ASHRAE Technical Committee

TC 5.3 Room Air Distribution

Airflow Patterns and Distribution of Airborne Contaminants in Indoor Spaces

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ASHRAE TC 5.3 Room Air Distribution

This document was developed by a TC 5.3 ad hoc committee formed in June 2020

Ad hoc Committee

Chair

Dr. Kishor Khankari
AnSight LLC
Ann Arbor, MI, USA

Contributors

Mr. Kevin J Gebke
DuctSox Corp
Dubuque, IA, USA
Mr. Mikhail Koupriyanov
Price Industries Ltd.
Winnipeg, MB, CANADA
Mr. Kenneth J. Loudermilk
Titus Products
Johns Creek, GA, USA
Mr. David A John
Stan Weaver and Company
Tarpon Springs, FL, USA
Dr. Andrey Livchak
Halton Americas
Scottsville, KY, USA
Dr. Peng "Solomon" Yin
University of Louisiana at Lafayette
Lafayette, LA, USA

Reviewers

Mr. Azmi S. Aboul-Hoda
EMergy, UAE
Dr. Chao Ding
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Berkeley, CA, USA
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Air System Components, USA
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Encon Expertise Pvt. Ltd., INDIA
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Halton Americas, USA
Apex, NC, USA
Dr. Duncan Phillips
RWDI, CANADA
Ms. Zahra Sardoueinasab
Nailor Industries, USA

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Mr. John Bade, Mr. Frank Cuaderno, Dr. Mohammad Hosni, Mr. Chad Huggins, Mr. David Johnson, Mr. Ryan Johnson, Mr. Robert Persechini, Mr. Julian Rochester, Mr. Krishnan Viswanath

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Introduction

The recent COVID-19 pandemic has raised concerns about the effects of space air distribution on the spread of airborne contaminants. This document was developed by ASHRAE Technical Committee 5.3: Room Air Distribution to provide high-level guidance in minimizing the spread of airborne contaminants within the indoor environment. In particular, the guidance provided in this document applies primarily to the room air distribution within mechanically ventilated non-residential spaces, such as offices, restaurants, and classrooms, as well as to long term care facilities. The document also assumes that the air supplied to a space is cleaner than the room air itself. Generalized airflow patterns associated with various methods of room air distribution systems are explained, and guidance for improving the contaminant removal efficiency is provided.

Background

The air we breathe is a mixture of gases, including nitrogen and oxygen, and various contaminants. These contaminants are both gaseous and particulates, the smaller of which are aerosols that include dust, smoke, bacteria, fungi, viruses, and radioactive decay particles from radon gas. Many aerosols are a cause for concern because they can adversely affect occupant health (ASHRAE 2017a).

The COVID-19 infection is assumed to spread primarily by the SARS-CoV-2 coronavirus present in large droplets (size greater than 5 µm), which are generated by the coughing and sneezing of an infected person. A separation of at least 6 feet (2 m) distance between individuals is advised to avoid contact with these droplets, which are presumed to fall within a short distance due to their size and gravitational pull. While the role of airborne aerosols in spreading the COVID-19 disease is still uncertain, a group of 239 scientists on July 6, 2020 appealed to the World Health Organization (WHO) in an open letter stating that it is “beyond any reasonable doubt that viruses are released during exhalation, talking, and coughing in micro-droplets small enough to remain aloft in the air and pose a risk of exposure at distances beyond 1 to 2 m from an infected individual” (Morawska and Milton 2020). As a result, the number of people exposed in a shared environment can be affected both positively and negatively by airflow patterns within the space (ASHRAE 2020a).

In April 2020, ASHRAE issued a Position Document on Infectious Aerosols that discusses airborne viral dissemination and that provides general guidance on controlling the spread of viral nuclei (ASHRAE 2020c). The document primarily addresses the HVAC system components and operation and suggests modifications that might reduce the concentration of contaminants introduced into an occupied space by various sources. It also identifies and qualifies various room air mitigation strategies that might help reduce the concentration of airborne contaminants. The document devotes minimal discussion to the room air distribution system and its effects on the transport of airborne contaminants within the space.

Continuously updated guidance regarding air handling unit operation and possible contaminant reduction strategies for various building types may be found at https://www.ashrae.org/technical-resources/resources.

It is important to note that system design or retrofits related to contaminant mitigation must comply with mandatory provisions of related codes and standards unless a waiver is granted. Nothing in this document is intended to supersede requirements specified in codes and standards, requirements of the authority having jurisdiction, or to replace the need to consult with a registered design professional, code officials, and site Environmental Health and Safety (EH&S) staff as might be necessary to achieve a safe environment for occupants and to protect property from damage.

Air Distribution Systems

Airflow patterns and the resulting flow path of airborne contaminants play an important role in the spread and accumulation of airborne contaminants and probable locations of surface deposition. Airflow patterns can also play an important role in reducing the risk of contaminant exposure by proper design of a containment strategy. The airflow patterns and the flow path of airborne contaminants can depend on several inter-related factors including the number, location, and type of supply outlets; supply airflow rates (air change rates) and associated diffuser throws; supply air temperature; number, size, and locations of return/exhaust grilles; locations and strengths of various heat sources in a room; an arrangement of furniture and other obstructions to airflow; and most importantly, the relative positions of contaminant sources in a space.

Natural convection currents that form due to temperature gradients within a space result in vertical air motion. The magnitude of these airflow patterns depends on the surface temperature of the heat source and the effects of other airflow patterns surrounding these sources.

While room air patterns are influenced by turbulent air jets as well as by natural buoyancy, the room air generally migrates along the path of least resistance to return/exhaust locations. A series of chapters in ASHRAE Handbooks (ASHRAE 2020b, ASHRAE 2017b) assign room air distribution design methods into three basic categories:

- Fully stratified systems
- Partially mixed systems
- Fully mixed systems

Figure 1 depicts the room temperature gradients associated with each of these.

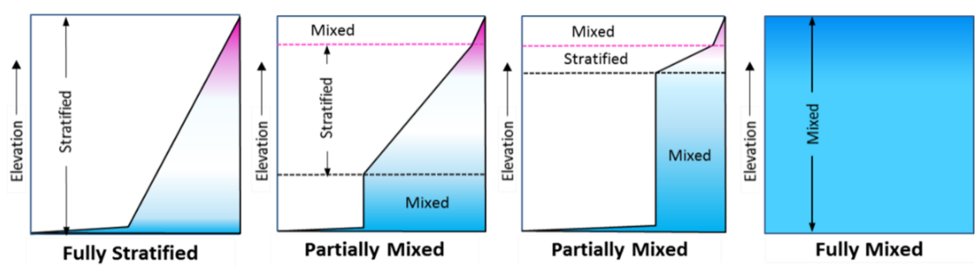

Figure 1: ASHRAE's Classification of Room Air Distribution Methods

Although fully stratified or fully mixed conditions are rarely achieved, the design objectives of the air distribution method chosen largely determine the room airflow paths.

Room air motion created by mixed air systems is primarily governed by the velocity of the turbulent supply air jets, the rate at which that velocity decays, and the projection they achieve. Typically, the supply and return diffusers are located at the ceiling for a mixed air system. The location and magnitude of heat sources within the space can also affect the room air airflow patterns, particularly heat gains or losses resultant from an exterior wall or window. In any case, the room airflow patterns created by mixed air systems are somewhat chaotic and circulatory and tend to migrate toward the location of the return/exhaust air outlets. It should be noted that most manufacturers' supply outlet performance data is based on isothermal air (air supplied at the same temperature as the space it serves) and will be affected by the actual temperature differential related to its application. The airflow patterns created by fully mixed systems can promote mixing and recirculation of airborne contaminants generated within the occupied space.

Room air patterns in fully stratified and partially mixed systems are largely dependent on the location and discharge velocities of their supply outlets. During the cooling mode, fully stratified systems deliver cold air at or near the floor, which results in upward airflow patterns that are created by thermal buoyancy forces and transport the room air to the upper region of the space. Stratified systems, if designed and operated properly, can promote upward migration of airborne contaminates during the cooling mode operation. Depending on the size and aerodynamics of airborne particulates such stratified systems may also promote stagnation of particulates in the breathing zone of the occupants. Stratified air systems are suitable only for cooling operation. Such systems need supplemental heating devices such as baseboard or radiant coils during the heating mode. Partially mixed systems create air motion patterns similar to those in fully mixed systems in portions of the space while other portions of the room remain thermally stratified.

Recommendations for Space Air Distribution

The number and location of supply diffusers and return grilles and their operation can have a major effect on room airflow patterns and the distribution of airborne contaminants. As such, the following recommendations apply to all room air distribution systems:

- Ensure that all supply diffusers and return grilles are performing as per the design intent and are consistent with contaminant control intent
- Ensure that all supply and return devices are unobstructed by furniture, architectural features, or other obstacles.
- Review the sequence of operation of the HVAC systems to ensure that the sequence matches design intent and is also consistent with contaminant control intent.
- Review room air set points for temperature, humidity, and pressure and the relevant sensor locations, and if necessary, make adjustments or replace malfunctioning devices so that the space can be operated as intended.
- Create a path of least resistance for the contaminated air to exit the space by increasing the size and number of return grilles at appropriate locations.
- Promote sweeping airflow patterns that move the contaminated air away from the occupants by placing the return grilles away from the occupants.
- Relocate supply outlets to eliminate air jet collisions that result in drafts (high velocities above the ASHRAE Standard 55 (2017a) recommendation of 40 fpm or 0.20 m/s) in the occupied zone. If relocation is not possible, replace them with high induction diffusers with shorter throws.
- Ensure that air motion is provided to all occupied areas of the space to avoid any stagnant zones with low air motion.
- Return grilles should be located outside the path of supply air jets to avoid any short-circuiting of clean supply air.
- In the case of fully stratified systems, since there is no recirculation of air from the upper part of the space back to the occupied zone, the use of upper-room UVGI or other upper level cleaning devices may be redundant in such cases.
- In the case of fully stratified systems, a fan-assisted portable filter unit must be used with caution because the air discharged by such devices can disturb the thermal stratification in the space.
- Follow source control recommendations such as mask use, social distancing, and install lids on all toilets and instruct occupants to close them before flushing to reduce aerosol escape.

- Each space is unique in its layout, airflow distribution, and in the resulting airflow patterns. Therefore, seek professional guidance before implementing any substantial retrofit of the airflow distribution system.

Computational Fluid Dynamics (CFD)

Systematic investigation of the combined effects of all the variables that affect airflow patterns and the flow path of contaminants using physical testing in indoor facilities is time and resource-intensive, and sometimes impossible. Computational Fluid Dynamics (CFD) analyses, if performed properly with adequate expertise, can predict airflow patterns and the probable flow paths of airborne contaminants in a space. Such analyses can be employed as a valuable design tool in developing appropriate mitigation strategies for existing spaces and during the early stages of new designs to optimize occupant comfort and indoor air quality, and to minimize the concentration of airborne contaminants. CFD simulations and analyses are based on the fundamental physical laws of air motion, heat transfer, and mass transport. Additional information regarding previous CFD studies is provided in Appendix B.

Air Cleaning Strategies

This document assumes that the air delivered to a space through supply outlets is free from airborne contaminants. There are several in-duct as well as in-room air cleaning strategies available in the market. However, the scope of this document is limited to room air distribution only, and therefore, only those air cleaning strategies that directly affect room airflow patterns or whose performance depends on room air distribution are discussed here.

Ultraviolet germicidal irradiation (UVGI) uses short-wave ultraviolet (UVC) energy, predominantly at a wavelength of 254 nm, to disrupt the RNA or DNA of viral, bacterial, and fungal organisms so they are unable to replicate and potentially cause disease (Bendjennat et al. 2003). Non-ozone producing UV lamps with tube material blocking UV wavelengths below 200 nm are used for these applications.

Fan-assisted filter units have a circulating fan, a high-efficiency filter, an air inlet, and an air outlet. A few designs also incorporate UVGI to inactivate airborne pathogens. They may be installed in the ceiling or be free-standing portable devices within the occupied levels of the space. They may be configured to simply recirculate room air or to exhaust it, either directly or by ducting it to return grilles within the space.

The efficiency of the in-room cleaning devices can depend on airflow patterns that are created by the room air distribution. The effectiveness of upper-room UVGI systems depends on the trajectory of airborne contaminants, inactivation dosage they receive, and their residence time in the active UV-C zone. Therefore, the local airflow patterns and resulting flow path of airborne contaminants can affect the performance of such systems. In the case of portable air cleaners, the local concentration and path of airborne contaminants will depend on the source type and location as well as the number of air distribution and exhaust/return devices. The location, capacity, discharge velocity, and the design of the device would affect the room airflow patterns and efficiency of such devices. Locations of such devices should be carefully selected and analyzed to create a clean environment in the breathing zone of the occupants and should avoid any adverse effect on the flow path of airborne contaminants.

- Fully mixed systems create air motion patterns that tend to migrate toward supply air jets. When these jets are confined within the upper portion of the space, they deliver the air and its associated aerosol contaminants to an unoccupied zone which can be fitted with UVGI lamps that deactivate the viral nuclei within the aerosol.

- During the cooling mode, thermally stratified systems like thermal displacement provide upward air motion around the space occupants. This motion naturally conveys the contaminants associated with their normal respiration to the upper unoccupied levels of the space where they can be removed with return air without affecting other space occupants. As such, additional room air mitigation devices are not generally necessary. Disturbances and obstructions to airflow in the stratified air distribution system can adversely impact the thermal stratification and upward buoyant movement of airborne contaminants.
- In the case of fully stratified systems, a fan-assisted portable filter unit must be used with caution because the air discharged by such devices can disturb the thermal stratification in a space.

Research Needs

ASHRAE Technical Committee TC 5.3 Room Air Distribution advocates for continued research in the following areas:

- Evaluation of the impact of locations and number of supply and return/exhaust grilles on the airflow patterns and distribution of airborne contaminants.
- Evaluation of the impact of supply air diffuser types on the airflow patterns and distribution of airborne contaminants.
- Development of innovative air distribution systems and devices to minimize the spread of airborne contaminants in the occupied spaces.
- Evaluation of the impact of air cleaners (portable, ceiling, and wall mounted) on the airflow patterns and distribution of airborne contaminants especially in the breathing zone of the occupants.
- Evaluation of the impact of the space airflow patterns on the efficiency of UVGI air cleaning systems.
- Development of factors that allow designers to accurately modify manufacturer's isothermal performance data to the applied temperature differential.
- Analysis of the influence of supply air jet's projection on room air motion patterns.
- Correlation of the zone air distribution effectiveness (E_Z) factors in Standard 62.1 (2019) with measured aerosol removal efficiencies.
- Correlation of ADPI rating of fully mixed systems against zone air distribution effectiveness in both cooling and heating operational modes.
- Development of Ventilation Effectiveness Index in establishing the effectiveness of the space air flow pattern in transferring the airborne contaminant from the source to the space outlet with limited mixing and spread.

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Resources

Free ASHRAE Webinars

- Analysis of Airflow Patterns and Flow Path of Airborne Contaminants Webinar (July 21, 2020) https://register.gotowebinar.com/recording/4897838726010585862
- Managing Your HVAC Systems to Help Mitigate the Spread of SARS-CoV-2 in Buildings Webinar (June 29,2020)
https://register.gotowebinar.com/recording/2728815644738615809
- Re-Opening Our Schools: Activities & Recommendations Webinar (June 16, 2020) https://register.gotowebinar.com/recording/8286972267180636944
- Reducing Infectious Disease Transmission with UVGI (April 21, 2020) https://register.gotowebinar.com/recording/8373797400651662856
- ASHRAE Epidemic Task Force Guidance (https://www.ashrae.org/technical-resources/resources)
- CDC (https://www.cdc.gov/coronavirus/2019-ncov/community/index.html)
- AIHA (https://www.aiha.org/public-resources/consumer-resources/coronavirus_outbreak_resources)
- EPA (https://www.epa.gov/coronavirus)

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APPENDIX A: Room air distribution systems and their effect on air motion patterns

Fully mixed room air distribution systems

Fully mixed room air distribution is the strategy most commonly applied in non-residential buildings. The design objective of these systems is to create a homogenous mixture of room and supply air with uniform temperatures and airborne contaminant levels throughout the space.

Mixed air systems most often utilize supply outlets located in the ceiling or sidewall. They usually discharge supply air parallel to a room surface in or near the plane in which they are mounted and rely on a phenomenon referred to as the Coanda effect to delay the separation of cool air from the surface until its initial velocity and temperature differential has been adequately reduced. Mixed air systems provide a time averaged delivery of conditioned air to maintain a desired dry bulb temperature in the space they serve.

Under ideal circumstances, fully mixed room air distribution systems exhibit the following operational characteristics:

- Room air outside the direct influence of turbulent supply air jets is homogenously mixed, resulting in uniform thermal and contamination concentrations throughout the occupied zone.
- The concentration of airborne contaminants is managed by dilution ventilation of the space. Dilution ventilation involves the delivery of ventilation air whose contaminant levels are lower than those that exist within the room in order to maintain acceptable room air concentrations.

Stratified room air distribution systems

The design objective for fully stratified room air distribution systems is to create stratified layers of temperature during a cooling operation such that cold supply air remains near the floor and the hot air remains near the ceiling where it can be exhausted from the space. Sensible heat gains emanating from space occupants, equipment, lighting, and exterior surfaces allow hot air to rise naturally and with minimal influence by the discharge air. Stratified systems, if designed and operated properly, can promote upward migration of airborne contaminants during the cooling mode operation. Depending on the size and aerodynamics of airborne particulates, such stratified systems may also promote stagnation of particulates in the breathing zone of the occupants.

Thermal displacement ventilation (TDV) systems are examples of fully stratified room air distribution systems. Conditioned air is discharged at 40 to 70 FPM (0.2 to 0.4 m/s) from supply outlets located at or near the floor. Unlike fully mixed systems, the low discharge velocity minimizes mixing between the supply and room air. The strength and location of heat sources in a space can affect the performance of the stratified air systems.

The operational characteristics of fully stratified room air distribution systems include:

- During the cooling mode, the formation of natural convection plumes that transport heat, odors, and airborne contaminants generated within the space vertically to the unoccupied upper region.
- Vertical stratification of room temperature that begins at the top of the supply air reservoir and extends above the unoccupied region where the heat and contaminants have been displaced.
- In the cooling mode, the airborne contaminant concentrations should potentially increase with the room elevation level.

Supply airflow calculations for fully stratified systems are based upon limiting vertical temperature gradients to those considered acceptable for maintaining adequate occupant comfort levels. Guidance regarding the thermal comfort effects related to space temperature gradients may be found in the aforementioned ASHRAE Standard 55 (2017). The supply airflow delivery must also assure that space latent cooling and ventilation demands are satisfied.

Supply air delivery systems may also create thermal stratification in certain regions of a space while turbulent mixed air conditions exist in other areas. Thermal stratification may be the design intent or may be the result of unexpected natural buoyancy forces or other physical influences. The ASHRAE Handbook (2020) classifies the resultant room air distribution as partially mixed because only portions of the room air volume are influenced by the dynamic introduction of turbulent supply air jets. For our discussion purposes, we instead refer to this as *partially stratified* room air distribution to distinguish its characteristics from the more often employed fully mixed systems. The following systems often result in partially stratified room air conditions:

- Low level delivery systems that involve vertically projected supply air jets.
- Task conditioning systems that provide cooling or heating to specific portions of a space.
- Overhead outlets that are used for both heating and cooling.

Underfloor air distribution (UFAD) systems utilize floor diffusers to discharge turbulent cool air jets. This promotes the mixing of the discharge air jet with the room air, which reduces the discharge jet velocity to roughly 50 FPM (0.3 m/s). At this point, thermal stratification begins and increases with elevation. When the vertical jet projections do not penetrate the occupants' breathing level, the system exhibits airborne contaminant removal efficiencies similar to that of a fully stratified system.

Task conditioning refers to the deliberate location of supply outlets to provide acceptable thermal comfort conditions within a specific portion of a space. This can involve overhead spot cooling or heating, but also local conditioning systems intended to afford occupants individual control of their micro-environment.

Utilizing overhead supply outlets for the delivery of warm air to offset perimeter heat losses often results in unintended thermal stratification. The buoyancy of the warm air limits its vertical projection, preventing it from penetrating lower levels of the space. Minimal room air motion occurs below the projection level as the supply air jet has no further effect on the room air motion patterns and stagnant air pockets may form.

Stagnation zones allow airborne contaminants to congregate. Eliminating any such zones that might encroach on the breathing location of the occupants is paramount to the effective control of infection that might be spread by airborne contaminants.

Stratified room air distribution systems are primarily utilized in high ceiling spaces like airport terminals, public assembly spaces, and warehouses. Underfloor air distribution is primarily applied in conjunction with raised access flooring systems in office buildings.

Certain challenges are inherent to the design of stratified air systems:

- Care must be exercised to ensure that the cool air delivery through low level supply outlets does not result in compromised levels of occupant thermal comfort. To avoid this occurring, the discharge velocity and temperature differential between the supply and room air is usually constrained to avoid discomfort.

- When these systems are applied in humid climates, adequate dehumidification of the supply air often requires cooling it to a saturation temperature that is significantly lower than the desired delivery temperature and requires subsequent reheat before it is introduced to the space.
- Supply airflow rates must also ensure that thermal stratification does not result in excessive vertical temperature gradients that might cause occupant discomfort.
- Stratified air ventilation systems are effective only during cooling operation. During the heating mode, such systems often require supplementary heating to maintain the desired thermal comfort.

References

ASHRAE. 2017. *ANSI/ASHRAE Standard 55-2017, Thermal environmental conditions for human occupancy*. Atlanta, GA: ASHRAE

ASHRAE. 2020. *ASHRAE Handbook HVAC Systems and Equipment,* Atlanta, GA: ASHRAE

APPENDIX B: Computational Fluid Dynamics (CFD) Analysis

Computational Fluid Dynamics (CFD) analysis involves the numerical solution of equations of air motion, heat transfer, transport of airborne contaminants, and similar transport processes. CFD analysis, if performed properly with adequate expertise, can provide valuable information related to the three-dimensional airflow patterns, temperature distribution, and flow path and distribution of airborne contaminants in a space. Such analysis can help visualize airflow patterns and the resulting flow path of airborne contaminants, which provide valuable insights for developing appropriate mitigation strategies. The following examples of previous studies demonstrate the insights gained into the airflow patterns and flow path of airborne contaminants.

Figure B.1 shows predicted airflow patterns in a hospital operating room. This CFD analysis indicates that the air changes per hour (1/h) do not affect the nature of airflow patterns in a room. This analysis further indicates that the resulting flow path of airborne contaminants is also not affected by ACH (Khankari 2018a and Khankari 2018b). This study indicates that increasing the ventilation rates can help in the overall dilution of contaminants. However, it would not help in altering the flow path of airborne contaminants and the zones of high concentration.

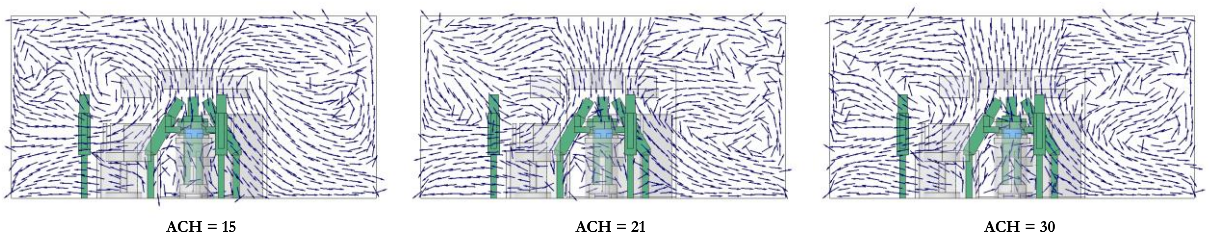
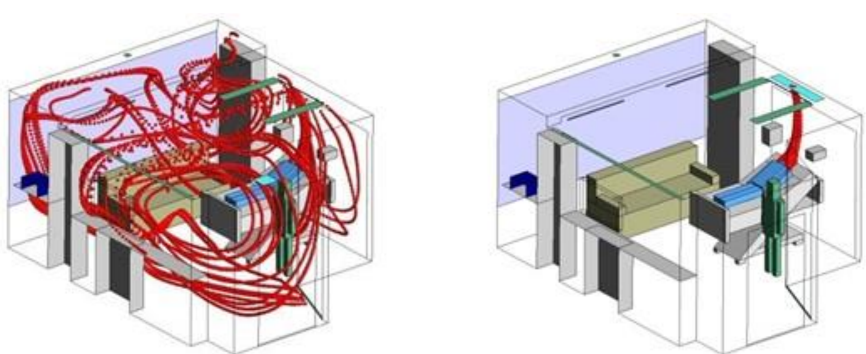


Figure B.1: CFD analysis of a typical hospital operating room showing airflow patterns (Khankari 2018a)

Figure B.2 depicts the predicted flow path of airborne particles released from a patient's face in a typical hospital patient room. This CFD analysis highlights an important observation that linear supply diffusers in this HVAC configuration entrain airborne particles back into the supply air stream, which eventually spreads into the entire room (Figure a). Placement of a return grille right behind the linear supply diffuser over the patient's head (Figure b) can potentially provide a ready flow path for airborne particles to exit out of the room without significant recirculation and entrainment back into the supply stream (Khankari 2016). This CFD analysis provides a valuable insight that airflow and the associated flow path of airborne contaminants follow a path of least resistance.



(a) (b)

Figure B.2: CFD analysis of a typical patient room showing the impact of the location of a return/exhaust grille on the flow path of airborne contaminants. (Khankari 2016)

Figure B.3 shows a predicted cloud of 25 ppm contaminant concentration in a typical laboratory space. These figures compare the impact of two versus three exhaust grilles configuration. This analysis indicates that a simple addition of an extra exhaust grille without increasing the supply airflow rate can reduce the contaminant spread and resulting occupant exposure in a space (Khankari 2018b). This CFD analysis provides an important insight that supply airflow or ventilation flow rates alone are not sufficient to create safe environment for the occupants. The number and locations of return/exhaust grilles can play a critical role in determining the exposure levels of occupants to hazardous contaminants.

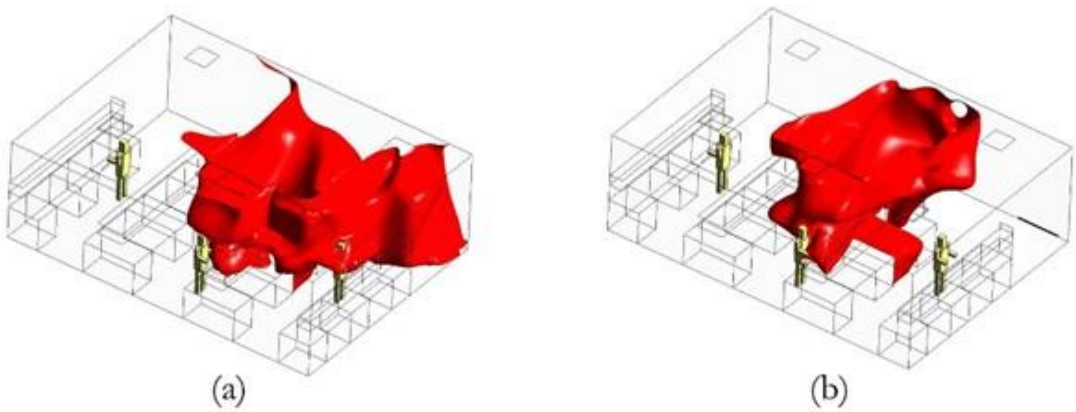


Figure B.3: CFD analysis of a typical laboratory space showing the impact of number of exhaust grilles on the spread of airborne contaminants. (Khankari 2018c)

References

Khankari, K. 2016. Patient room HVAC. *ASHRAE Journal* 58 (6): 16.

Khankari, K. 2018a. CFD analysis of hospital operating room ventilation system Part 1: Analysis of Air Change Rates. *ASHRAE Journal* 60 (5): 14

Khankari, K. 2018b. CFD analysis of hospital operating room ventilation system part 2: analyses of HVAC configurations. *ASHRAE Journal* 60 (6): 16

Khankari, K. 2018c. Analysis of Spread Index: A Measure of Laboratory Ventilation Effectiveness. *ASHRAE 2018 Annual Conference*, Houston, TX.

APPENDIX C: Space Air Cleaning Strategies

When supplied by a dedicated outside air (DOAS) system, all the removed contaminants are exhausted from the building. However, most air handling units mix return air with outside air and can recirculate many of its contaminants. When this is the case, final filter upgrades to MERV13 or better or the use of other mitigation devices such as portable or stationary air cleaners can be used.

Portable or stationary fan assisted filter

These devices are typically installed within an occupied zone. They have a circulating fan, an air inlet, and an air outlet. Filters or combination of filters and UVGI are used to capture or capture and inactivate airborne pathogens, respectively. When a combination of filters and UVGI is used, filter media should be a UV resistant material. The effectiveness of these devices is determined by the amount of pathogen free airflow they can provide to a given space. It is important to understand that the location of these devices within a space and their interaction with room air motion patterns will impact their effectiveness. The local concentration and path of airborne pathogens will depend on the source type and location as well as on the number of air distribution and exhaust/return devices. The ideal location for portable devices would be close to densely populated areas or along the most probable pathway taken by airborne pathogens. The discharge velocity and pattern of filter/UV devices will influence air and contaminant distribution in the space and should be taken into consideration when conducting a CFD analysis.

Space Dilution and Supply air flow rates

Dilution strategies are often employed to reduce the concentration of airborne contaminants, and thereby, probability of infection. The Wells-Riley equation (C.1) and Figure C.3 show the relationship between the supply airflow rate of clean air and the probability of infection (Riley et al. 1978). It should be noted that this equation assumes instantaneously fully mixed conditions with airborne contaminants in the space. Such fully mixed conditions are rare even for the simplest space layouts.

$$C = S(1 - \exp\left(\frac{Iqpt}{Q}\right)) \qquad \textit{(Equation C.1)}$$

where,

C = estimate of new infections
S = number of susceptibles
I = number of infectors
q = number of infectious doses, 1/min
p = pulmonary ventilation rate per susceptible, cfm
t = exposure time, min
Q = flow rate of uncontaminated air, cfm

Figure C.3 demonstrates how the Wells-Riley equation can be used to calculate the effect of clean air supply on infection rate. Assuming that the baseline minimum outside airflow is 1 and the infection rate under this condition is 1, by increasing the clean airflow rate 4 times, the probability of infection drops to 0.26. That is, 1/0.26 = 3.8 times reduction of the airborne infection probability.

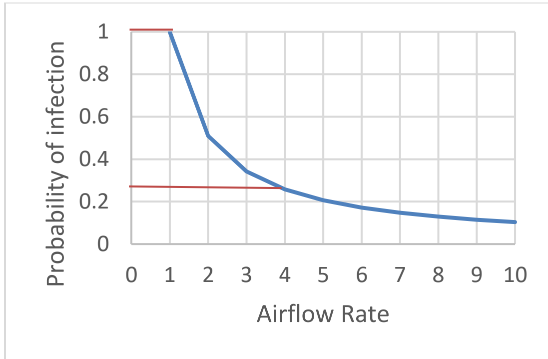


Figure C.3 Normalized infection rate as function of the clean airflow increase

References

Riley, E., G. Murphy and R. Riley. 1978. Airborne spread of measles in a suburban elementary school. *American journal of epidemiology* 107: 421-32.