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Designing Beyond The Well-Mixed Space

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The well-mixed space is one of HVAC design's core assumptions. It is the basis of the equation used for calculating required airflows for thermal loads. And it provides the rational underpinnings for dilution-based ventilation. But sometimes well-mixed spaces do not behave as ideally mixed spaces. So, designers should use ASHRAE standards and other guidance, which address the nonuniform nature of the built environment.

The idealization of a well-mixed space is convenient because it posits that all physical properties of the space are equivalent. The implications are that the location of inlets and outlets, the velocity and direction of airflows, and the location and intensity of heat sources and of contaminant sources are immaterial because the space's environmental conditions are all uniform. Any experienced designer or occupant knows all these factors have an influence on the overall quality of the built environment.

Chapter 58 of the *2019 ASHRAE Handbook—HVAC Applications* has an extensive discussion on room air distribution and addresses the different characteristics and design considerations for spaces that are fully mixed to spaces that are fully stratified. The discussion of fully-mixed spaces includes a description of the air distribution performance index (ADPI), which is the percentage of points within the space that are within –3°F and +2°F (–1.6°C and +1.1°C) of the draft adjusted cooling setpoint and –4°F and +3.6°F (–2°C and +2°C) of the draft adjusted heating setpoint, with a rating of 80 or higher indicating a well-mixed space.[1] By this definition, a well-mixed space is clearly not uniform.

Studies have shown how the position of air devices, discharge patterns and air speeds and air temperature can influence the temperatures and air velocity distribution within a space.[2,3] Burkett recently discussed the relationship between airborne transmission of viruses and air distribution, noting local effects such as relative position and motions of occupants and heat sources that are more significant than the overall airflow pattern.[4] Well-mixed environments have variations in physical properties, which means that real environments, even well-mixed ones, are not ideally mixed.

Examples of How ASHRAE Standards and Other Guidance Address Nonuniform Characteristics of Spaces

ASHRAE Standard 55-2020 includes temperature asymmetry and air velocity as factors that impact thermal comfort.[5] ASHRAE/ASHE Standard 170-2021 requires certain types of diffusers in different patient care areas and even prescribes the location and velocities of supply diffusers and return diffusers in operating rooms.[6] Another example of this level of specificity is that exhaust outlets in airborne infection isolation (AII) rooms must be located at the patient headwall or above the patient bed.[7] The basis for this recommendation is in a study that used computational fluid dynamics to show the position of air inlets and outlets had greater

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influence on contaminant removal effectiveness than air changes.[7]

Air distribution is also included in the ASHRAE Epidemic Task Force's Core Recommendations, which state that, "[w]here directional airflow is not specifically required, or recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person-to-person."[8]

An effective method of limiting occupants' exposure to contaminants is source capture. Designers apply this principle when using kitchen hoods, as described in ASHRAE Standard 154-2016.[9] Other common applications of source capture include manufacturing tool exhaust systems, decontamination and sterilization areas and benchtop snorkels in science and research laboratories. The American Conference of Governmental Industrial Hygienists publishes a design manual[10] covering many topics related to source capture systems.

Source capture works best when there is a known and stationary, or at the very least limited in motion, source of contaminants, and effective velocities can be achieved to capture the contaminants. In cases where the contaminants are widespread or would only be considered nuisances outside of the space in which they are generated, containment may be an effective strategy. Two examples of containment devices include air curtains and fume hoods. Both devices maintain velocity at a boundary to inhibit the passage of contaminants.

An alternative to maintaining velocity is to maintain pressure between spaces, because a fixed pressure difference induces air movement in a prescribed direction to either exclude or contain contaminants. ASHRAE/ASHE Standard 170-2021 includes exclusionary pressure relationships, such as the +0.01 in. w.g. (2.5 Pa) pressure requirement for protective environment rooms and operating rooms and containment pressure relationships, as with the –0.01 in. w.g. (–2.5 Pa) pressure requirements for AII rooms.[7] ASHRAE Standard 62.1-2019 includes exclusionary pressure relationships with its positive pressure requirements for occupied spaces relative to environmental tobacco smoke areas, attached parking garages and the outdoors, and includes containment pressure relationships with requirements for negative pressure of Class 4 exhaust air ducts and all spaces requiring exhaust air.[11]

The broad inclusion of containment and source control requirements within ASHRAE standards is not new and should not be surprising, but it is not as frequently discussed as other requirements of the standards that relate directly to the well-mixed assumption. The well-mixed model as applied to ventilation leads to the conclusion that the solution to pollution is dilution. This is only logical since in an ideally mixed environment the only way to remove a contaminant is to dilute it. This way of thinking leads to an emphasis on increasing air change rates, removing contaminants from the supply airstream with filters or air cleaners or removing contaminants directly from the space. This emphasis has been reflected in government guidance[12] and the media[13] on strategies to deal with the COVID-19 pandemic.

Although dilution and filtration can often be effective in improving indoor air quality, they do not reflect the entirety of the recommendations of ASHRAE. It is incumbent upon our community to not only be knowledgeable of, but conversant in, all the design strategies for a built environment that is other than ideal.

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