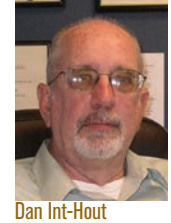
Dan Int-Hout

Air Distribution in the OR

BY DAN INT-HOUT, FELLOW ASHRAE

Since the publication of my October ASHRAE Journal column "You Have to Prove It," people have asked me several questions about operating room air distribution, including air distribution performance of "laminar" systems versus air curtain designs, verification of computational fluid dynamic (CFD) models, ASHRAE/ASHE Standard 170, *Ventilation of Health Care Facilities,* local codes and construction issues.

The first and most important requirement for any operating room air distribution system is to minimize the risk of infection. All other requirements must adhere to this basic need. If not, as in the case of critical surgical procedures that expose patients for hours (such as open heart, orthopedic, or new cancer treatments), this leaves the door wide open to infectious organisms that can get embedded in the body and create post-operative infections that are difficult to treat (and may have fatal results). What is worse is with the increase of drug-resistant strains of organisms, infections that develop from less critical procedures can still be highly problematic.

Temperature control and room pressurization that controls both supply and exhaust rates play an important role in the operating room, both for the operating staff and the patient. A typical operating room has several heat sources, including the medical personnel, a number of high intensity lights, and all sorts of mechanical devices.

The lights are often placed directly over the patient, which can be problematic if the surgeon has any special requirements, such as a rapid cooldown during a procedure. The location of these lights can also be an obstacle to the desired airflow pattern, which, if not properly taken into account, can increase the risk of introducing contaminants into the operating theater.

Several HVAC designs have been in common practice for operating room suites. These include ceiling or sidewall located perforated panels, ceiling perforated panels with physical curtains (extending from the ceiling to just above the surgical team), and ceiling panels with vertical air curtains (surrounding the operating team)

Recent data suggests that two types of designs have become more prevalent than others. The first design is the multiple panel system, often found in cleanrooms (but at much lower airflow rates). The second type is the air curtain system.

Typically, perforated panels have faceplates with less than 25% perforation and include supply plenums, designed with internal baffles to deliver air uniformly over the face of the device. For designs that include air curtains, they are generally created using a couple of linear slot diffusers with supply plenums, which, similarly, are designed to deliver air evenly over the length of the air slot. The slots may or may not be adjustable. One design, which has been used for more than 40 years, has two fixed slots that create a vertical air column that directs air slightly outward from the operating theater.

Perforated supply air outlets located in the ceiling have been used in designs for many years. Often described as "laminar airflow panels," the assumption is that low velocity air moves in a straight line from the face of the air outlet toward the floor.

What actually happens, however, is not ever a true "laminar" airflow. The individual perforations,

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especially those at the perimeter of the air outlet, in some cases can have a higher velocity than the average over the face.

According to basic physics, we know that if a jet of air has lower static pressure than the surrounding air mass, the air jet will induce air from its surrounding air mass. In other words, a perforated face air outlet will induce some air from around the air column. The supply air is almost certainly a bit colder than the average temperature in the room, which means it has negative buoyancy and will gain speed and contract as it drops into the room. The greater the temperature difference between the jet and the room, the greater the acceleration, and the higher the mean velocity across the jet.

An air column measuring 25 fpm (0.13 m/s) just below the panel will likely read 50 fpm (0.25 m/s) a short distance above the operating table or patient, with a few degrees change in temperature. Should multiple panels be located close to one another, there is a mass effect, which further increases the air speed at the patient.

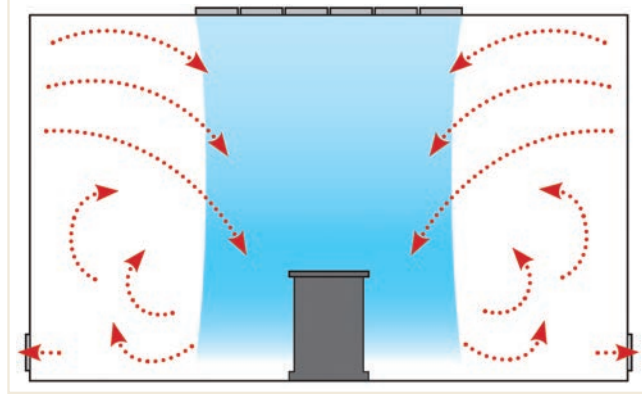
Regardless of the design chosen, the HVAC unit that supplies air to the operating room needs to have HEPA filtration to remove contaminants from the airstream. These filters may be located in the ductwork that feeds the operating room, at the air handler, or in the operating room integrated in the diffuser. Because room cleanliness is critical, one has to be cautious when accessing filters for removal/replacement, being careful to not contaminate the air supply system or the operating room during the process.

For older designs without HEPA filtration, we have seen them retrofitted with fan filter units, which are essentially HEPA filter perforated "laminar flow" devices with a built-in fan to provide the additional pressure required by the filters. These units often have ECM motors, which are able to keep a constant flow until the rpm limit is reached, then display an alarm for a filter change.

A lot of effort is put into the design of an operating room air distribution system. So, it is important that we evaluate all the parameters to ensure the choices made will generate intended and realistic results. Both computational models and physical measurements have been used for years to accomplish this.

In fact, today's modeling programs have been improved to provide quick solutions for very complex, turbulent flow environments. Evaluations should not rely on the computational models alone. Additionally,

FIGURE 1 Laminar array.



physical measurements that include the use of radiant shielded temperature probes and omnidirectional low speed air movement sensors will aid in the validation.

For further verification, tests conducted in the surgical space should include both wet and dry particles, as it appears that moist particles seem to exhibit different dispersion patterns than dry ones. ANSI/ASHRAE Standard 113-2013, *Method of Testing for Room Air Diffusion,* provides a good reference for the minimum requirements for any air distribution measurements.

Taking physical measurements during an actual operation will of course provide the best validation, but in today's litigious environment, it is unlikely any facility's legal staff would allow such procedures. A number of tests were, however, conducted in the past. A discussion of them can be found in a 2006 *ASHRAE Transactions* paper[1] by Gerry Cook and me, as well as in a 2009 ASHRAE Journal article.[2] More recently, a series of CFD and validation tests were conducted in Egypt and reported by Khalil.[3]

In these tests, it was validated that using an air curtain minimized the transport of viable particulates from the space outside the immediate operating area by blocking the return air pathway along the ceiling to the laminar panel arrays required by Standard 170.

Hospital operating rooms and cleanroom environments that are in constant use require vast amounts of air. For this reason, it is crucial to manage energy consumption. At the same time, however, a clean supply of air (typically 100% outside air) must be maintained.

Some would suggest that to keep costs down, the least amount of air supplied the better. Building codes, though, mandate minimum air quantities for different applications, ranging from 15 to 30 air changes per hour

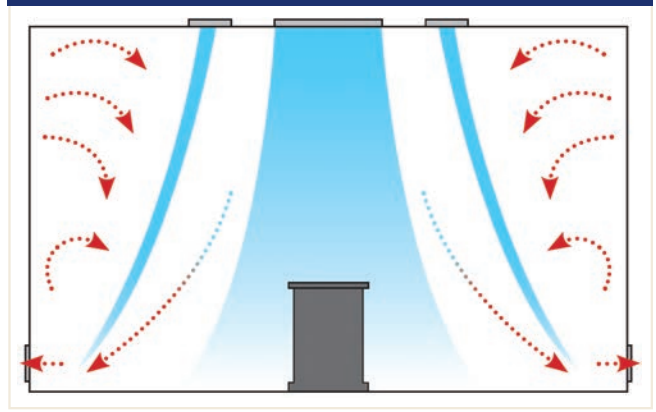
(ach). Cleanrooms, in particular, usually have "laminar" panels over the entire ceiling and mandate significantly higher air supply rates.

First cost decisions need to factor in not only the cost of the air distribution outlets, but other items as well, including their construction, the type of ceiling in which they are to be installed, as well as the location of the necessary air supply ductwork and balancing dampers.

For the construction of air outlets, stainless steel provides for the most sterile surface, when cleaned. It is, however, considerably more expensive. Products made of aluminum can run the risk of being etched by some cleaning chemicals, resulting in the development of micro-pores, which can become contaminant breeding grounds.

Up in the ceiling plenum of an operating room, there are conflicting requirements between operating room light mounts, HVAC ductwork, electrical wiring, plumbing and gas piping that make layouts a challenge. Multiple HVAC connections compound the issue and may prevent the installation of an unbroken array of air outlet panels. Breaks between panels are dangerous and can provide a pathway for infectious particles to be induced into the supply airstream.

FIGURE 2 Air curtain system.



When the ceiling type is considered, a plaster ceiling, instead of lay-in ceiling tiles, is often mandated to help control room pressure, which subsequently makes the process of accessing and balancing dampers difficult.

The decisions involved in designing a hospital operating room are complex, as a number of requirements (sometimes conflicting) must be taken into consideration. Successful designs are those that can adequately balance all the aspects of the air distribution system, including the room's airflow pattern, pressurization, temperature control, cleanliness, exhaust, filtration, energy consumption, and first costs, all the while working toward the goal of minimizing the risk of infection.

Of course, we also have to be mindful that the tools we use to make these choices, whether it is CFD analysis or otherwise, are simply providing estimates. Computer analysis alone is not sufficient for making critical decisions that may have a negative life-safety outcome. Some means of validation needs to be included that takes into consideration the nature of viable particulates.

References

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