LAMINAR FLOW: GENERAL

Conventional vs. Critical Space Applications

With human comfort in mind, conventional air distribution strategies typically employ rapid mixing of supply and room air for thermal equalization and effective ventilation (or ventilation efficiency), with low air velocities within the occupied zone for draft free conditions (figure 1)

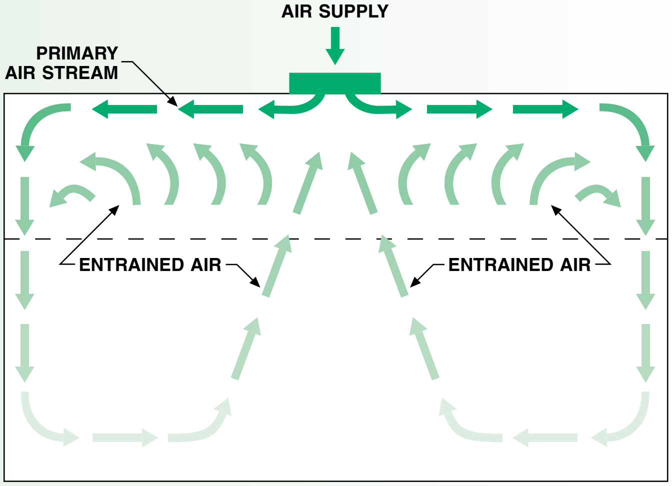


Figure 1: Conventional Mixing System

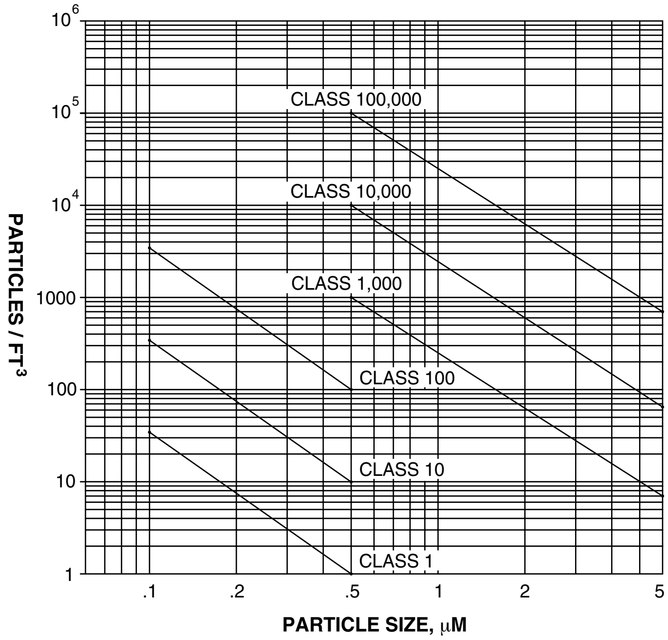
Because mixing of air is desirable, turbulent flow is preferred. Although thermal comfort is important within critical spaces, airborne particle control is often the basis for the application of air distribution systems in these spaces. Control refers to the management of the quantity, type/size, and location of particles, and is dictated by the space function. In these cases, entrainment of room air with the clean, supply air is not desirable and specialized air distribution devices must be considered.

What are Particles?

Particles can exist as bacteria (Tuberculosis, Legionnaire's disease), viruses (chicken pox, measles), pollen, skin flakes, hair, dust, live or dead organisms, lint, etc. Particles may be considered contaminants when they negatively influence a process, procedure, or human / animal physiology. Sources of external microbial contaminants in a space include the supply air to the space or infiltration through room openings from other spaces. These are easily controlled with air filtration and space pressurization. Internal sources include equipment and people. Research indicates that in hospital operating rooms the surgical team and their activities contribute the greatest quantity of contaminants to the space. Considering this continuous stream of contaminants is being shed over and around the operating table, air distribution strategies for these spaces must effectively carry away particles to minimize surgical site infections.

Measuring Particles

Space cleanliness is often quantified using Federal Standard 209 that specifies particulate cleanliness classes and measures the number and size of particles per cubic foot of air sampled in the space (graph 1 & table 1). For example, the semiconductor industry typically requires Class 100 or cleaner, meaning no more than 100 particles/ft^3 of a size .5μm and larger.



Graph 1: FS209 Class Limits

	Max # of particles per ft^3 of air @ diameters equal / larger than shown		
Class	**0.1 μm**	**0.5 μm**	**5.0 μm**
1	35	1	-
10	345	10	-
100	3,450	100	-
1,000	34,500	1,000	7
10,000	345,000	10,000	65
100,000	3,450,000	100,000	700

Table 1: FS209 Class Limits

LAMINAR FLOW CONCEPTS

Laminar Flow

Laminar or streamline airflow is defined as airflow in which the entire body of air moves with steady, uniform velocity along parallel flow lines with a minimum of eddies – a piston-like delivery of air.

Air Piston Flow

Laminar flow distribution panels consist of thousands of small holes per square foot. The small air jets exit each hole, moving parallel to each other to form an air piston. As the individual jets coalesce, the edge of the air piston actually necks inward a bit within the first few inches from the panel, and expands outward as the piston travels downward.

Boundary Mixing

Laminar flow panels discharge air at a uniform velocity and create an air shower or air piston that moves in free space with edge boundary effects occurring between the column of clean, supply air and the surrounding room air. The perimeter boundary is not stationary, but moves downward in a turbulent manner. It is at the boundary layer where mixing occurs, and surrounding particulate is entrained into the air stream.

Cooling Differential

Surprisingly, the cooling differential (supply air and room air temperature difference) has very little influence on the air velocity and projection distance downward. This is because the mass of cooler, supply air constituting the laminar piston within its boundary layer, exhibits nearly a zero vertical temperature difference, and consequently, no buoyancy effects due to air density.

Panel Free Area

The laminar panel open perforated area has little impact upon the sound level and projection distance when considering holes with relatively small diameters. Increased momentum due to mass and velocity increase is discernable only within a few inches of the panel only (10-40 hole diameters).

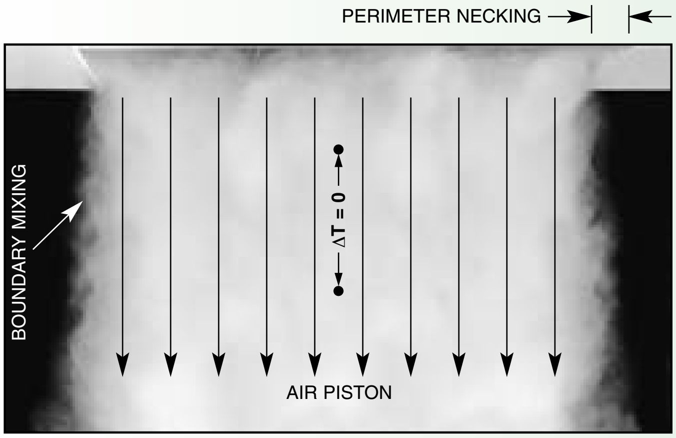


Photo 1: Flow pattern from (3) 24" x 48" MV-2 Laminar Flow Panels.

LAMINAR FLOW STRATEGIES

Laminar flow one-pass systems (sometimes referred to as "plug flow") are used to bathe an area in a clean, continuous shower of filtered air. The laminar panel is designed to minimize mixing (non-aspirating), while providing a unidirectional air stream that is perpendicular to a perforated panel. Particle control is achieved by removing the particles from the source, and away from a defined critical area. Air distribution systems for particle control will typically consist of horizontal laminar flow, vertical laminar flow, or a hybrid system of vertical laminar flow coupled with perimeter air curtains.

Horizontal Laminar Flow Systems

Horizontal flow applications (figure 2) with installed wall systems commonly provide one pass, unidirectional flow in spaces utilized for sensitive processes or activities, and where turbulent eddies or whirlpools caused by obstructions have been evaluated and deemed acceptable. Inherent benefits of these systems include nearly unidirectional flow from the wall supply air outlets to the opposing wall air exhaust or returns, easy monitoring and replacement of final filters, and the physical installation of equipment. Consideration must be given to upstream-downstream relationships with respect to particle flow, and the fact that critical work envelopes in series with each other may be affected. Horizontal flow may also be considered to treat small, bench top work envelopes.

Vertical Laminar Flow Systems-Entire Ceilings

Vertical flow applications with active laminar panels filling the entire ceiling provides complete wall to wall coverage of the space by bathing the entire space with clean air, and is the best arrangement for many clean space applications (figure 3). The orientation of laminar panels above the critical work envelope typically provides the most direct, unobstructed path of airflow. This approach requires high air change rates, and may not be practical for certain applications due to cost or installation constraints. Vertical hanging curtains (figure 4) or other partition materials may be utilized to create a "micro" clean space within a larger space to achieve the benefits of complete ceiling coverage but at a lower operating cost.

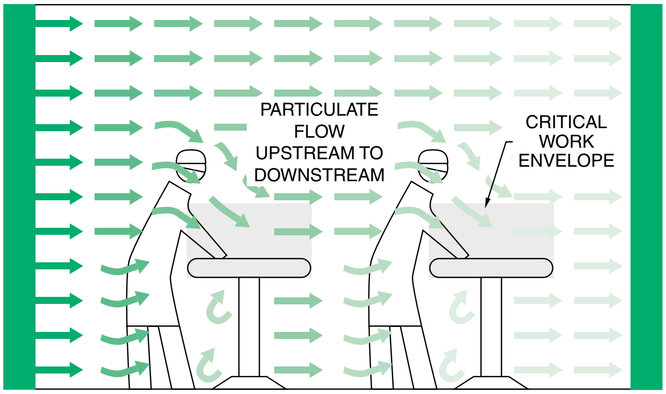


Figure 2: Horizontal Laminar Flow

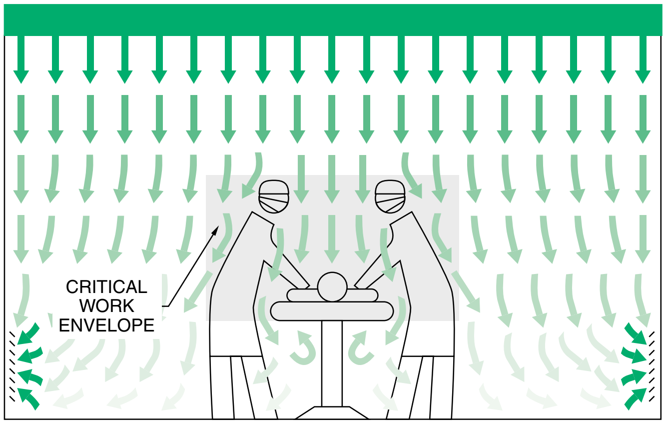


Figure 3: Vertical Laminar Flow, Entire Ceiling

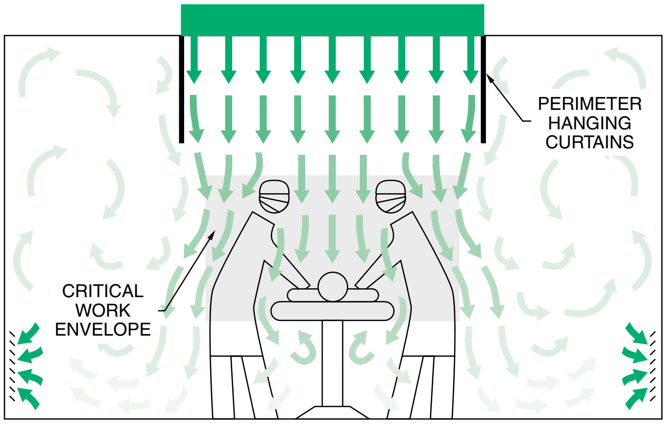


Figure 4: Vertical Hanging Curtains

Vertical Laminar Flow Systems- Limited Ceiling Array

Vertical flow applications consisting of an array of ceiling laminar flow panels strategically located just over the critical work envelope are often utilized in operating/surgical suites and similarly critical areas in health care facilities (figure 5).
It is generally accepted that a properly installed and operated system, providing a clean source of supply air, will reduce the incidence of infections due to airborne contaminants.
Contaminant control within health care facilities varies by space, but the operating or surgical suite is by far the most aseptic (control of bacterial growth within acceptable limits). This arrangement is preferred where an entire ceiling array is not practical, but can still require high air change rates based on the size of the treated area. Because of mixing at the boundary of the air piston, the perimeter of laminar flow panel array should be sized to extend beyond the critical work envelope by at least 6" (figures 5 & 6).

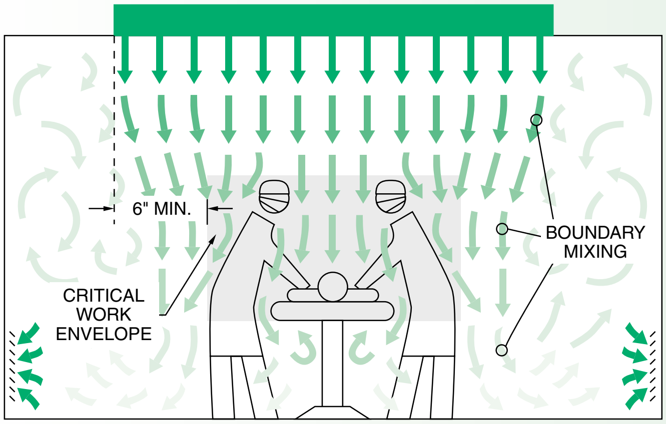


Figure 5: Laminar Flow Panel Ceiling Array

Hybrid Systems - Vertical Laminar Flow with Perimeter Curtains (Anemostat AORTA System)

Hybrid air distribution systems have evolved utilizing the benefits of laminar systems as described above, and ideally include a continuous perimeter air curtain around an interior laminar flow panel or array of panels, essentially creating a "space within a space" (figure 7). Because particles enter the laminar flow air stream at the boundary of the stream by entrainment, air curtains (angled outward from 5-15°) are utilized as a buffer to isolate the critical work envelope. The perimeter curtain reduces the quantity of particles entering the laminar flow field from the surrounding, less clean air. The interior "cube" formed by the air curtains maintains a positive pressure relationship compared to the exterior or surrounding area outside the air curtains, resulting in high to low pressure particle movement. The total supply air quantity for the space is typically proportioned with a 2:1 ratio - 1/3 for the central laminar flow field, and remaining 2/3 for the perimeter curtains. These systems typically require lower overall air change rates for the space, with higher air change rates resulting in the cube within the air curtain.

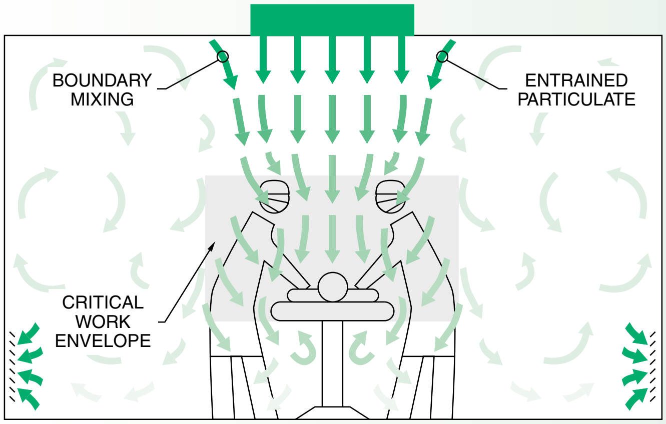


Figure 6: Critical Work Envelope Contamination

RETURN / EXHAUST GRILLES

A minimum of two grilles or registers located low in the side walls at least 3" above the floor typically on opposite sides of the room is recommended (figure 7). Particulate movement from the critical envelope down along the floor and out of the space represents the shortest path for removal. The air quantity extracted from the space through these grilles will determine the room pressure and the pressure relationship of the space with respect to adjacent spaces, either positive (exfiltration or flow out of the space to an adjacent space), negative (infiltration or flow into the space from an adjacent space), or neutral. Guidelines for space pressure are published by ASHRAE, AIA, CAN/CSI, and other code authorities based on space function.

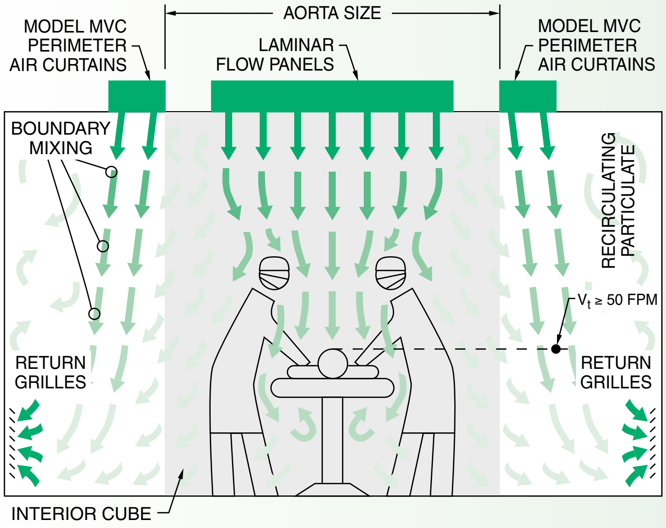


Figure 7: Anemostat AORTA System

DESIGN FACTORS

Design factors pertinent to equipment selection and placement include:

Sound level / Room NC – refer to ASHRAE handbooks for recommended space sound levels. Air outlet sound levels can be adequately controlled by selecting an appropriate neck size for a reasonable duct velocity. The additive sound of multiple inlets and outlets should also be considered.

Total supply air quantity (CFM) – this is determined by considering both the required air change rate and space cooling loads. The air change rate is often the determinant. Air Changes per Hour (ACH) is the time rate at which the room air is replaced based on total supply air quantity into the space and room volume. Table 2 reflects guidelines from ASHRAE and the AIA (American Institute of Architects) regarding ventilation rates for various space functions in health care facilities. To calculate CFM, the required total supply air to a space:

$$CFM = (V \times ACH) / 60$$

where:

V = room volume, ft^3
ACH = air changes per hour

For example, a 4000 ft^3 room volume assuming 25 air changes per hour (25 ACH) requires about 1,670 CFM into the space.

Special modes of operation should be considered which may require higher air flow rates and cooling differentials. This may include procedures such as cardiac surgery.

Critical Work Envelope (CWE) – the location within the room identified as a zone of significant influence on a process or procedure taking place, as compared to other envelopes within the same room. In surgical suites, this includes the patient and surrounding team.

Projection Distance – the required distance, in feet, resulting in a velocity at that distance to effectively remove particulate away from the CWE. In surgical suites, this is the distance from the laminar flow panels in the ceiling down to about 6" above the operating table. There has been considerable debate regarding the ideal terminal velocities in the critical work envelope for hospital operating rooms to minimize SSI (surgical site infections) and control contaminants. Past recommendations of the CDC (Centers for Disease Control and Prevention) and HICPAC (Healthcare Infection Control Practices Advisory Committee) have suggested 60-100 fpm over the operating field. New AIA (American Institute of Architects) and NIH (National Institute of Health) guidelines are recommending velocities of 25-35 fpm. The recommendations of these organizations are based on the latest and most current research available, and may change as new research becomes available. Anemostat's Multi-Vent series of laminar flow panels have been designed for flow uniformity at both low and high terminal velocities as recommended by these agencies.

Laminar Panel Active Area – the size of an array of laminar panels required to cover the critical work envelope with an air piston of sufficient velocity to effectively carry away particulates. For applications with laminar flow panels only, the array should extend at least 6" beyond the edge of the critical work envelope.

Supply Air Temperature Differential (ΔT) – the difference between the actual space temperature and the supply air temperature. With space heating and cooling loads, the supply air must be warmer or colder than the design set point of the space. Applications requiring heated supply air require special attention as laminar flow air distribution is designed to perform with isothermal or cold supply air systems only.

Obstructions – laminar flow air streams are disrupted from their paths by obstructions such as lights, IV poles, and other ancillary equipment. Priority should be given to maintaining unobstructed flow during design. Obstructions are inevitable and the preferred arrangement is to include the obstruction entirely within the perimeter of the CWE to keep turbulent eddies totally within the clean air column. Particulate that strikes an object will typically move around and be carried away from it within the air stream.

Heat Sources – equipment and surgical teams create thermal plumes that oppose the direction of the laminar air stream to flush away particles. These sources should be located sufficiently within the CWE, or completely outside the CWE.

TABLE 2: AIR CHANGE RATES FOR CRITICAL SPACES

	Space Function	ASHRAE		American Institute of Architects (AIA)	
		Minimum Total Air Changes / Hr (ACH)	Minimum Outside Air Changes / Hr (ACH)	Minimum Total Air Changes / Hr (ACH)	Minimum Outside Air Changes / Hr (ACH)
Surgery & Critical Care	Operating Room (100% Outside Air)	15	15		
	Operating Room (Recirc Air)	25	5	15	3
	Delivery Room (100% Outside Air)	15	15		
	Delivery Room (Recirc Air)	25	5	15	3
	Recovery Room	6	2	6	2
	Nursery Suite	12	5	6	2
	Trauma Room	12	5	15	3
Nursery	Patient Room	4	2	6	2
	Intensive Care	6	2	6	2
	Protective Isolation	15	2	12	2
	Infectious Isolation	6	2	12	2
	Labor/delivery/recovery/postpartum	4	2	6	2
Diagnostic & Treatment	Bronchoscopy	10	2		
	Exam Room	6	2	6	-
	Treatment Room	6	2	6	-

Notes: Refer to ASHRAE HVAC Applications handbook or AIA "Guidelines for Design & Construction of Hospital & Health Care Facilities" for latest guidelines and additional information related to Air Change Rates.

AORTA System selection example utilizing Model MVC perimeter air curtains with Model MV-2 dual chamber laminar flow panels in the CUBE:

1. Room use: Hospital operating room
   Minimum air changes required: 25 air changes/hr (ACH)
   Room size: 25' x 30' x 10' ceiling
   OR table height: 30" A.F.F.

2. Calculate the required projection distance from the ceiling to 6" above the operating table, or:

   Distance = 10 feet – (30"+6") = 7 feet

3. Calculate space volume:

   V = 25 ft x 30 ft x 10 ft = 7,500 ft3

4. Calculate the required total space air flow rate:

   CFM = (Room Volume x ACH) / 60 = 3,125 CFM

(This assumes the cooling load is met with the ACH recommended)

5. Determine the Length x Width of the critical work envelope (CWE). This should include a working perimeter around the operating table and one additional foot beyond. Assuming a 2' working perimeter and OR table size 30" x 72", the CWE Length x Width is 12' x 8.5' :

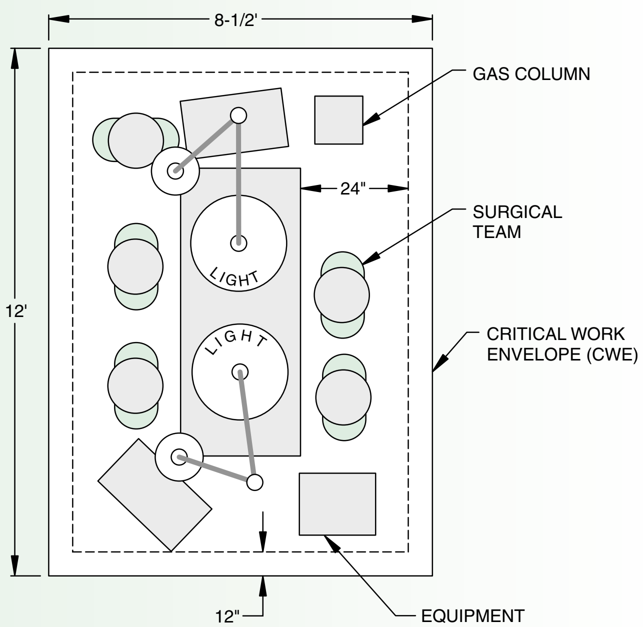


Figure 17: Operating Room, Plan View

6. Size an AORTA system that provides the necessary coverage for the CWE determined above. An AORTA 1012 would be an appropriate selection (see table 3).

7. Once the CWE is selected, the system size (31, 42, 53, 54) must be defined based on the calculated design air flow rate of 3,125 CFM. This is a bit more complicated, but ultimately the selection of the perimeter air curtain is of primary importance. Table 3 is based on a ceiling height of 10' and an assumed projection distance of 7'. System 31, 42, 53, & 64 flow rates have been calculated resulting in a perimeter air curtain that establishes a minimum terminal velocity of 50 fpm at a 7' distance from the ceiling (= the operating table height + 6").

The 50 fpm velocity at this location should be the minimum for the system to effectively contain and remove particulate. The total flow for the space is calculated based on a 2:1 ratio of perimeter curtain flow to interior laminar air flow rates. In this example, the AORTA 1012, System 53 is selected with a nominal total capacity of 3,240 CFM. If the design air flow rate was 2,700 CFM, a System 42 would be selected, with 1,800 CFM feeding the perimeter curtains, and 900 CFM applied to the central laminar flow panels (2:1 ratio). The increased curtain air flow rate will increase the terminal velocities within an acceptable range. Selection of the central laminar flow panels should be evaluated and selected based on a 7' projection distance (example shown on page A-11).

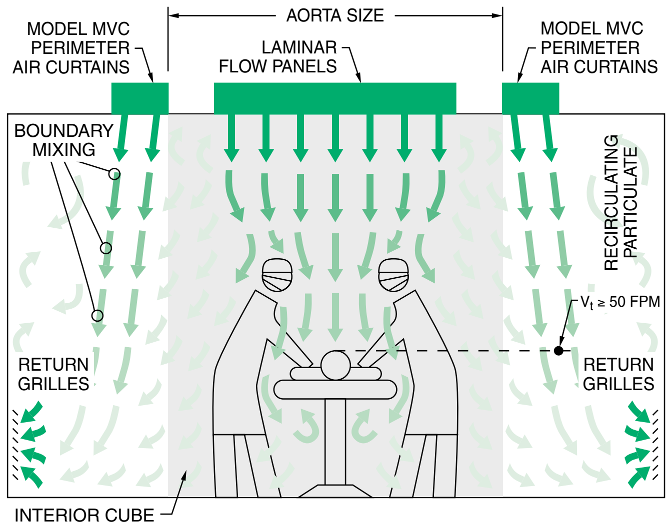


Figure 18: Anemostat AORTA System