ENHANCED HVAC INFECTION CONTROL: VENTILATION EFFECTIVENESS

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Introduction

Our previous white paper on *Dilution Ventilation* examined how the concentration of contaminants in the air can be significantly reduced by introducing "cleaner" outdoor air into the occupied space. In this paper we will discuss how well we can expect the outdoor air to mix with the air in the rooms and the likelihood that any airborne contaminants in the rooms will be captured and returned to the HVAC equipment for treatment or removal.

Ventilation – More Than Just Outdoor Air

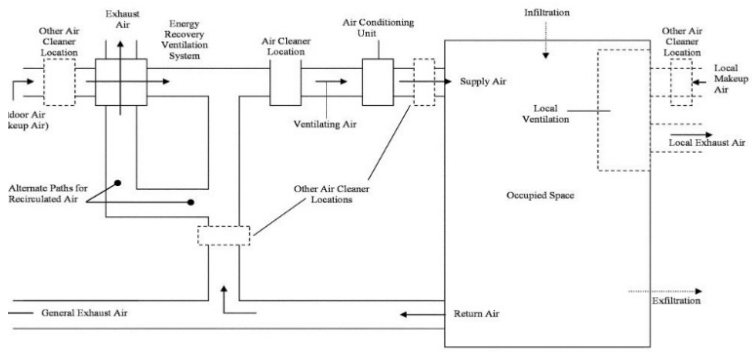
Proper ventilation of the occupied spaces is critical to maintaining acceptable indoor air quality (IAQ) and thereby the overall health and wellbeing of the inhabitants of the building. Ventilation design has been a topic of debate among engineers for decades, with ever changing theories on the best methodologies, air exchange rates and distribution strategies necessary to achieve acceptable indoor air quality. With the advent of improved digital monitoring and control technologies, these debates have been quelled by the empirical data gathered regarding the required ventilation rates necessary to achieve acceptably low concentrations of known airborne contaminants.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has developed the de facto standard for designing for and monitoring indoor air quality in its *ANSI/ASHRAE Standard 62.1 – Ventilation for Acceptable Indoor Air Quality*. Nearly all codes today refer exclusively to this Standard.

ASHRAE defines "Ventilation" as:

> *The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.*

It is important to note that ventilation involves not only outdoor air ventilation, but also the recirculation of air within the building. Very few buildings are configured for a 100% outdoor air ventilation rate, therefore, it is important to consider both recirculated room air and the outdoor air that is introduced at the HVAC equipment, along with other components including infiltration and localized exhaust systems. The diagram below, reprinted from ANSI/ASHRAE Standard 62.1-2019, illustrates the various components that potentially contribute to the overall ventilation of any occupied space.



ANSI/ASHRAE 62.1 Ventilation System Diagram

Room Air Mixing Efficiency

Nearly all HVAC systems deliver primarily recirculated air, along with a percentage of fresh air from the outdoors, as part of the supply air delivered to the occupied spaces. It is a given that the supply air delivered to the spaces by the HVAC unit is well mixed due to the turbulence of the air in the ductwork system, however how well does the supply air delivered to the room mix with the rest of the air in the room?

The goal of diluting the contaminants in the room air depends on the efficiency of the mixing of the air in the room. If portions of the room or rooms have little or no air movement, the dilution of contaminants will be inconsistent and will not be as effective in the stagnate areas.

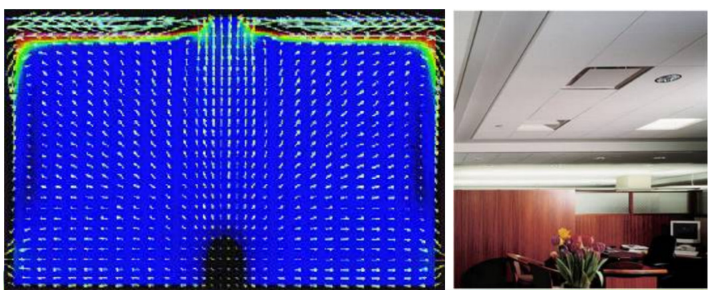
A number of factors affect the mixing of air in a room. They include, in no particular order:

- Quantity, type, and location of the diffusers.
- The temperature and volume of air delivered.
- The supply air discharge velocity.
- The supply air discharge patterns.
- The location of the return air grilles with respect to the

occupied zone and with respect to the supply air diffuser(s).

- The location of the exhaust air grilles with respect to the sources of contaminants and with respect to the supply air diffuser(s).
- The overall layout and physical configuration of the room itself.
- The air exchange rate.

The preceding factors are just a few of the many variables influencing the mixing of air in the occupied spaces. However, these are the factors that are most likely to be influenced by the system designer. The end goal of any air distribution system design is to achieve a well-mixed distribution of air throughout the space. Perfect air mixing everywhere is not easily attainable, however using proper discharge device selection and location the system designer can aid in the thorough mixing of the air in the room.



High Induction Supply Air Diffuser Design

The key to good air mixing in the space (effectiveness) is having a relatively high velocity of air discharged from the supply air diffusers so that room air movement is induced by the high velocity stream of supply air. The temperature of the air delivered to the space has a very significant impact on the mixing of air, particularly if the air volume is varied based on the load in the room, as occurs in a Variable Air Volume (VAV) system.

Air change effectiveness (ACE) is a calculation of an air distribution system's ability to effectively deliver ventilation air to a building, zone or space. ACE is defined by ASHRAE as the age of air that would occur throughout the building if the indoor air was perfectly mixed divided by the average age of the air where the occupants breathe. The "age of the air" in the ACE calculation refers to the average time elapsed since molecules of air in a given volume of air entered the building from outside.

Studies have consistently shown that during the cooling mode (supply air discharge temperatures of approximately 55°F), air mixing is generally very good, approaching (or exceeding) a 1.00 ACE rating.

However, during the heating mode ACE often drops dramatically, particularly in Variable Air Volume (VAV) systems operating at or near their minimum total circulation rate. ACE in the heating mode, for systems with ceiling level supply diffusers, can range from as low as 0.69 to a high of 0.91, with a mean value of 0.72. This reduced air mixing in the heating mode, combined with the many other seasonal influences on the spread of viral contaminants (humidity, activity level, etc.), helps explain why viral infections typically spread more rapidly in cold northern climates during the winter months.

The ACE values described herein are based on the assumption of a well-designed approach to air delivery to the space. Poorly designed systems that result in short circuiting of the air from the supply diffusers to the return/exhaust grilles, or an insufficient amount of total air delivered to the space will see markedly lower ACE values. Good air distribution design is essential to the effective mixing of fresh air and room air in the occupied spaces.

ANSI/ASHRAE Standard 62.1 provides some generalized zone level effectiveness values (E_z) for use in the calculation of the minimum required rate of outdoor air introduction necessary to achieve acceptable indoor air quality. From the table on the following page, it is clearly evident that the selection of the supply diffuser and return/exhaust grille locations is very important to proper room air mixing and therefore the amount of outdoor air ventilation required to maintain the air quality within the defined acceptable range.

Table 6-4 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Well-Mixed Air Distribution Systems	
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is less than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is equal to or greater than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	1.0
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply outlet located more than half the length of the space from the exhaust, return, or both	0.8
Makeup supply outlet located less than half the length of the space from the exhaust, return, or both	0.5

ANSI/ASHRAE 62.1 2019 Ventilation Effectiveness

The better the supply air mixes with the air in the occupied space, the better the chances are that any airborne contaminants will be carried back to the HVAC unit, where they can either be trapped or rendered inactive by any of the air cleaning methods installed in the unit. Short circuiting of the air in the space should be avoided under any circumstances.

Droplets vs. Aerosols

A "droplet" is defined by Merriam-Webster as *a tiny drop (as of a liquid)*. Droplets produced by exhalation, coughing, sneezing or speaking are referred to as respiratory droplets. Respiratory droplets consist of mucus and other matter from the respiratory tract surfaces, containing various microbes, viruses and other contaminants that can be spread to other humans. Respiratory droplets are typically larger in size and usually fall to the ground or nearby surfaces relatively quickly to become "fomites" - objects or materials which are likely to carry infection.

An "aerosol" is defined by Merriam-Webster as *a suspension of fine solid or liquid particles in a gas*. Respiratory aerosols, which are also produced by exhalation, coughing, sneezing or speaking, are small enough in size to have significant buoyancy and can remain airborne for much longer periods of time before succumbing to gravity.

A 2008 study by Chao, Wan, Morawska, Johnson, Ristovski and Hargreaves, in combination with a 1987 study by Fairchild and Stamper found that the respiratory droplet and aerosol particulate size range for coughs, sneezes and speaking range anywhere from 0.3 µm to 1500 µm, with the highest particle concentrations in the 6-14 µm range, whether based on total particle count (6 µm) or the mean diameter of the particles expelled (12.3-14.0 µm).

Respiratory droplets are commonly divided into two size groups, large droplets (>5 µm in diameter) and small droplets (≤5 µm in diameter).

Large droplets fall rapidly to the ground or onto other surfaces, where they can remain viable for anywhere from a few hours to a few days depending on the surface material and room conditions. Based on various research studies, these larger particles rarely travel more than six feet from their source. This is the basis of the six foot social distancing recommendations coming from public health officials. These larger particles are not transported back to the building's air handling equipment for discharge or removal by filtration, exhaust or sterilization devices. Therefore, HVAC systems are completely ineffective at stopping the spread of SARS-CoV-2 between building occupants due to large droplet transmission.

Facial coverings (masks) are by far the most effective means of stopping these larger particle sizes at their source, reducing the risk of infection of others in the area or others that will come in contact with the surrounding surfaces in the near future.

Smaller droplets (≤5 µm) remain airborne much longer and can evaporate into *droplet nuclei*, which can remain suspended in the air for up to 3 hours, according to several studies. These droplet nuclei and associated aerosols are the types of infectious particles that HVAC systems can be very effective at removing or neutralizing, provided the ventilation effectiveness of the room is good, the particles are captured at the return/exhaust air grilles and they are transported to the air handling equipment by the return air or exhaust air ductwork. There, they can either be removed by filtration/exhaust or neutralized by the various sterilization methods discussed in our previous white papers.

Summary

At present time, it is not believed that the primary transmission method of the SARS-CoV-2 virus is through airborne droplet nuclei or aerosols. However, recent reports have suggested that the virus may indeed be capable of significant airborne transmission, particularly in poorly ventilated buildings or rooms. Many of the "super-spreader" events appear to be the result of airborne transmission to large groups of people in sub-standard indoor locations. This has prompted the World Health Organization and the Centers for Disease Control to acknowledge that the possibility of significant airborne transmission exists.

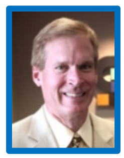
As a result, ventilation effectiveness, coupled with proper ventilation rates and increased filtration efficiency, is an area of concern that must be addressed in order to safely reopen our buildings. Ventilation effectiveness is largely dependent upon how well the HVAC system has been designed to ensure adequate mixing of the air in the occupied space, so that the smaller infectious particles can be quickly transported to the HVAC equipment, where the other measures of infection control covered in this series of white papers can have a meaningful impact on the spread of the virus. Even in existing facilities, relatively minor revisions can be made to improve the ventilation effectiveness of a system, without requiring complete renovations.

According to all known studies of modern air distribution design, ventilation effectiveness is quite high when the system is in the cooling mode, approaching 100%. However, it can drop significantly in the heating mode, due to reduced airflows and stratification of the air in the space. With some relatively minor adjustments to the control systems, particularly in Variable Air Volume (VAV) systems, ventilation effectiveness can be significantly improved using higher heating airflow rates and adjustments to the recirculation rates at the air handling equipment.

About Pedro:

Pedro Ferrer, P.E. has been involved in the design of mechanical systems for malls, mixed-use developments, corporate offices, national retail roll-outs, commercial and institutional buildings for over 26 years with Schnackel Engineers.

About Greg:



Gregory Schnackel, P.E., LEED AP has been involved in the design of mechanical, electrical, plumbing, fire protections and information technology systems for malls, mixed-use developments, corporate offices, national retail roll-outs, schools, hospitals, medical facilities, commercial and institutional buildings for over 40 years with Schnackel Engineers.

RESOURCES	
ASHRAE	https://www.ashrae.org/
National Center for Biotechnology Information	https://www.ncbi.nlm.nih.gov/
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
National Institutes of Health	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7293495/
eLife	https://elifesciences.org/articles/57309
National Environmental Balancing Bureau	https://www.nebb.org
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World Health Organization	https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public
Centers for Disease Control	https://cdc.gov