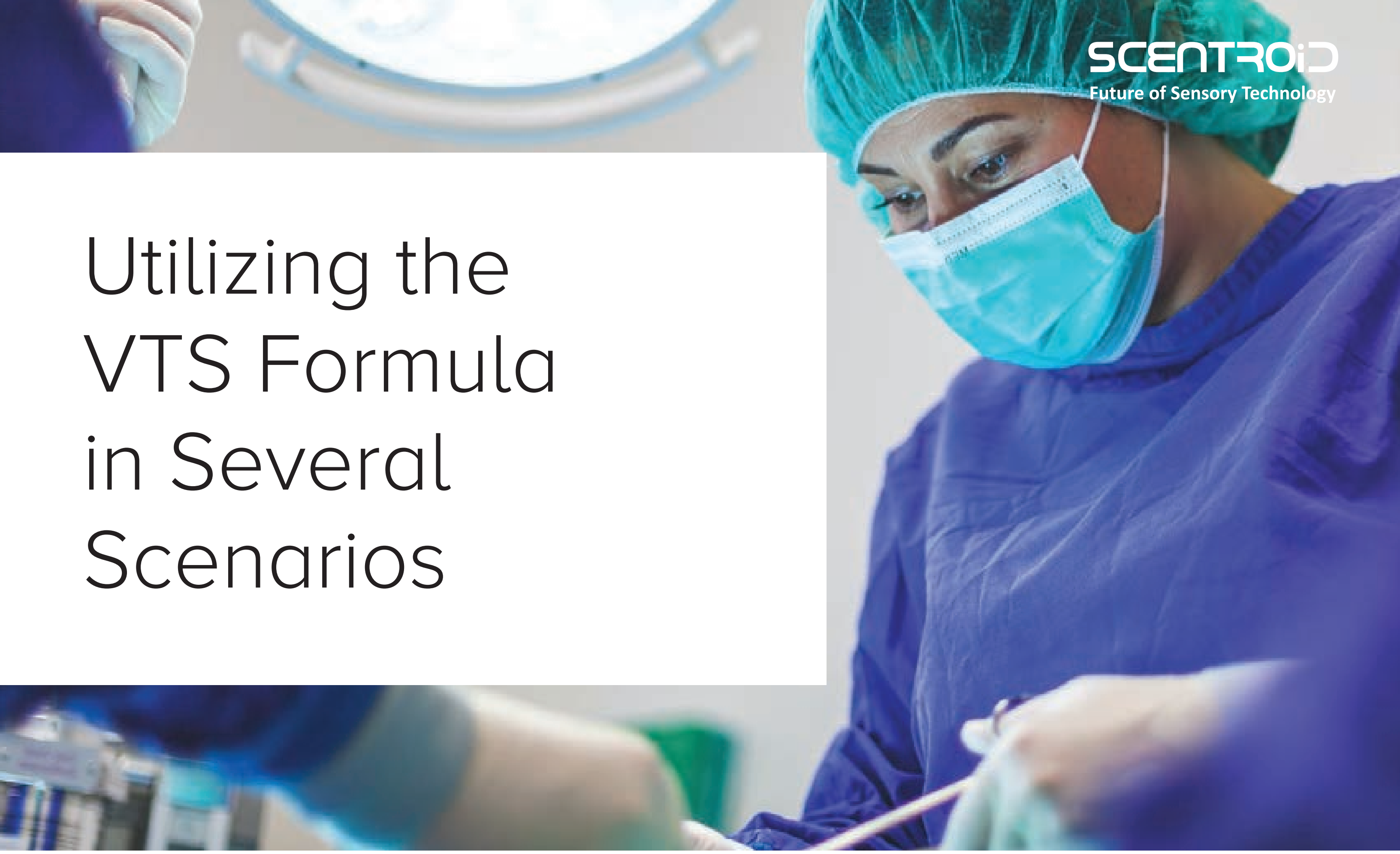
To effectively collect data, an indoor stationary device is necessary, and it must be an appropriate size to house a sensor payload suitable for creating an in-depth analysis of a space's Viral Transmission Score (VTS). It must also have a screen or an effective method of communication to display any hazards quickly and effectively or to communicate a rapidly increasing VTS.

We decided on using our Scentroid AQSafe Indoor Air Quality Monitor.

The AQSafe Indoor Air Quality Monitor observes the air quality of an enclosed space with a wide range of sensors. Our sensor detection ranges from dust (PM1, 2.5, and 10), Carbon Dioxide, temperature, humidity, pressure, to many other chemical compounds found indoors within any public facility or space.

The AQSafe features a compact, low profile design. It is both easy to install and operate. The touch screen incorporates control over a variety of advanced gas sensor technologies, designed to monitor areas of concern. Not only has it been proven for long term stability, but all sensors have been calibrated and prepared. The AQSafe is designed with labor saving, cost-effective, and health and comfort measures in mind.

The AQSafe features built in software for graphical representation, statistical data, and alarm systems (including text message and email notifications), ideal to calculate and communicate a hazardous VTS immediately in real-time.



Utilizing the VTS Formula in Several Scenarios

Hospitals

Through careful and continuous monitoring of ambient indoor air, the AQSafe is capable of pinpointing COVID risks such as stagnant air, increased traffic, or even a malfunctioning or inadequate HVAC system. Through the sending of monitored information in relation to a building's ventilation system, the optimization of air exchange rates is made possible, and can be automatic depending on the setup of the instrument.

AQSafe can play a key role in ensuring critical spaces are safe from contamination. Through monitoring pressure, the AQSafe provides a safeguard against air leaks and ensures the HVAC system is providing adequate positive pressure for air isolation. Once the pressure drops below a particular threshold, the AQSafe can relay a warning that ambient air has been compromised. The use of disinfectants and sanitizers in general will release harmful volatile organic compounds into the air causing short term and long-term health effects on patients, staff, and even visitors. UV disinfectants used widely in hospital isolation rooms can cause free ozone to be released indoors, potentially resulting in severe health issues.

Public Transportation

An important factor to consider is how an airborne virus behaves with regards to airflow with regards to an underground transit system. By monitoring CO2, the AQSafe can assess various COVID risks such as stagnant air, increased traffic, or even a malfunctioning or inadequate air recycling system. Currently, a typical transit system recirculates approximately 70 percent of the air within, and 30 percent is pulled from the outdoors.[18] The filters used have a Minimum Efficiency Reporting Value (MERV) of 8. MERV ratings increase up to 20 - the higher the number, the smaller the particles a filter can trap.

Filtration on a subway or train car can trap larger particles like mold spores, pollen, fibers, and dust - however, airborne viruses will remain. During times of low usage and traffic, the AQSafe can reduce HVAC activity or potentially increase airflow cycles once VTS begins to approach hazardous levels.

School Safety

Students, school staff, and parents continue to be concerned about preventative COVID measures and whether schools are meeting appropriate ventilation and air quality standards. A push against at home learning could result in more students and staff returning to school and remaining indoors despite an overall lack of government information regarding mandated inspection of ventilation systems. Poor ventilation raises the risks of super spreader events. The risk of catching COVID-19 indoors is 18.7 times higher than in the open air[19], according to the US Center for Disease Control and Prevention.

As school systems are typically found in denser urban areas, they are more likely to collect particulate pollution from outdoor sources. These small airborne particles could potentially carry COVID-19 and other viruses on their surfaces. By simply installing an AQSafe and potentially communicate the Viral Transmission Score to any persons requesting it, confidence in school safety measures will slowly be rebuilt.[20]

[19] https://www.cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html

[20] https://montreal.ctvnews.ca/education-unions-are-urging-the-government-to-test-air-quality-in-all-schools-1.5280098

Public Spaces

With the AQSafe, a user can create an alarm system that could potentially warn of increased CO2 levels. In some of the most modern venues in Japan, screens displaying CO2 levels are being stationed facility wide. For example, within Tokyo's Chiyoda Ward, a large screen has been built at the edge of concert stages. During live events, the colors of the screen change indicating increases or decreases of Carbon Dioxide. Attendees are notified at the start of every performance – "the hall is well ventilated, so enjoy our performance without any worries". These same systems are now being found in restaurants, airports, and other public spaces.[21]

Displaying airborne CO2 concentrations makes a noticeably clear statement on whether a site is properly ventilated. However, further monitoring is required to adequately prevent the three C's of COVID-19 transmission: Closed, Crowded, and Close-Contact settings. With air quality monitors and the Viral Transmission Score system, visitors will be ensured that they are in a safe and monitored indoor space.

Connecting and Controlling HVAC systems

The AQSafe provides the ability to monitor an HVAC system to ensure facility occupants remain protected. It does this through the use of real time high accuracy air quality monitoring based on temperature, humidity, and several other environmental factors. By capturing monitored data in relation to an indoor area's ventilation system, the AQsafe and the built-in VTS algorithm will increase HVAC efficiency as required to lower the viral transmission score. Once a lower VTS has been achieved, the AQSafe will then assist with an overall reduction of energy costs by optimizing air exchange rates.

What fail-safes do HVAC providers implement within a facility? A typical high grade HVAC system could fail from a lack of maintenance, aged and uncleaned filtration, pilot light malfunctions, mechanical wear and tear, ventilation failure, blown fuses, or even a dirty condenser or evaporator coils. The AQSafe can warn a user immediately upon any major changes to indoor air, and will continue to provide a viral transmission score rating based on these factors.

[21] http://www.asahi.com/ajw/articles/13832094

Case Study: Data Collection Within a Pharmacy

An AQSafe equipped with Viral Transmission Score technology was used within a pharmacy in Canada for several days to determine potential COVID transmission risks. As illustrated in figure A, daily cycles can be noted after prolonged in-occupancy with low fresh air intake. During times of high occupancy, the rate of change of CO_2 increased with continual occupancy. As customers/staff leave and the occupancy level goes down, the CO_2 level reduces. This cyclic process is observed every 24 hours with some deviation due to the changes in the occupancy level. Therefore, the VTS correctly indicated the danger of continual airborne viruses and remained high.

Figure B indicates a temperature variation within the space, also cyclic within the 24-hour period. Temperatures increase with higher occupancy, and lower with reduced occupancy. Ambient temperature has also affected the indoor space temperature to an extent.

As seen in figure C, disturbances to airborne dust particles creating small spikes in particulate matter readings and changes to the VTS score. These particles continued to travel within the airspace, allowing particulates to stay airborne until the particles are removed by means of filtration or fresh air exchange. Increases to air filtration may help with reducing particulate matter concentration.

Once the air filtration rate increased, the relative humidity decreased. Figure D displays an accumulative behavior with regards to the variations of relative humidity within the space

Figure E shows the variation of the VTS with time for the space, which is obtained by combining all the data gathered by all the sensors and using the method provided here to determine VTS. The VTS score shown in figure E is divided into three (3) ranges:

1. Low probability with score of 1 to 5 shows ideal conditions and requires no action.
2. Moderate probability spanning VTS of 5 to 7 indicating pro-active measures such as upgrade of HVAC system or reduction of occupancy loading is required. Systems with intelligent HVAC or air filtration systems would activate at higher capacity when VTS reaches this range.
3. Critical range of 7 to 10 indicating immediate action is required including reduction of occupancy load.

Figure A

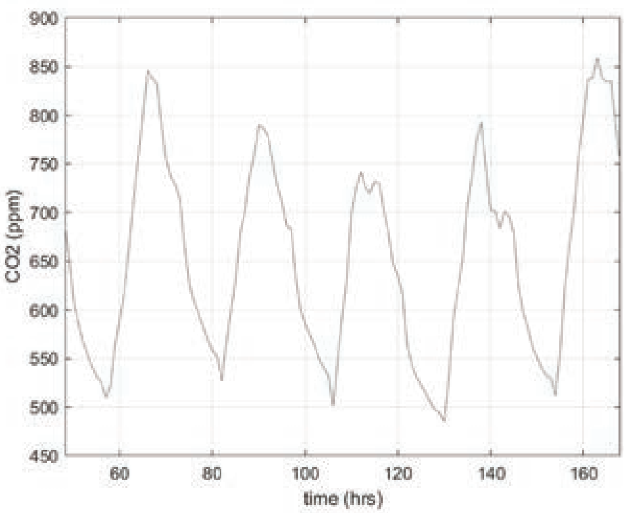


Figure B

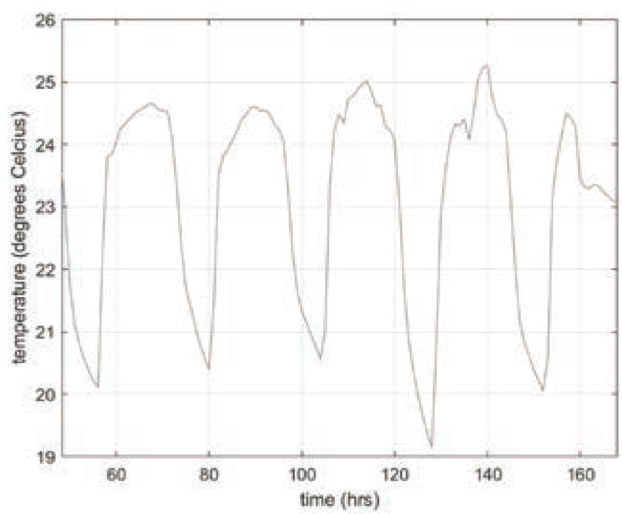


Figure C

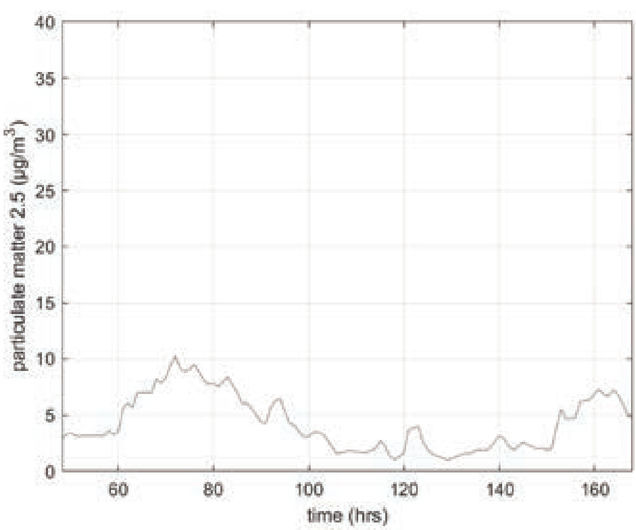
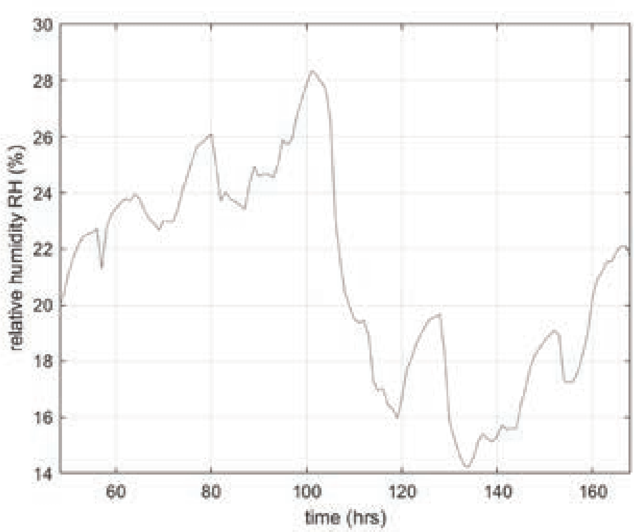
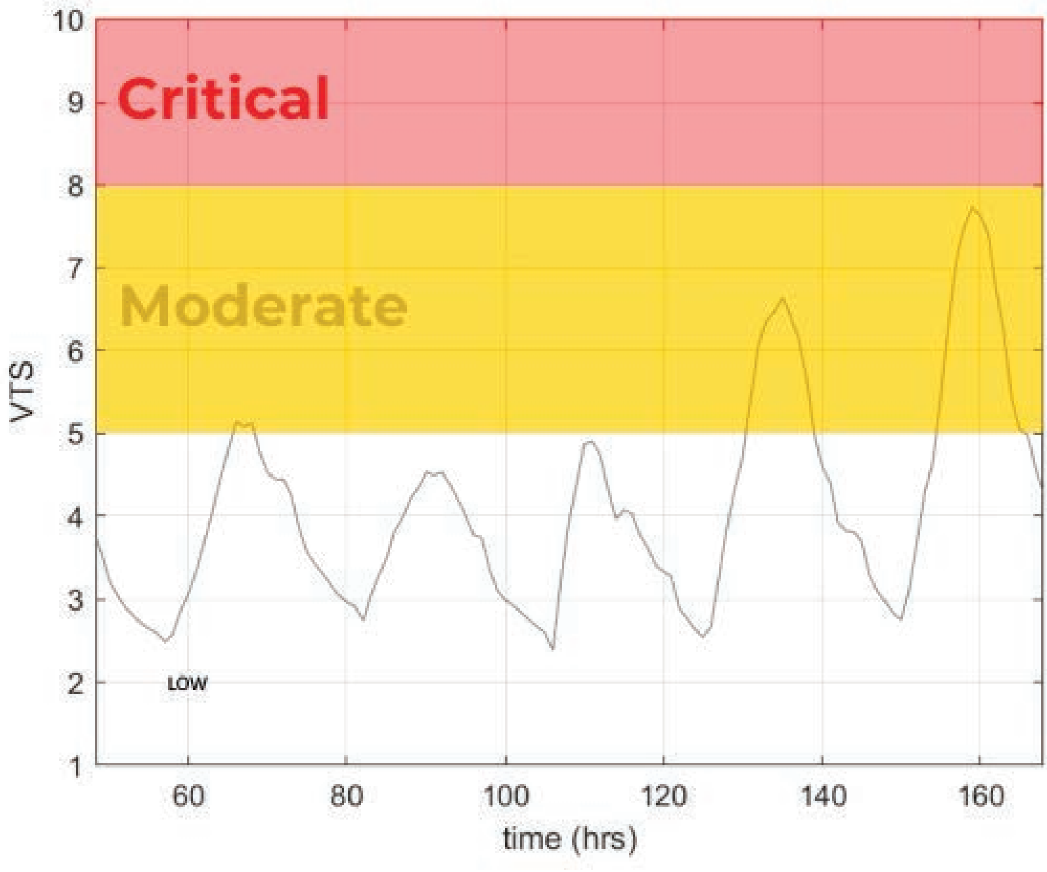


Figure D



The results demonstrate the importance of the interaction of all measured parameters. For example, while occupancy had not increased between 130-170 hours as demonstrated by the CO2 measurements, the VTS score shows exceedance into the Moderate range due to low humidity levels. This information could be used by the facility manager to improve humidification of the space to ensure a safer environment for the occupants.

Figure E



Conclusion

The objective of the Viral Transmission Score (VTS) is to provide a singular metric assessing the conditions of an indoor environment for transmission of infectious diseases among the occupants. This singular metric will encompass factors that will affect the probability of viral transmission including occupancy rate, fresh air intake, temperature, humidity, and particulate concentration. This will allow:

1. Governmental regulators to set VTS limits that would keep occupants safer than simple occupancy limits.
2. Rapid inspection and continuous monitoring of an indoor space to identify deficiencies in HVAC system, occupancy control, and other systems that would affect the safety of the occupants in terms of disease transmission.
3. Building engineers to take viral transmission into account when designing a new space to ensure occupant safety.

The AQSafe and the Viral Transmission Score system was designed to assist with restoring confidence in facilities forced to close their doors during the pandemic, and to help front-line workers feel safer in their environment. It will not only revolutionize the future of sensory technology - it will also alter our perception of the air we breathe in indoor spaces.

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