PRODUCT APPLICATION

A technical bulletin for engineers, contractors and students in the air movement and control industry

Air Distribution in Critical Environments: Cleanrooms & Operating Rooms

Mechanical engineers working in the construction industry must consider many factors while selecting an air distribution system that will work well with their design. In most commercial applications, the majority of air distribution devices will consist of basic ceiling diffusers, return grilles, sidewall grilles, and linear slot diffusers.

However, when one designs a "Critical Environment," it is necessary to delve deeper into what an air distribution system accomplishes. What differentiates Critical Environments from regular commercial construction is the necessity for very carefully controlled parameters for the quality of air. Depending on the type of critical environment, these parameters for air quality could include specific temperatures, humidity, pressure, velocity, particle counts, oxygen content, etc.

Two common types of critical environments are Operating Rooms and Clean Rooms. Clean Rooms are used in applications that require extremely clean air, such as manufacturing microchips. In a process such as manufacturing microchips, even a few particles of dust in every cubic foot of air could be a disaster for the microscopic components on the surface of the chip. Dust particles are measured in microns, and 1 micron is 1 millionth of a meter. A human hair is normally between 70-100 microns. A dust particle that is only 0.5 microns in diameter can destroy a microchip. Typically, the air in a clean room is HEPA-filtered and supplied using laminar flow diffusers. The laminar flow diffusers maintain the supply air velocity at a constant rate, while the HEPA filtration removes 99.97% of particles larger than 0.3 microns from the air. One way to rate Clean Rooms is on a scale of Class 1 to Class 100,000, with the class number being the number of particles larger than 0.5 microns allowed within 1 cubic foot of air.[1]

In a clean room, the largest priority is to prevent particles from getting into the space. This is why all air is heavily filtered, and occupants or workers within the space are required to wear clothing that reduces the creation of particles.

In Operating Rooms, there is also the necessity to reduce particle counts, but there is an enhanced focus to reduce biohazardous particles, such as viruses, bacteria, and mold spores. An operating room focuses on particles that are generated within the space. These can be generated from various sources such as the operating room staff, components brought into the operating room, or even from the patients themselves. The main focus is to try to sweep those particles away as quickly and effectively as possible. In an Operating Room, it is quite common for a patient to have their body cavity open to the environment during surgery or other procedures. This makes it extremely easy to acquire an infection or illness from airborne bacteria or viruses.

The VA Design Guide for Surgical Services directly outlines the main goal of an HVAC System in an operating room."(In an operating room,) the air supply system must be designed to minimize airborne bacteria from entering the sterile field, in addition to keeping the remaining operating room as clean as possible."[2] In an Operating Room, the two most common systems for accomplishing this goal are:

1. A laminar flow panel array
2. An air curtain system

Laminar Flow Systems

A laminar flow panel array uses a series of laminar flow panels situated over the operating room table. During use, the laminar flow panels will supply clean, filtered air to the space. As per ASHRAE Standard 170-2008, laminar flow panels should maintain an airflow rate between 25 cfm/ft^2 and 35 cfm/ft^2. This guideline is used because it is understood by HVAC designers that higher flow rates can begin to induce surrounding air into the flow, which can increase the probability of particle infiltration. These guidelines work well when assuming an isothermal situation with constant temperatures.

However, in real-life situations, the supply of air is rarely isothermal. Realistically, supply air could be introduced to a space at a temperature 10-20°F lower than the ambient temperature. This temperature differential works well for cooling an area quickly, but this temperature change also equates to a substantial change in air density. A significant temperature difference between airstreams will cause large accelerations in the flow due to buoyancy forces. Another consideration is the tendency for adjacent air jets to combine and coalesce. When multiple laminar flow units are side by side, the air streams can combine and cause acceleration which can alter the expected velocity at the table height.

These changes in velocity might not be too important to consider in a commercial project such as a store or a restaurant, but in an operating room, an engineer must analyze air velocity very carefully. While supplying cooler air above a patient, one must take into consideration the downward momentum of the flow due to the driving pressure, as well as the accelerations due to buoyancy and the induction of adjacent airstreams. Undesired fluctuations of air velocity in an operating room can make it difficult to control particles around the operating area and can increase the chances of contamination.

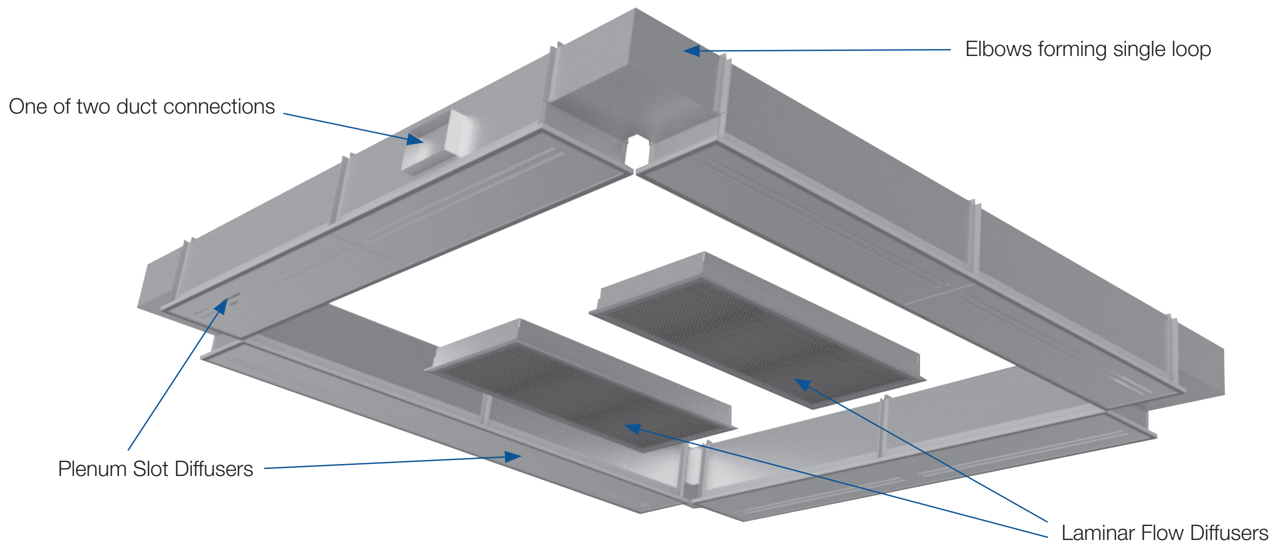
As an example, let us assume a face velocity of 30 feet per minute from a laminar flow diffuser. If the air is 20°F lower than ambient temperature, then the air will continue to accelerate as it drops, doubling the velocity to over 60 fpm at six feet from the diffuser. Because of these factors, a laminar flow diffuser array is not the optimal system to use in an operating room. To help avoid the issues mentioned above, an air curtain system should be utilized.

Air Curtain Systems

The most effective type of operating room ventilation system is the Air Curtain System. Air curtain systems consist of laminar flow diffusers and a perimeter of high-velocity air curtains combined with sidewall returns located near the floor. This combination allows for slow-moving, clean air to be vertically supplied from the laminar flow diffusers, while the air curtains along the perimeter help to create a barrier against contaminants.

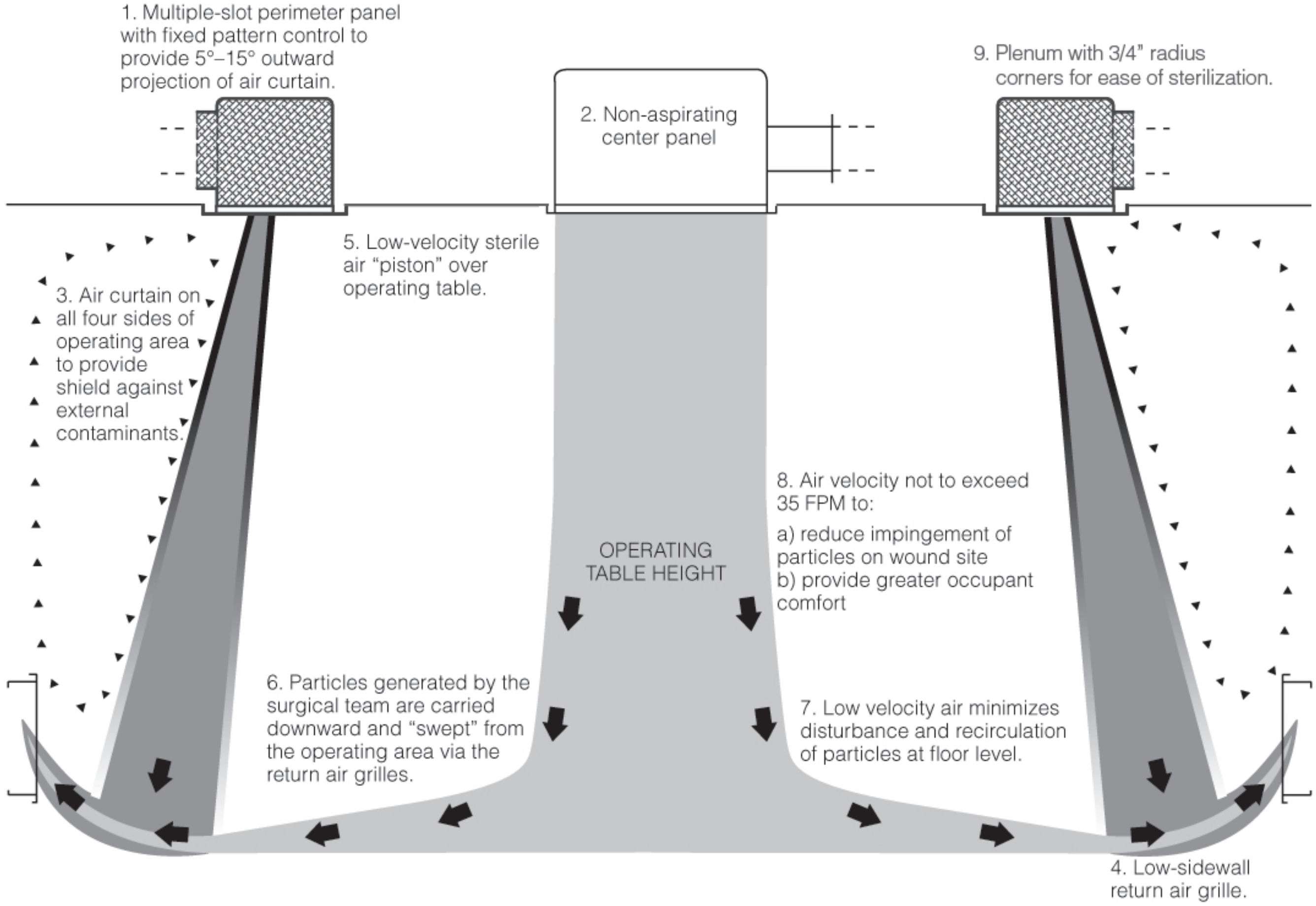
Air Curtain systems offer many benefits compared to laminar flow systems, and several of these benefits are discussed in the next section. In general, an air curtain system can allow for careful control of velocities and particles, however, the Greenheck HLC-SAC (see Figure 1) goes a step further and combines accurate airflow balancing with ease of installation.

Figure 1 Greenheck HLC-SAC Air Curtain System



See Figure 2 for an overview of the Greenheck HLC-SAC Operating Room System and its various components.

Figure 2 HLC-SAC System Cutaway Overview



The air curtain system has several distinct advantages over the laminar flow system used in an operating room. First, in the HLC-SAC system, the air curtains help to maintain low-velocity laminar flow over the operating table. A problem with laminar flow diffusers is that airflows from adjacent units tend to coalesce and combine, which leads to an increased velocity, and the entrainment of particles.

However, on the contrary, when air curtains are used in conjunction with laminar flow diffusers, the high-velocity air curtain creates a jet with lower pressure which induces the laminar airflow. The central laminar airflow is pulled outward into the perimeter high-velocity jet, filling the zone within the curtain with low-velocity laminar airflow. This induction and expansion maintain true laminar flow within the operating zone and avoid the issues one would encounter using laminar flow units alone. Since the low sidewall returns are used to extract the airflow, this helps to keep particulates flowing away from the operating room table and out of the space.

Another important function of an air curtain system is to prevent any particles from outside the curtain from re-entering the sterile field. Figure 2 also illustrates the expansion and induction of the laminar flow plume into the high-velocity air curtain jet.

Secondly, the air curtain effectively creates a barrier against external contaminants from outside the operating area. Since the laminar flow diffusers provide sterile air over the operating room table, it is important to ensure that no contaminants can make it to the operating area. An air curtain perimeter accomplishes this by establishing a boundary by which no particles can infiltrate from outside the table area. The sterile supply air washes over the patient and can carry away particulates or biohazardous materials which are then swept away by the high-velocity jet and extracted by the sidewall return.

Third, the Greenheck HLC-SAC is unique because the entire perimeter of the air curtain consists of a single plenum. This single "loop" plenum allows for only two duct connections for the entire perimeter. This saves the installer time and effort since many comparable systems use a handful of inlet connections. When a system uses multiple inlets, each inlet will require airflow balancing to maintain equivalent velocities through each air curtain and any change in overall system pressure will require re-balancing. If the air curtains have different velocities, this can cause the entire system to function incorrectly thereby increasing the chance of contamination.

In the HLC-SAC system, once both duct connections are active, the entire loop becomes pressurized. As the plenum loop becomes pressurized, each air curtain along the perimeter will maintain the same velocity. This makes the Greenheck HLC-SAC system one of the easiest operating room systems to install, as well as one of the most effective systems for maintaining a clean operating room.

References

1. Bhatia, A. "HVAC Design for Cleanroom Facilities." *Continuing Education & Development, Inc., https://www.cedengineering.com* (2012)
2. U.S. Department of Veterans Affairs. 1993. *Design Guide: Surgical Service,* Draft 11-15-93

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