

METADATA DRIVEN METHOD AND SYSTEM FOR AIRBORNE VIRAL
INFECTION RISK AND AIR QUALITY ANALYSIS FROM NETWORKED AIR
QUALITY SENSORS

TECHNICAL FIELD

[0001] The subject matter described and disclosed herein relates to air quality monitoring of rooms or space in buildings, and more particularly to networked analysis systems and method interacting continuously or periodically with a plurality of remotely located networked air quality sensors, analyzing to assess the risk of airborne virus infection and air quality from sensor real-time air quality measurements. The subject matter further relates to reporting trends of risk factors, generation of alarms and actionable messages to managers, building owners and occupants regarding air quality and a calculated risk of airborne virus infection, particularly SARS-COV-2/COVID.

BACKGROUND OF THE INVENTION

[0002] Air quality is an important issue for decades. Today we have the increasing levels of pollution and climate change related forest fires. Even more critical to families and human life, health and our world economy is deaths and hospitalizations of the SARS-COV-2 pandemic. The future will hold new and unknown viral pandemics.

[0003] Various air quality monitoring devices and sensors are known. What is still lacking in the art is an autonomous computer implemented system and analysis method for analyzing real-time measurements of a plurality of networked air quality sensors in one or more monitored air spaces in one or more building, dispersed, and analyzing the measurements to determine a risk of airborne viral infection transmission. Such a system would fill an unmet need in the determination and reduction in the risk of airborne viral infection transmission to occupants in buildings, public spaces, schools, offices, shopping malls, and then facilitate their reopening and safe operation.

SUMMARY OF THE INVENTION

[0004] Coronaviruses such as SARS-COV-2 are well known to be spread from person to person. The virus most often spreads through people who have symptoms, but not always. Unfortunately, it is possible to pass the virus on to other people even when the infected carrier shows no visible signs of being infected. People who don't know they've been infected can unintentionally infect others. This is called asymptomatic spread. There are several modes of transmission for this to happen.

[0005] Contact transmission - Surfaces may become contaminated with the virus when someone who has the virus touches, coughs or sneezes near or onto the surface. Virus containing droplets or micro droplets may settle onto surfaces, contaminating them. Prevention strategies include surface disinfectants and improved cleaning schedules.

[0006] Respiratory transmission- When an infected person coughs, sneezes, or talks, droplets from the infected person carry the virus into the air from their nose or mouth. Larger droplets may fall to the ground relatively quickly. For larger droplets, social distancing and PPE (personal protective equipment) such as face masks are known to be prevention strategies.

[0007] Airborne transmission- Social distancing and PPE are less effective or ineffective with airborne transmission of virus laden micro droplets. Airborne transmission of virus carrying micro droplets are available to infect persons entering a room, even if for an extended time long after the infected individual has left. Long distance transmission over a longer time via virus-laden micro droplets has been recorded, first on cruise ships, and then restaurants and shopping malls. Micro droplets can remain airborne for a longer period of time, for example 30 minutes or longer, and so are available to infect persons entering a room for significant time after the infected individual has left. Prevention strategies here include air quality monitoring (such as the method and system disclosed herein), ventilation, air filtration and purification.

[0008] An object of the present inventive disclosure is to provide a computer implemented system and method of analyzing real-time measurements of a plurality of air

quality sensors to calculate an overall airborne virus infection risk score, to advise others at risk. In some embodiments of the invention, the computer implemented system and method of analyzing real-time measurements of a plurality of air quality sensors may be configured to take direction action by communicating set points and commands over the network to HVAC systems, or to portable air treatment/ filtering appliances to improve outside air flow, increase filtration, reduce humidity, etc., improving room air quality and reducing viral infection risk. The real-time measurements of several air quality parameters have been correlated with the risk of indoor virus infection and so are useful, in combination, for calculating a risk of airborne virus risk infection from, for example, SARS-COV-2.

[0009] The computer disclosed method and system autonomously scans, detects, analyzes and informs of known critical pollutants, which add to airborne virus transmission, calculates the risk and provides actionable recommendations on how to minimize risk for building occupants. A SARS-CoV-2 Airborne Virus Infection Risk Score, (CAIRS) is introduced herein which spans numerically from 0 to 100 and splits or chunks the risk levels into three categories: Low (0-33), Moderate (34-66), and High (67-100) as a simplified presentation of risk.

[0010] For example, studies have shown that carbon dioxide (CO₂) is directly correlated with virus concentration in the air if an infected person is in the room. Therefore CO₂ concentration in the air is a great indicator for indoor infection risk determination.

[0011] Particulate matter (PM) in the air is useful as an indicator of filtration efficiency. Increased PM levels put additional stress on the human respiratory system, and are suspected to function as virus carriers. Measurement of PM_{2.5} and PM₁₀ concentrations can be used as a proxy to determine aerosol concentrations.

[0012] Humidity is important. Corona viruses decays slower in dry and in very humid environments. Additionally, too high of a humidity level may increase the risk for building damage.

[0013] A published study of "Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces" as published by the American Society of Microbiology (Lisa M. Casanova et al.) found that the greatest level of virus inactivation took place at 50% RH. In the study, the lowest level of virus inactivation took place at 20% RH. Virus inactivation is more rapid at 20°C than at 4°C at all humidity levels. Viruses were inactivated more rapidly at 40°C than at 20°C. Interestingly, the relationship between inactivation and relative humidity (RH) was not monotonic. There was a greater virus survival or greater protective effect at low RH (20%) and high RH (80%) than at moderate RH (50%).

[0014] A study published by the National Center for Biotechnology Information, U.S. National Library of Medicine, titled: "Influence of airborne transmission of SARS-CoV-2 on COVID-19 pandemic. A review" and published online June 23, 2020 found that an increase of only 1 microgram per cubic meter of air in PM_{2.5} is associated with an 8% increase in the SARS-COV-2 death rate. The results were statistically significant and robust to secondary and sensitivity analysis. A small increase in long term exposure to PM_{2.5} is linked to a large increase in SARS-COV-2 death rate.

[0015] The Sars-COV-2 pandemic is a devastating to human health in epic proportions, endangering individual well-being, family health and survival, and ultimately the world economy.

[0016] As can be seen from the above, there remains a significant need for a computer implemented cross network implemented process and system of gathering real-time air quality measurement of building rooms or enclosed spaces and applying for continuous analyzing the measures to manage or control indoor air quality parameters to reduce the risk of airborne virus transmission and resulting infection. Such a system find value by meeting a significant human health need in monitoring indoor air quality and using this information to calculate a real-time virus infection risk score, monitoring indoor airspaces and altering building owners or occupants when conditions change, increasing risk, and by generating actionable alerts to responsible individuals or group for corrective actions, or in other cases direct output instructions to building HVAC control system, implementing changes to ventilation, filtration, humidity and air quality factors to effect

the reduction in the risk of airborne virus transmission. Disclosing such a solution in a system and method is a primary objective of this inventive disclosure.

[0017] One aspect of the disclosure relates to a metadata driven computer implemented process of calculating an airborne viral infection risk score. The process may include interacting continuously or periodically with a plurality of remotely located air quality sensors over a network to receive real-time air quality measurements, for example receiving and analyzing the real-time air quality measurements of a plurality of air quality sensors; and to calculate an airborne viral infection risk score and optionally air quality indicators of one or more monitored air spaces. The one or more monitored spaces may be spaces of one or more buildings. The computer implemented process being configured to be implemented on a system. The system may include a local or wide area network communications interface device, which may be configured to communicate over a network with the plurality of remote air quality sensors measuring air quality parameters within the monitored air spaces. The system may include a database for storing current and/or history data. The system may include a network web portal configured to provide remote network access and one or more of presentation of measurements, analysis results, and reports over the network to remote network connected devices. The system may include processing circuitry. The system may include a non-transitory computer-readable medium, the non-transitory computer-readable medium containing one or more sets of computer instructions configured to instruct the processing circuitry to perform the computer implemented process in accordance with various embodiments.

[0018] The process may include communicating with the plurality of air quality sensors and retrieving over the network current indoor air quality measurements of the monitored air space in the one or more buildings. The air parameter measurements may include one or more of air CO₂ concentration; air fine particulate matter PM_{2.5} concentration; air inhalable particulate matter PM₁₀ concentration; air relative humidity; and air temperature. The process may include adding a time-date stamp and storing the current sensor air parameter measurements to the database. The process may include smoothing the sensor air parameter measurements, for example by averaging the current sensor air parameter measurements with the previous air parameter measurements of the

same sensor over a configured period of time. As used herein, smoothing may mean reducing measurement noise.

[0019] The process may include storing the sensor air parameter measurements (which may be smoothed) to the database for access by the web portal. The process may include one or more of: (i) calculating a CO₂ instantaneous airborne infection risk score from the, optionally smoothed, CO₂ sensor air parameter measurement of the monitored air space; (ii) calculating a PM_{2.5} instantaneous airborne infection risk score from the, optionally smoothed, PM_{2.5} sensor air parameter measurement of the monitored air space; (iii) calculating a PM₁₀ instantaneous airborne infection risk score from the, optionally smoothed, PM₁₀ sensor air parameter measurement of the monitored air space; (iv) calculating relative humidity instantaneous airborne infection risk score from the, optionally smoothed, relative humidity sensor air parameter measurement of the monitored air space. The process may include storing the instantaneous airborne infection risk scores to the database for access by the web portal.

[0020] The process may include determining which one of measurement types (for example CO₂, PM_{2.5}, PM₁₀ and relative humidity or a subset thereof, e.g., depending on provided sensors) has a highest instantaneous airborne virus infection risk score. The process may include calculating a decay rate for viral infectivity as a function of the (optionally smoothed) air temperature and (optionally smoothed) relative humidity of the monitored air space. The decay rate for viral infectivity may be inversely proportional to a pre-determined virus half-life, for example determined as $1/(\text{the pre-determined virus half-life})$.

[0021] The process may include applying the decay rate for viral infectivity as a scale factor to the highest instantaneous airborne infection risk score to obtain an overall decay rate adjusted highest instantaneous airborne virus infection risk score. The process may include storing the overall decay rate adjusted highest instantaneous airborne virus infection risk score and the highest measurement type to the database for access by the web portal. The process may include repeating the plurality process steps for a next or same monitored air space.

[0022] In some embodiments, the process may include transmitting an alert to an air conditioning system associated with the monitored air space for which the instantaneous airborne virus infection risk score is greater or equal to the configured risk level threshold. The alert may include the measurement type of the air parameter measurement having the highest instantaneous airborne virus infection risk score. The air conditioning system is capable of influence one or more of temperature, humidity, and may have filter capabilities. The process may include generating, e.g., by a processor of the air conditioning system, operation mode instructions to modify the air property, of the monitored air space corresponding to the measurement type thereby reducing instantaneous airborne virus infection risk score. The process may further include carrying out the operation mode instructions by the air conditioning system. For example, one or more functions may be available, and the instructions may cause the air conditioning system to do one or more of: enhance filtration, reduce air temperature, increase air temperature, decrease air relative humidity, increase air relative humidity, increase air exchange with a room's exterior, depending on the available functionality.

[0023] In some embodiments, the computer implemented process may include generating, for example, by the processing circuit or by the web portal, operation mode instructions to cause an air conditioning system associated with the monitored air space to modify the air property corresponding to the measurement type for reducing instantaneous airborne virus infection risk score. The air conditioning system is capable of influence one or more of temperature, humidity, and may have filter capabilities. The process may further include transmitting the operation mode instructions to the air conditioning system. The process may further include carrying out the operation mode instructions by the air conditioning system. For example, one or more functions may be available, and the instructions may cause the air conditioning system to do one or more of: enhance filtration, reduce air temperature, increase air temperature, decrease air relative humidity, increase air relative humidity, increase air exchange with a room's exterior, depending on the available functionality.

[0024] In some embodiments, the storing the current sensor air parameter measurements to a database comprises adding a time-date stamp and storing the current

sensor air parameter measurements to a database for storing current and history data. The process may further include predicting future risk increases based on historical trends determined from history data. The process may further include (i) transmitting an early message to network connected smartphones, tablets, or network connected devices configured to receive infection risk updates; and/or (ii) generating operation mode instructions to cause an air conditioning system associated with the monitored air space to modify one or more air properties to counter the trend for reducing the future risk. The process may further include carrying out the operation mode instructions by the air conditioning system. For example, one or more functions may be available, and the instructions may cause the air conditioning system to do one or more of: enhance filtration, reduce air temperature, increase air temperature, decrease air relative humidity, increase air relative humidity, increase air exchange with a room's exterior, depending on the available functionality.

[0025] One aspect of the disclosure relates to a control system (or simply system) configured to calculate an airborne viral infection risk score of one or more monitored air spaces. The system may include a local or wide area network communications interface device. The device may be configured to communicate over a network with a plurality of remote air quality sensors for measuring air quality parameters within the monitored air spaces. The system may include the plurality of samples. The system may include a database for storing sensor air parameter measurements. The system may include a network web portal configured to provide remote network access and one or more of presentation of measurements, analysis results, and reports over the network to remote network connected devices. For example, the network web portal may be implemented on a server connected to the network. The system may include a processing circuitry. The system may include a non-transitory computer-readable medium, the non-transitory computer-readable medium may comprise one or more sets of computer instructions configured to instruct the processing circuitry to perform the computer implemented process of determining an airborne viral infection risk score in accordance with various embodiments of the process.

[0026] One aspect of the disclosure relates to a non-transitory computer-readable medium, the non-transitory computer-readable medium comprising one or more sets of

computer instructions configured to instruct a processing circuitry to perform the computer implemented process of determining an airborne viral infection risk score in accordance with various embodiments of the process.

[0027] According to an aspect of the disclosure, a computer implemented process or method is provided herein for interacting with, obtaining measurements from and analyzing real-time measurements of a plurality of air quality sensors arranged in monitored air spaces in one or more building and then calculating and sharing an infection risk score from the measured parameters. The computer-implemented process is executed on an infection risk analysis server computer that may be located at significant distances away from the monitored building(s) and the air quality sensors provided therein. Communication between the analysis system and the sensors occurs continuously/periodically and autonomously by data communication or packets over a wide area network such as the Internet.

[0028] Studies have shown that:

- A greater level of virus inactivation occurs around at 50% RH.
- A much lower level of virus inactivation occurs around 20% RH.
- Virus inactivation occurs more rapidly at 20C than 4C at all humidity values.
- Viruses were inactivated more rapidly at 40C than 20C.

[0029] However, the relationship not monotonic. Greater virus survival occurs at low RH 20% and high RH 80% than at moderate RH 50%.

[0030] Studies have shown that infectious corona virus deposited on stainless steel have persisted for at least 3 days at 50%RH and 20°C and for up to 28 days at 20%RH.

[0031] In heated dry indoor air (20°C, 20%RH), 80% of corona viruses on surfaces have been shown to be viable for a week. Humidification of the air 50%RH reduces viable viruses to less than 1% in 20 days (fastest deactivation) and significantly decreases infection risk ($-2.5 * \log_{10}$ in two days).

[0032] Virus Inactivation at 20%RH and 20°C: Inactivation $\log_{10} = -0.081$ %/day

[0033] Virus Inactivation at 80%RH and 20°C: Inactivation $\log_{10} = -2.12$ %/day

[0034] Virus Inactivation at 50%RH and 20°C: Inactivation $\log_{10} = -0.896$ %/day

[0035] Studies have shown that an increase of 1μ gram/ m^3 in PM_{2.5} has been associated with an 8% increase of SARS-COV-2 death rate.

[0036] As such, the computer implemented analysis system and method of the present disclosure provides significant benefit to human health and survival in the SARS-COV-2- 19 pandemic and is very likely applicable to future coronavirus or viral pandemics.

[0037] In aspects of the invention, the present inventive disclosure provides a computer implemented system and method of analyzing real-time measurements of a plurality of network connected air quality sensors to calculate an Air Quality Index (AQI) for each of a plurality of indoor air spaces or rooms of one or more buildings. The computer implemented system and method performs this and the airborne virus risk infection for building that may be dispersed across great distances, such as differing continents, in different continents or countries, as the computer implemented system and method is specifically configured to interact with the air quality sensors autonomously through a wide area network.

[0038] The Air Quality Index (AQI) was created by the U.S. Environmental Protection Agency (EPA) and is determined by the worst relative pollutant concentration measured. Each category corresponds to a different level of health concern. The six levels of concern, according to the EPA, and what they entail are:

[0039] Good - AQI is 0 to 50. Air quality is considered satisfactory, and air pollution poses little or no risk.

[0040] Moderate - Air quality is acceptable; however, for some pollutants there may be moderate health concern for a very small number of people.

[0041] Unhealthy for Sensitive Groups - AQI is 101 to 150. Although the general public is not likely to be affected at this AQI range, persons with heart and lung disease, older adults, and children are at greater risk.

[0042] Unhealthy - AQI is 151 to 200. Everyone may begin to experience some adverse health effects, and members of the sensitive groups may experience more serious effects.

[0043] Very Unhealthy - AQI is 201 to 300. The air quality is dangerous and would trigger a health alert signifying that occupants may experience serious health complications.

[0044] Hazardous - AQI greater than 300. This would trigger a health warning of emergency conditions. The entire population is more likely to be affected.

[0045] Air pollutant sources and associated networked monitored air spaces sensors may include:

[0046] Particulate Matter (PM_{2.5}, PM₁₀). Common sources are Industry, traffic, cooking and indoor smoking. Health impacts include heart disease and cancer.

[0047] Volatile Organic Compounds (VOCs). Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate from the liquid or solid form of the compound and enter into the surrounding air, a trait known as volatility. Common sources are paint, aerosols, cleansers, carpets, furniture. Health impacts include respiratory irritation, damage to liver and kidneys. Formaldehyde (HCHO) and other volatile organic compounds (VOCs), for example toluene and xylenes, are a concern due to their toxicity. Formaldehyde is a priority VOC because of its frequent occurrence in indoor air and the serious health outcomes resulting from exposure. Common sources include building materials, cleaners. Health impacts include irritation of the skin, eyes, nose, and throat.

[0048] Carbon Dioxide (CO₂) - Common sources include breathing, combustion of fossil fuels. Health impacts include headaches and fatigue.

[0049] In another aspect of the invention, the computer implemented system and method of analyzing real-time measurements of a plurality of network connected air quality

sensors analyzes the sensor data and provides a real-time air quality overview to a sets of network connected devices configured to receive AQI updates for buildings, rooms, stores, conference rooms school rooms, etc. and trend the Air Quality Index (AQI) data time, providing graphs and reports to connected devices configured to receive AQI updates. Data is also accessible through a web portal provided by the computer implemented system, accessible from network connected smart phones, tablet, or device, accessible, for example, though web browsers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050] The accompanying Figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the present invention.

[0051] Features of the present invention, which are believed to be novel, are set forth in the drawings and more particularly in the appended claims. The invention, together with the further objects and advantages thereof, may be best understood with reference to the following description, taken in conjunction with the accompanying drawings. The drawings show a form of the invention that is presently preferred; however, the invention is not limited to the precise arrangement shown in the drawings.

[0052] FIG. 1 - schematically depicts a system for airborne viral infection risk evaluation and air quality analysis, consistent with the present inventive disclosure;

FIG. 2 - presents a process for airborne viral infection risk evaluation and air quality analysis, consistent with the present inventive disclosure;

FIG. 3 is an Air Quality Index (AQI) chart, finding support in the U.S. Environmental Protection Agency Air Quality Index standards, as pertinent to the present inventive disclosure;

FIG. 4 is a 3-dimensional color plot depicting how the half-life of corona virus is related to temperature and humidity;

FIG. 5 is an example of the relationship between the recorded concentration of Fine Dust Matter (PM_{2.5}) and how it relates to the airborne infection risk score; and

FIG. 7 presents a relationship between indoor air CO₂ levels and the volumetric flow rate of air cubic feet of air per minute (cfm)-per-person of outside air ventilation rates.

[0053] Skilled artisans will appreciate that elements in the figures are generally shown schematically simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

DETAILED DESCRIPTION

[0054] Before describing in detail embodiments that are in accordance with the present invention, it should be observed that the embodiments reside primarily in combinations of apparatus components related to a filter apparatus. Accordingly, the apparatus components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

[0055] In this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms “comprises,” “comprising,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by “comprises ... a” does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

[0056] As used herein and in accordance with various embodiments, an air conditioning system is capable of influence (e.g., change or control) one or more of temperature, humidity of the air. The air conditioning system may include air filtering capabilities (e.g., air purification). In one example the air conditioning system is an HVAC system, such as a building integrated HVAC system. The air conditioning system may be operably coupled to the network. The air conditioning system may be configured to receive instructions, for example operation mode instructions to cause the air conditioning system to do one or more of: enhance filtration, reduce air temperature, increase air temperature, decrease air relative humidity, increase air relative humidity, increase air exchange with a room's exterior, depending on the available functionality.

[0057] FIG. 1 schematically depicts a metadata driven system 100 for interacting continuously or periodically with a plurality of remotely located air quality sensors 102, 104, 106, 108, 110, 112, 114 over a network, such as wide-area network 118 to receive real-time air quality measurements.

[0058] The air quality sensors, especially to support an airborne viral infection risk calculation, may include one or more, e.g., all, of air CO₂ concentration sensor 102, air fine particulate matter PM_{2.5} concentration sensor 104, air inhalable particulate matter PM₁₀ concentration sensor 106, air relative humidity sensor 108. The air quality sensors may include very fine particulate matter sensors, such as one or more of PM_{2.0}, PM_{1.5}, PM_{1.0}, or additional types of air quality sensors.

[0059] To support air quality measurements, such as the U.S. Environmental Protection Agency (EPA) standards of Air Quality Index (AQI) measurements and reports, additional sensors may include VOC volatile organic compound sensors 112, such as formaldehyde sensors 114, as well as other types of air quality sensors.

[0060] As used herein, and in accordance with various embodiments, PM_x may mean particulate matter suspended in air which is small enough to pass through a size-selective inlet with a 50 % efficiency cut-off at x μm aerodynamic diameter. As an air pollutant, the airborne particulate matter has a negative effect on health, causally affecting

mortality, cardiovascular diseases, cancers, respiratory diseases, and as discussed herein, is shown to effect the airborne virus transmission of the coronavirus.

[0061] PM10 does not exactly represent a sharp division with particles of aerodynamic diameter of 10 microns; rather the PM10 definition attempts to replicate the separation behavior of the upper respiratory tract. In various embodiments, PM10 level or concentration may be determined in accordance with EN 12341:2014 (1.08.2014). PM10 may also be determined by a particulate matter sensor calibrated in accordance with EN 12341:2014 (1.08.2014).

[0062] PM2.5, aerodynamic diameter of 2.5 microns, generally corresponds to “alveolene-like” particulate matter (also called fine dust). In various embodiments, PM2.5 may be determined in accordance with EN 12341:2014 (1.08.2014). PM2.5 level or concentration may also be determined by a particulate matter sensor calibrated in accordance with EN 12341:2014 (1.08.2014). PM2, PM1.5, and PM1 level or concentration may be determined analogously.

[0063] As discussed earlier in the Summary section, particulate matter (PM) in the air is useful as an indicator of filtration efficiency. Increased PM levels put additional stress on the human respiratory system and are suspected to function as virus carriers. Measurement of PM2.5 and PM10 concentrations are useful as a proxy to determine aerosol concentrations in the air. Carbon dioxide (CO₂) is directly correlated with virus concentration in the air if an infected person is in the room. Therefore, CO₂ concentration in the air is a great indicator for indoor infection risk determination. Humidity, as discussed earlier, is important as corona virus decays more slowly in dry and in very humid environments. As discussed earlier the combination of air temperature with act humidity act together to affect the rate of virus inactivation.

[0064] The air quality sensors 102, 104, 106, 108 110, 112, 114 are arranged in one or more buildings having one or more monitored air spaces 120 (for example, room or halls, offices, school rooms, etc.). The air quality sensors 102, 104, 106, 108 110, 112, 114 communicate with the wide area network 118 to periodically or continuously transmit air quality measurement to the computer implemented airborne viral infection risk analysis

and air quality calculation system 122. Preferably, the air quality sensors 102, 104, 106, 108 110, 112, 114 act autonomously to periodically push transmissions of current sensor measurements to the computer implemented airborne viral infection risk analysis and air quality calculation system 122 over the network 118. Periodic transmissions, for example, may be at 30 second, 1 minute or 5 minute intervals. Alternately, the computer implemented airborne viral infection risk analysis and air quality calculation system 122 may transmit a data request to the air quality sensors 102, 104, 106, 108 110, 112, 114, requesting a transmission of the current air quality measurements, or by reading the measurements over the network. The air quality sensors 102, 104, 106, 108 110, 112, 114 may, in some cases, operate on an exception basis, such that sensor measurements are transmitted when the sensor measurement has changed by a pre-defined or configurable amount, although as envisioned, periodic transmissions are preferred.

[0065] It is preferred, but not required, that the air quality sensors 102, 104, 106, 108 110, 112, 114 are network enabled, preferably WIFI enabled, such that they may communicate directly with the network 118 and to the computer implemented airborne viral infection risk analysis and air quality calculation system 122.

[0066] The plurality of monitored air spaces 120 are generally enclosed air spaces within buildings, such as rooms, offices, conference rooms, restaurants, stores, gather places, etc. The buildings may be separated from each other by significant distances. For example, individual buildings may be located in different states in the United States, or may be located apart in different countries, perhaps separated by oceans (for example). The wide area network 118 such as the Internet makes the location and the distance between the dispersed monitored air spaces 120 and the computer implemented airborne viral infection risk analysis and air quality calculation system 122 essentially unimportant.

[0067] The computer implemented airborne viral infection risk analysis and air quality calculation system 122 includes (shown schematically) a processor including processing circuitry 124, and a non-transitory computer-readable medium 128, the non-transitory computer-readable medium 128 containing one or more sets of computer instructions configured to instruct the processing circuitry to perform a plurality

processing steps for receiving real-time air quality sensor measurements, receiving and analyzing the real-time air quality measurements of the plurality of air quality sensors and calculating an airborne viral infection risk score and the air quality indicators of one or more buildings having one or more monitored air spaces, and other process reporting and message or warning steps as discussed herein. Sensor measurement data and metadata about the measurements, analysis data or metadata from the calculating processes, generated reports, etc. may be stored to database 126. A network interface device 130 interfaces the computer implemented airborne viral infection risk analysis and air quality calculation system 122 to the wide area network 118.

[0068] The computer implemented airborne viral infection risk analysis and air quality calculation system 122 autonomously processes the received air quality sensor measurements, performs an analysis of the measurements to ultimately calculate the airborne virus airborne infection risk score, and the air quality index (AQI). The computer implemented airborne viral infection risk analysis and air quality calculation system 122 may generate one or more (e.g. all) of: trend reports, monthly reports, special reports on request, and may further provide one or more (e.g. all) of: measurement, intermediate calculated results, trends, warning e-mails, and advisory e-mails, recommended action messages, and historical data, to network connected devices such as smart devices, smartphones 132, tablets, or computers 134 of building occupants, responsible people, owners, subscribers etc. over the network 118. As shown and well known, the smartphones 132 may communicate with the network 118 through a cellular service provider 136 having one or more cell towers 138 for wireless transmission. Computers and tablets may use this cellular link also.

[0069] FIG. 1 shows an exemplary flowchart for the process in accordance with various embodiments. FIG. 1 is only exemplary and not limiting. Not all shown steps are necessary, and further steps may be added. As shown schematically in FIG. 1, the monitored air spaces 120 (or rooms) of buildings may optionally be provided with air treatment or filtering appliances 140 (schematically shown). The air treatment or filtering appliances 140 may be network enabled to receive control commands directly from the computer implemented airborne viral infection risk analysis and air quality calculation

systems 122 over the network 118. The air treatment or filtering appliance 140 may preferably be equipped with HEPA filtering, with bio-active filter coatings and may include UV-C light treatment, to filter, capture and inactivate viruses and bacteria, and to responsively improve or correct air quality. As an alternative, the building managers, owners, occupants, etc. may receive advisory SMS message, emails or alerts from the computer implemented airborne viral infection risk analysis and air quality calculation systems 122 over the network 118, with suggested instructions to act upon regarding room occupancy, such as through the air treatment or filtering appliance 140. For example, the suggested instructions may include one or more of: increasing outside air flow, reducing humidity, and increasing filtration.

[0070] As an initial high-level introduction, there may be 3 computations that are made to calculate an initial infection risk score for each pollutant:

- Calculate the instantaneous risk from the current pollutant concentration in the space,
- Calculate the instantaneous decay rate from the temperature and humidity in the space,
- Apply scaling to the risk score using the resulting decay rate calculation.

[0071] The worst overall pollutant (or highest risk) is chosen to represent the "overall Airborne Infection Risk Score (CAIRS) score risk" at each time interval.

[0072] FIG. 2 presents a metadata driven computer implemented process for airborne viral infection risk evaluation and air quality analysis 200, consistent with the present inventive disclosure. The process steps described in FIG. 2 are generally intended for programmatic autonomous execution on the computer implemented airborne viral infection risk analysis and air quality calculation system 122 (see FIG. 1) with network communicated measurements from at least some of the air quality sensors 102, 104, 106, 108 110, 112, 114 and interacting over the network enabled devices 132, 134 etc. as shown in Fig 1.

[0073] In step 202, the configured site information for dispersed buildings having monitored air spaces, customer information, etc. is read from the database 126.

[0074] Then in step 204 a building and its one or more monitored air spaces is selected, selecting a monitored air space as the current monitored air space.

[0075] In step 206, air parameter measurements from the networked air quality sensors 102, 104, 106, 108 110, 112, 114 in the current monitored air space 120 are read over the network 118. The air parameter measurements including one or more (e.g. all) of: air CO₂ concentration; air fine particulate matter PM_{2.5} concentration; air inhalable particulate matter PM₁₀ concentration; air relative humidity; air temperature. networked air quality sensors may further include a fresh air flow rate sensor configured to provide a measurement of volumetric fresh air flow to the monitored air space. The air parameter measurements may include volatile organic compounds (VOC), and a respective VOC sensor, for just one example, formaldehyde concentrations, particularly for AQI calculations.

[0076] In step 208, some or all of the current air parameter measurements may optionally be smoothed. According to various embodiments, smoothing may mean reducing noise. In one example, smoothing may be performed by averaging together a most recent number of air parameter measurements of each sensor over a defined period of time, just for example, 1 minute or 5 minutes. For example, as a simple moving average or a cumulative moving average.

[0077] In step 210, a calculated infection risk score (individually) of each measured CO₂, PM_{2.5}, PM₁₀, and humidity, according to available sensors and measurements, is calculated and stored to the database.

[0078] In step 212 a decay rate of viral infectivity (calculated as 1/corona virus half life) is calculated.

[0079] In step 214, the highest of the instantaneous risk score is scaled with the decay rate of viral infectivity to calculate a decay rate adjusted infection risk score.

[0080] In step 216, sensor measurements, calculations, decay rate, smoothed measurements are stored to the database, including for access by the web portal of the computer implemented airborne viral infection risk analysis and air quality calculation system 122.

[0081] In step 218, measurement data, historical trends is updated for the web portal, calculated results is updated for the web portal. SMS advisory messages are generated and sent to configured smartphones. Advisory e-mail message are generated and send to configured network devices. In some aspects of the invention, in some sites, in step 218 additional network commands or instructions may be generated and may be sent to configured network connected air treatment or filtering appliances 140 and/or building HVAC systems configured to accept network commands so as to respond proactively to improve filtration, adjust fresh air flow rates, adjust UV-C treatment, etc. to improve air quality (AQI) and reduce airborne virus risk.

[0082] In step 220, a next monitored air space of the same or a next building (is selected as the current monitored airspace. Control then transfers to step 206.

[0083] FIG. 3 is an Air Quality Index (AQI) chart, finding support in the U.S. Environmental Protection Agency Air Quality Index standards, as pertinent to the present inventive disclosure. The Air Quality Index (AQI) is determined by the worst relative pollutant concentration measured. Each category corresponds to a different level of health concern.

[0084] The Air Quality Index (AQI) was created by the U.S. Environmental Protection Agency (EPA) and is determined by the worst relative pollutant concentration measured. Each category corresponds to a different level of health concern.

[0085] FIG. 4 is a 3-dimensional plot depicting how the half-life of corona virus is related to temperature and humidity (in shades of white to black). For better understanding in a black and white presentation, additionally the general or approximate positions of half-life duration zones are marked by letters: A = 35 minutes, B = 30 minutes, C = 25 minutes,

D = 20 minutes, E = 15 minutes and F = 10, for an easier understanding of the plot. Approximate break lines are shown between the zones, for easier understanding.

[0086] The calculation basis for FIG. 4 half-life decay of airborne SARS-COV-2 is supported by the following equation (accredited to Paul Dabish et al., and now may be found in “The Influence of temperature, humidity, and simulated sunlight on the infectivity of SARS-COV-2 in aerosols”, Aerosol Science and Technology, Volume 5S 2021, Issue 2:

$$k_{infectivity} = 0.16030 - 0.04018 \left(\frac{(T - 20.615)}{10.585} \right) + 0.02176 \left(\frac{(RH - 45.235)}{28.665} \right) - 0.14369 \left(\frac{(S - 0.95)}{0.95} \right) - 0.02636 \left(\frac{(T - 20.615)}{10.585} \right) \left(\frac{(S - 0.95)}{0.95} \right)$$

wherein:

$k_{infectivity}$ = decay constant for viral infectivity, in min^{-1} , i.e.: 1/(Covid virus half life), units: min^{-1} ; T = temperature, in $^{\circ}\text{C}$; RH = relative humidity, in %; and S = integrated UVB irradiance, in W/m^2 .

[0087] FIG. 5 is an example of the relationship between the recorded concentration of Fine Dust Matter (PM_{2.5}) and how it relates to the airborne infection risk score. FIG. 5 is an example. The CAIRS score output for each pollutant is calculated in the same manner as in this example. This relationship can be specifically defined using the following logic (using PM₁₀ for an example):

[0088] Airborne virus risk infection score for PM₁₀ = (current_pmten - pmten_low) / (pmten_high - pmten_low)

wherein:

current_pmten = current detected concentration of PM₁₀;

pmten_low = configured, calculated or detected lowest concentration of PM₁₀;

pmten_high = configured, calculated or detected highest concentration of PM₁₀;

each of pmten_low and pmten_high may be pre-determined.

[0089] With the PM10 high and low values defined (in this example) as 10 and 17 respectively (see FIG. 5).

[0090] For an airborne virus risk infection score for PM10 less than 10, this value is smoothed to 0 using the following equation:

$$0.068 * e^{(0.5 * (\text{current_pmten} / \text{pmtwo_low} * 10))}$$

[0091] FIG. 6 is a plot of the viable virus percentage remaining vs elapsed time in days.

[0092] Relative Humidity 20%, Temperature 20°C, Inactivation $\log_{10} = -0.081/\text{day}$ (see 602, FIG. 6).

[0093] Relevant for human-to-human transmission in climate in enclosed spaces, where we spend 90% of our life, work, sleeping, commuting, etc. Coronaviruses on surfaces stay viable for about a week. From these surfaces viruses may be transmitted by direct and indirect contact as well as resuspension and inhalation to susceptible persons.

[0094] (FIG. 6, 604) viable virus percentage remaining vs elapsed time in days, in heated dry indoor air (20°C 80%RH), Inactivation $\log_{10} = -0.212/\text{day}$.

[0095] (FIG. 6, 606) viable virus percentage remaining vs elapsed time in days, in heated humid indoor air (20°C 50%RH). Inactivation $\log_{10} = -0.896/\text{day}$. Humidification of the air to 50% RH reduces the viable viruses to less than 1% in 2 days and significantly decreases infection risk. Refer to Casanova LM et al. "Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces", APPLIED ENVIRONMENTAL MICROBIOLOGY, May 2010 p.2712-2717.

[0096] FIG. 7 presents a relationship between indoor air CO₂ levels and cfm-per-person of outside air ventilation rates. This is an important factor in determining a safe occupancy rate of monitored air spaces, for example: classrooms. Increasing outdoor air ventilation can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. In an enclosed space with low ventilation (fresh air) rate, there is a higher chance of rebreathing exhaled air and viruses. Increasing ventilation rate reduces

exposure to exhaled breath and virus containing aerosols or airborne viruses. As a result, the CO₂ concentration in an indoor space can be directly related to a fresh air ventilation rate per-person in the space, therefore it directly correlates with virus concentration in the air. FIG. 7 shows a relationship between CO₂ levels and cfm-per-person outside fresh air ventilation rates. For each ventilation rate there is a corresponding CO₂ level. Assuming an outside concentration of 400 ppm, an indoor CO₂ concentration of 1100 ppm would be considered equivalent to 15 cfm per person and a concentration of 700 ppm would be considered equivalent to 30 cfm/person. The correlation of CO₂ levels to fresh air ventilation rates is independent of the number of occupants in the room.

[0097] In the foregoing specification, specific embodiments of the present invention have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

WHAT IS CLAIMED IS:

1. A computer implemented process of determining an airborne viral infection risk score of one or more monitored air spaces (200), comprising:

communicating (206), by a processing circuit and over a network, with the plurality of air quality sensors and retrieving over the network current indoor air quality measurements of the monitored air space in the one or more buildings, the air parameter measurements including:

air relative humidity;

air temperature; and

one, two, or all, of:

air CO₂ concentration;

air fine particulate matter PM_{2.5} concentration;

air particulate matter PM₁₀ concentration;

storing the sensor air parameter measurements to the database for access by a web portal;

calculating relative humidity instantaneous airborne infection risk score (210) from the relative humidity sensor air parameter measurement of the monitored air space;

calculating an instantaneous airborne infection risk score (210) for each of further measured air parameter measurement types of the monitored air space;

storing the instantaneous airborne infection risk scores to the database for access by the web portal;

determining which one of measurement types of the air parameter measurements has a highest instantaneous airborne virus infection risk score;

calculating a decay rate (212) for viral infectivity as a function of the air temperature and relative humidity of the monitored air space;

applying the decay rate for viral infectivity as a scale factor to the highest instantaneous airborne infection risk score (214) to obtain an overall decay rate adjusted highest instantaneous airborne virus infection risk score;

storing (216) the overall decay rate adjusted highest instantaneous airborne virus infection risk score and the highest measurement type to the database for access by the web portal;

repeating the plurality process steps for a next or same monitored air space.

2. The computer implemented process (200) of claim 1, comprising smoothing (208) the sensor air parameter measurements, before storing the sensor air parameter measurements, as smoothed air parameter measurements, to the database for access by the web portal and calculating the instantaneous airborne infection risk scores; optionally by averaging the current sensor air parameter measurements with the previous air parameter measurements of the same sensor over a configured period of time, the smoothing to reduce measurement noise.

3. The computer implemented process (200) of claim 1 or claim 2, wherein the air parameter measurements includes:

air CO₂ concentration;

air fine particulate matter PM_{2.5} concentration;

air inhalable particulate matter PM₁₀ concentration;

and calculating an instantaneous airborne infection risk score (210) for each of further measured air parameter measurement types of the monitored air space includes:

calculating a CO₂ instantaneous airborne infection risk score from the smoothed CO₂ sensor air parameter measurement of the monitored air space;

calculating a PM_{2.5} instantaneous airborne infection risk score from the smoothed PM_{2.5} sensor air parameter measurement of the monitored air space;

calculating a PM₁₀ instantaneous airborne infection risk score from the smoothed PM₁₀ sensor air parameter measurement of the monitored air space.

4. The computer implemented process (200) of any of the previous claims, wherein the one or more monitored spaces are a plurality of monitored spaces distributed in one or more buildings.

5. The computer implemented process (200) of any of the previous claims, wherein communicating (206), by a processing circuit and over a network, includes using a network communications interface device, configured to communicate over the network with the plurality of remote air quality sensors.

6. The computer implemented process (200) of any of the previous claims, wherein the network web portal is configured to provide remote network access and one or more of: presentation of measurements, analysis results, and reports, over the network to remote network connected devices.

7. The computer implemented process (200) of any of the previous claims, wherein the decay rate for viral infectivity is inversely proportional to a pre-determined virus half-life.

8. The computer implemented process (200) according to any one of the previous claims, wherein

after the step of applying the decay rate for viral infectivity as a scale factor, the method further includes:

communicating the overall decay rate adjusted highest instantaneous airborne virus infection risk score over the network to network connected smartphones, tablets, or network connected devices configured to receive air quality or infection risk updates.

9. The computer implemented process (200) according to any one of the previous claims, wherein

the step of communicating the overall decay rate adjusted highest instantaneous airborne virus infection risk score further includes the steps of:

reading configured risk level thresholds from the database;

determining that an instantaneous airborne virus infection risk score is greater or equal to the configured risk level threshold.

10. The computer implementer process of claim 9, comprising
transmitting a warning message (218) to network connected smartphones, tablets, or network connected devices configured to receive infection risk updates.
11. The computer implemented process (200) of claim 9 or claim 10, comprising
transmitting an alert to an air conditioning system associated with the monitored air space for which the instantaneous airborne virus infection risk score is greater or equal to the configured risk level threshold, the alert including the measurement type of the air parameter measurement having the highest instantaneous airborne virus infection risk score,
wherein the air conditioning system is capable of influence one or more of temperature, humidity, and has filter capabilities; and
generating, by a processor of the air conditioning system, operation mode instructions to modify the air property, of the monitored air space, corresponding to the measurement type thereby reducing instantaneous airborne virus infection risk score.
12. The computer implemented process (200) of claim 9 or claim 10, comprising
generating, for example, by the processing circuit or by the web portal, operation mode instructions to cause an air conditioning system associated with the monitored air space to modify the air property corresponding to the measurement type for reducing instantaneous airborne virus infection risk score,
wherein the air conditioning system is capable of influence one or more of temperature, humidity, and has filter capabilities; and
transmitting the operation mode instructions to the air conditioning system.
13. The computer implemented process (200) according to any one of the previous claims, wherein
in the step of communicating with the plurality of air quality sensors, the air quality sensor air parameter measurements further include:

an air volatile organic compound (VOC) concentration, selected from the set consisting of formaldehyde, toluene, xylenes, or combinations thereof;

wherein after the step of adding a time-date stamp and storing the current sensor air parameter measurements and storing to the database, the method further comprises:

calculating an Air Quality Index (AQI) from the smoothed sensor air parameter measurements of the monitored air space; and

storing the Air Quality Index (AQI) to the database for access by the web portal.

14. The computer implemented process (200) according to any one of the previous claims, wherein

after the step of applying the decay rate for viral infectivity as a scale factor, the method further includes:

generating electronic, for example e-mail and/or SMS, risk score notification messages and transmitting over the network or a cellular network to smartphones, tablets or network connected devices configured to notifications for the current monitored air space.

15. The computer implemented process (200) according to any one of the previous claims, wherein storing the current sensor air parameter measurements to a database comprises adding a time-date stamp and storing the current sensor air parameter measurements to a database for storing current and history data;

the process (200) further comprising predicting future risk increases based on historical trends determined from history data; and

- (i) transmitting an early message to network connected smartphones, tablets, or network connected devices configured to receive infection risk updates;
and/or
- (ii) generating operation mode instructions to cause an air conditioning system associated with the monitored air space to modify one or more air properties to counter the trend for reducing the future risk.

16. A system (100) configured to calculate an airborne viral infection risk score of one or more monitored air spaces, comprising:

a local or wide area network communications interface device (130), configured to communicate over a network (118) with a plurality of remote air quality sensors measuring air quality parameters within the monitored air spaces;

a database (126) for storing sensor air parameter measurements;

a network web portal configured to provide remote network access and one or more of presentation of measurements, analysis results, and reports over the network (118) to remote network connected devices (132, 134);

processing circuitry (124), and a non-transitory computer-readable medium (128), the non-transitory computer-readable medium (128) containing one or more sets of computer instructions configured to instruct the processing circuitry to perform the computer implemented process of determining an airborne viral infection risk score (200) of any one of the claims 1 to 15.

17. A non-transitory computer-readable medium (128), the non-transitory computer-readable medium (128) containing one or more sets of computer instructions configured to instruct a processing circuitry to perform the computer implemented process of determining an airborne viral infection risk score (200) of any one of claims 1 to 15.