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Ventilation Control for COVID-19 & Beyond

ABSTRACT

Outdoor air ventilation is essential to providing a healthy indoor environment. The pandemic of coronavirus disease 2019 (COVID-19), brought about by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is putting new focus on the approach to ventilation design and operation of buildings. This is because control of ventilation above normal rates is necessary to create a safe indoor environment while protecting the building infrastructure.

A safe and healthy building is dependent on dilution ventilation and maintaining proper pressurization. A building's ventilation system during normal operation strives to achieve acceptable indoor air quality (IAQ) based on building codes. The setup and operation of ventilation systems has variances and limitations. When a ventilation system fails to provide adequate ventilation, the effects of this are not immediately known. Unless the rate of outdoor airflow is actively measured, determining under-ventilation may only come after it is too late to prevent the outcome.

A building is a complex system, and it and the HVAC systems are subjected to dynamic changes. Degradation over time, impedes the HVAC system's capabilities. Weather and seasonal changes impact the ability to provide consistent ventilation. Proxy solutions, such as CO_2 control, can provide an indication of ventilation but no definitive value. Controlling ventilation and exhaust is necessary to set building pressurization and to control indoor temperature and humidity. There are health, productivity, and increased property value benefits when creating a healthy indoor environment. In the case of combating a health crisis, monitoring and controlling ventilation is paramount.

SARS-CoV-2 is recognized as an airborne virus through aerosolization. This fact has changed the dynamic from providing ventilation rates to minimize dissatisfaction with IAQ, to providing ventilation rates that dilute the concentration of virus particles in the air[1,2,3]. This dilution through mechanical ventilation is recognized as the primary means of virus removal for all indoor environments[1,3,4,5]. Monitoring and controlling actual flow rates in and out of the building is essential in ensuring dilution, pressurization, maximizing efficient operation of HVAC equipment, and creating a safe and healthy building.

BACKGROUND

Building codes and standards specify minimum ventilation rates to provide acceptable IAQ. Achieving acceptable IAQ is when 80% or more of the occupants do not express dissatisfaction and there are no significant known contaminant concentrations or an unusual source that would create a contaminant of concern[6]. Acceptable IAQ is designed in accordance with the Ventilation Rate Procedure to determine the minimum outdoor air for the occupants, per space use and building type[6]. The rates are intended to dilute dissatisfying odors from individuals, and off-gassing from furniture, components, and building materials. Some spaces within buildings have exhaust requirements (e.g. toilet rooms, kitchens, janitor closets), as they have higher concentrations of odors. Buildings that are designed for laboratory or patient care use do not fall under this procedure, as they have a higher level of ventilation and exhaust design requirements and operational controls to limit the migration of infectious diseases or harmful contaminants.

When building outdoor air ventilation systems are designed for commercial buildings, they are typically engineered in accordance with the mechanical code prevailing for a local jurisdiction (e.g. International Mechanical Code (IMC), Uniform Mechanical Code (UMC), California Title

24 part 6 (T24), ANSI/ASHRAE Standard 62.1 (62.1)). These codes and standards are under continuous maintenance and constantly evolving with a new full publication every 3 years. Throughout North America there are several published versions in effect by state, province, county, or city. The prescriptive ventilation rates within these codes are minimum requirements. Most professionals design only to these minimum rates as there is always a trade off between ventilation and energy, although some owners choose a design that enhances ventilation by following WELL[7], LEED[8], IGCC[9].

Ventilation rates are typically set by a Testing Adjusting Balance (TAB) professional. If a project does not enlist these services, then it typically falls on the installing contractor or in case of T24, an Acceptance Test Technician. If there is a Commissioning (Cx) professional on the project, they may perform functional performance tests to verify outdoor air ventilation and exhaust systems are operational. The conventional thinking is that a designed ventilation rate will be setup during construction, and that this one-time setting will forever maintain the correct ventilation requirements of the building. However, certification that airflow rates meet specification is the most difficult field measurement that a TAB engineer has to perform[10].

The amount of outdoor air ventilation in an indoor environment is difficult to perceive with our senses. Unless it is directly measured, a person cannot determine if the amount of ventilation air is the correct amount. There are delayed indications of inadequate ventilation that effect humans, such as headaches, fatigue, and upper respiratory irritations. When this happens to a large percentage of building occupants, it is termed as sick building syndrome (SBS)[11].

When the ventilation setpoint is made, it is typically adjusted to deliver the ventilation rate designed for full occupancy at full flow with all zones proportionally balanced[10,12,13]. Section 5.1 and 5.3 of 62.1 requires the minimum ventilation airflow be maintained and delivered under any load condition or dynamic reset condition, and provided with controls that maintain no less than the outdoor air intake flow as required by the prescriptive ventilation procedure[6]. The 62.1 User's Manual[14] clarifies this by stating *"To comply, most variable-air-volume (VAV) systems will need special design considerations and often features such as outdoor airflow sensors, modulating dampers and injection fans."* It further states *"A major consideration with VAV systems is that the negative pressure behind the outdoor air intake in the mixed air plenum will typically vary with supply air volume. At low supply airflow rates, this negative pressure will decrease, and sufficient outdoor airflow may not be maintained with a fixed outdoor air intake damper position—or even if a dedicated fixed minimum air intake is used."*

With the ongoing effort to save energy in the operation of buildings, the energy codes and standards (e.g. International Energy Conservation Code (IECC), California Title 24 part 6 (T24), ANSI/ASHRAE Standard 90.1 (90.1)) have incorporated fan airflow control on constant volume units that reduce the supply fan speed as a function of load. The effect of this change in airflow is no different than VAV. Therefore, newer constant volume systems need to address outdoor ventilation control in the same manner as VAV. Furthermore, the 62.1 User's Manual[14] addresses another problem with constant volume systems *"If the thermostat in such a system has a fan on/off/auto switch and the switch is left in the auto position, the fan will cycle off when the temperature set point is reached. If the fan system also supplies outdoor ventilation air, the cycling fan causes the outdoor air supply and ventilation to be discontinuous. Since many untrained people do not understand this, the switch is often placed in the auto position, resulting in inadequate ventilation."*

Outdoor damper curves are different for system operation at design and turndown. The amount of damper opening to maintain constant minimum is greater at turndown than design[15.] Additionally, dampers and actuators have combined hysteresis, the tendency to arrive at different positions for the same signal input when moving in different directions[15]. It makes the position of the actuators very inaccurate; this is especially serious concerning the minimum position of the outside air damper[16]. Hysteresis is caused by internal damper linkages and low leak seals, large damper sections, actuator to damper linkages, multiple sections jack-shafted, and higher torque applications requiring "piggy backed" actuators. Actuators have signal hysteresis to protect motors and mechanical hysteresis due to internal gear trains and springs. An actuator's feedback is believed to be a closed loop control, however, it only provides information on actuator position, not actual damper position or the ventilation flow rate.

Changes in weather and seasons impacts ventilation setpoints. Wind can hinder intakes or exhausts; the ventilation rate can be reduced by wind pressure[17]. Wind creates pressures that affects the mixed air plenum pressure in the similar way as varying the fan speed. On systems without mixing plenums (e.g. exhaust, makeup air, Dedicated Outdoor Air Systems (DOAS)) the wind can add a pressure source in series with the fan that impacts operation on the fan curve[17]. Fixed damper setpoints are affected by wind and stack pressure[18]. Stack pressure known as Stack Effect is due to density differences in the air. This density difference is caused by temperature differences between indoor and outdoor and creates a pressure difference that changes with seasons. This pressure can act on HVAC openings and extend through return or exhaust ducts that extend multiple floors. The pressure differential is directly proportional to building height and the difference between indoor and outdoor temperatures[19]. Although it is often considered a phenomenon to tall buildings, locations that have large temperature differences between summer and winter can experience stack effect on smaller buildings as well. Thereby an effort to balance intakes and exhausts in the summer can result in reduced flow rates in the winter. This pressure also varies across the building envelope and floor to floor making maintaining building pressurization control, to prevent infiltration, a dynamic problem.

Not all velocity and airflow measurement systems are equal. Some have limitations in ranges and application, are more affected by installed conditions, are dependent upon field measurement, or have wide ranges in precision[17]. Since all systems have some degree of turndown, it is important to look at the complete range of operation. It is important to understand all the components that make up the flow measurement device, such as measurement limitations and potential drift, and any maintenance or calibration requirements associated with them (e.g. pressure transducers). It is best to use a measurement device that has been factory calibrated for the application and is traceable to a national airflow measurement standard such as NIST. Products that have low density measurement or require set up based off field measurement carry additional error.

Demand control ventilation (DCV) is an energy saving strategy that is required by energy codes, for some high occupancy and variable load spaces. It is permitted by ventilation codes and standards as a means of Dynamic Reset. One of the more popular ways to reset the zone ventilation and/or the outdoor air ventilation rate is by sensing CO_2 in the space as a proxy for occupancy count. This is because the VRP has a ventilation rate per person component. CO_2 DCV has many challenges in implementation, among them is determining the correct generation rate by knowing the population make up and activity level[20]. It is important to note that CO_2 is a lagging indicator and steady-state concentrations will only be achieved if conditions including occupancy are constant for long periods of time. Sources of error for this strategy are accuracy of CO_2 sensors, their placement, and requiring that the air in the space is well-mixed. Too often control strategies and some standards make incorrect assumptions in the parameters used. There is a codependent relationship between CO_2 levels and ventilation rates and will differ for occupancy type. It is also common for controls to not increase ventilation off floor area base rates until desired steady state measurements (e.g. 1000 ppm) are reached. This approach saves energy, however, it causes under-ventilation by not providing the ventilation rate for the actual current population. There are improved approaches to incorporate CO_2 DCV[21].

DISCUSSION

Viruses have been identified as the most common cause of infectious disease acquired within the indoor environment[22]. Airborne transmission can occur via direct contact with droplets, skin flakes, and fungal spores. Aerosols can be generated (atomized) during breathing, speech, sneezing, singing, vomiting, and feces evacuation and toilet flushing[22,23]. Aerosols can be as large as 100 µm (microns) in diameter and can exist in liquid or solid form with the majority of respiratory aerosols being less than 10 microns [22,23,24]. As a reference, the human hair is between 50 to 70 microns. A study has shown that individuals coughing while infected with influenza can release 75,000 respiratory droplets[25]. The size distinction is important because larger droplets settle (fall to floor, furniture, clothing), and smaller ones remain suspended in air from minutes to hours[4,22,26].

The room environment impacts the survival of the virus and its ability to remain airborne[26]. When a respiratory droplet is expelled, it is at 100% relative humidity (RH) and it decreases rapidly in size by evaporation into a room with a lower RH[27,28]. This reduced size droplet has the potential to survive longer in the air and to reach different parts of the respiratory tract. Those that remain in the air may eventually, become inactivated, settle out, or be diluted out by ventilation and exhaust[29]. It is important to note that the virus itself is smaller in size than the respiratory droplet, so there can be more than one virus particle per respiratory droplet. As an example, SARS-CoV-2 is 0.12 microns and influenza is 0.10 microns. It is also possible for a larger droplet to settle out and then to be resuspended back into the air as a smaller droplet from clothing, the floor, or other surface that is disturbed[4,6]. Other viruses that can be transmitted via airborne aerosols are tuberculosis, measles, chickenpox, legionella, SARS-CoV-1, and MERS-CoV[4,5,30].

Characteristics of viruses is unique to a virus and requires significant research. Typically, a virus crisis ends before much is known about it. We have a version of Influenza on an annual basis, however, scientists still do not know all there is to know about its ability to transport and infect people[31]. What we know is that the infectious concentration in the air is dependent on the generation rate (Quanta) and the removal of the virus by settling, inactivation (decay rate), and ventilation[29]. The Quanta is influenced by how it is atomized, droplet size, temperature, and humidity. Indoor environments are perfect for the transmission of viruses. However, we can increase the decay rate and strengthen the human response if we keep room RH between 40-60%. Viruses have more vitality, or less chance of inactivation, when the RH is > 90% or <40%[27,29,32,33]. It is also known that the amount of virus RNA copies atomized, increases with metabolic rate and vocal level[34]. It is recognized that coughing and sneezing produce significant levels of atomized particles. However, in some case more particles are produced by singing and shouting; also, breathing and general speaking will also release virus particles[23,35,36].

A study of SARS-CoV-2 breath emission into the air, during the early stages of COVID-19, measured up to 100,000 RNA copies per minute[37]. Another study looked at the risk for infection before and after lockdown in Italy in different retail buildings, with the post lockdown cases limiting personnel and using PPE. It showed an infected person spending only 10 minutes inside the store, has the potential to infect another person who comes in 16 minutes after the first person leaves. The risk increases the more the individuals spend time indoors. In both pre and post lockdown calculations, mechanical ventilation significantly lowered the risk[35]. Ventilation, when implemented correctly as an engineering control, can have significant impact to providing a safe environment.

Lack of ventilation control will create an environment that is at risk. Without adequate ventilation, the virus concentration will continue to climb and the recirculated air distribution within the indoor space can act as a super-spreader; infections go from close contact additive to sharing the same space exponential[36,38]. In the case of a call center in South Korea, there was a 43.5% infection rate (94 cases), within a few days. In another case in Canada a small church social event of only a few hours, where they followed social distances and wore gloves, resulted in 58% infection rate (24 cases). It was reported that none of the attendees had traceable contact to any know infected person. It is thought that the virus was in the church air from the previous day[39].

Air moving components (e.g. fans, dampers, louvers, ducts) and heat transfer equipment (e.g. hydronic coils, DX coils, energy wheels) are typically sized to convey and condition only the minimum ventilation requirements. The ability to add additional ventilation air may be limited while maintaining comfort and energy efficiency. However, the need to provide more dilution for a safer indoor environment should outweigh the penalties.

DCV should be disabled during times that need enhanced dilution ventilation[1]. Maximizing economizing by increased high limits and using integrated economizer control strategies will increase dilution air. Resetting supply and space temperatures will also assist in providing more ventilation. However, a building must be treated as if it is a system. Any change in the operation in one area can have an unexpected change someplace else. In general, buildings should be kept slightly positive to neutral. Any changes in ventilation rate must have corresponding change in exhaust rate. It is not fan pressure that creates building pressure, it is the differential of flows into and out of the building (pressurization flow) that creates and maintains pressurization[40]. In more complex buildings, flow maps should be created to determine interaction of systems and ensuring intended flow paths and pressurization flow. This is common for laboratories and hospitals and should be standard practice for all multiple zone buildings.

History has a way of repeating itself. A drive towards energy efficiency creates new challenges in building operation. After the 1970's energy crisis, reduced ventilation and tighter buildings generated SBS and fungal growth. The push for tighter buildings, demand control ventilation, and/or the use of air cleaning technologies to limit the outdoor ventilation rates handicaps buildings to maintain a healthy indoor environment. The focus is misdirected to building operating cost and ignoring the #1 asset, the occupant. Enhanced ventilation not only protects the people it also enhances their performance. Ensuring the correct amount of ventilation and exhaust is not only insurance, but an investment in health, productivity, and protection of the building and occupants[41,42].

In another paper's conclusion it was stated *"However, the air-conditioners in current use in most buildings may be unable to use MERV-13 filters or have fans that are not able to handle the required volume of outdoor air. Indeed a new generation of air-conditioners that meet these requirements may be needed."*[38] What is needed can be achieved today with the correct planning and integration of airflow measurement and control into buildings.

CONCLUSION

High sensor density airflow measuring devices should be incorporated at a minimum in outdoor air, supply air, return air, and exhaust air. Strong consideration should also be made to accurately measure flows to zones in DOAS and VAV systems[43]. Additional airflow measuring devices may be needed to combat wind and stack effect[40]. Avoid CO_2 control as means to provide accurate and repeatable ventilation as it has drift, and is often misunderstood and applied. Make sure you select the correct airflow measurement device to suit the application[17].

Whether it is ensuring the minimum ventilation or integrating enhanced ventilation with new control strategies, accurate and repeatable measurement of the outdoor ventilation air is necessary to achieve the most efficient system operation. Not only will real-time airflow measurement provide the rate of flow, this valuable data can be used to set upper and lower limits, maintain proper pressurization throughout operating conditions, perform ventilation load calculations, reset rates as conditions change, and initiate alarms.

It is a perfect time to evaluate existing HVAC systems and determine how outdoor air ventilation can be better measured and controlled. It is an easy and economical way to show your building is in compliance with codes and can meet needs of enhanced dilution for safer indoor environments. It essentially pays for itself by bringing value to the building and occupant productivity benefits[41,42]. Some building types such as schools, have significant research showing ventilation is a systemic problem that leads to respiratory health problems, absenteeism, developmental challenges, and building damage[44]. This is not the first airborne virus and it will not be the last. Act now, not only for today's challenges, also for the future.

RESOURCES

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