

## **Air Distribution Strategy Impact on Operating Room Infection Control**

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### **SUMMARY**

This paper discusses the impact of different air distribution strategies on infection control in operating rooms. The quality of air in an operating room is primarily assessed with regard to how effective the air distribution strategy is in minimizing the possibility of airborne particles causing infection to the patient. The ASHRAE Research Transaction paper titled, "Comparison of Operating Room Ventilation Systems in the Protection of Surgical Sites" [1], is reviewed as a starting point. A number of air distribution strategies are then reviewed and a qualitative assessment of each strategy will be presented. The design concepts to be reviewed were:

- Type of supply air diffusers
- Exhaust/ Return air locations
- Lighting and medical equipment location effects

Constant air exchange rates and supply air temperatures were assumed in the case studies, which include: 1) The new operating rooms at University of Massachusetts (UMass) Memorial in Worcester, MA, USA in which an air curtain/ laminar flow supply air diffusion concept was implemented: and 2) The new Hospital for Special Surgery in New York City in which laminar flow panels with manually variable airflow direction have been installed to study impacts on patient outcomes and infection control. Computational Fluid Dynamics (CFD) models of each of the case studies are presented with documented findings which support the qualitative assessment.

### **INTRODUCTION**

#### **Infection Control Overview**

The assessment of indoor air quality depends on the type of space being assessed. In a healthcare environment, indoor air quality is primarily assessed by minimizing the effects of the rate at which the ventilation distribution system either protects the patient from infection, or conversely, contributes to infection risks. While infection control is clearly the primary focus in air distribution strategies, thermal comfort issues should also play a role in assessing the quality and effectiveness of the air distribution system, even in a healthcare environment. This is especially true in what many consider to be the most critical of spaces in a hospital- the operating room- where the thermal comfort of the patient and medical personnel in the operating room are a very different issue.

Recognizing that patient outcomes may be affected by the thermal comfort of the operating room occupants, infection control is still the main concern. One recent study [2] has shown that 2.54% of patients that have invasive procedures experience complications related to post operative infections. While it is commonly held, and for good reason, that the major concerns are the sterile procedures used by the healthcare practitioners, the air distribution and exchange rate strategy can have a significant effect on the patient outcome as it relates to the likelihood of complications due to infection.

Intuitively, indoor air quality would not appear to be a primary concern in a critical environment like an operating room. Instead, issues such as the quality of the lighting, room layout and how potentially life saving equipment is placed, sterile procedures, and overall cleanliness of the room would seem to be paramount. However, as evidenced by the detailed requirements outlined in the American Institute of Architects (AIA) Guidelines for Healthcare [3], the concepts for how air is distributed, filtered or exhausted, and how often the air is changed in the room are very important.

In an operating room, the AIA Guidelines specify a minimum exchange rate of 15 air changes per hour. It is important to understand that the guidelines only address minimum standards for the air distribution and thermal control systems. Most hospitals have standards that require higher air exchange rates than the minimum AIA standards. The most recent version is the 2006 AIA release of "Guidelines for Design and Construction of Hospital and Health Care Facilities". [3] There are other guidelines, such as Association for Heating Refrigeration and Air Conditioning Engineers (ASHRAE) and the Center for Disease Control (CDC) in the U.S. These guidelines include ASHRAE's new design manual "HVAC Design Manual for Hospitals and Clinics" [4] and CDC's "Guidelines for Environmental Infection Control in Health-Care Facilities". These new standards are being updated due to the Infection Control Risk Assessment (ICRA) [5] which is "conducted by a panel with expertise in infection control, risk management, facility design, construction, ventilation, safety, and epidemiology" as required by AIA Guidelines [3].

In addition to these guidelines, there are studies, both theoretical and evidenced based, that show that increasing the air exchange rate reduces the amount of contaminated air in a space and, therefore, reduces infection risks for the patient. In a study done by The Center for Health Design, it was found that infections are transmitted through air, surface contact and water [3].

In addition to the evidenced based support for the importance of higher air exchange rates, there have been recent ASHRAE-supported studies which used some of the latest software techniques to attempt to model air distribution concepts in operating rooms to determine theoretical optimization of the air distribution concept, as they relate to infection control. Specifically, one by Memarzadeh and Manning [1] attempted to address this topic from a computer modeling framework utilizing computational fluid dynamics software.

The intent of this paper is to extend concepts presented in this theoretical study to two real-life systems designed and constructed within the past year; the new operating rooms at the University of Massachusetts Memorial Lakeside Addition in Worcester Massachusetts, and the new operating rooms at the Hospital for Special Surgery in New York City.

### **Summary of the paper “Comparison of Operating Room Ventilation Systems in the Protection of the Surgical Site [1]”**

The main focus of this paper was to examine the different outcomes of a common operating room with two variables, first being the diffuser locations and second being the air change rate per hour (ACH). The reader is referred to the study for detailed criteria regarding assumptions for modeling the space and equipment in the room.

This study evaluated eleven systems, each of which consisted of a different diffuser set up, a different ACH, or a combination of the two. During the simulations performed for this study, particle tracking was done from three different sources. These particle origination sources were the surgical staff leaning over the patient, the circulating nurse and the tracked particles known as “main” which represented the particles passed from general surgical activity around the table.

The three different particle start locations were tracked with each of the eleven possible ventilation systems. The outcome of the research was analyzed in two different categories based on whether the particle was removed or if it hit the surgical site or back table. For the first situation of the particle being vented from the room after one hour it was found that the laminar flow diffuser with 150 ACH system was the best for all three particle cases. The most inefficient concept was the U-shaped diffusers.

The second category for evaluating the different system concepts was based on if the particle hit the surgical site or the back table proved that the laminar flow diffuser with mixed (high and low) exhaust / return elevations was the most efficient at keeping the particles from hitting the surgical site, however only had a mediocre performance at keeping particles from hitting the back table. The most inefficient at keeping the particles from the surgical site was the conventional diffusers.

From this research it can be concluded that the best systems were the laminar flow systems. While the outcome varied based on location of the diffusers, it was not significant enough to firmly conclude that the high and low exhausts systems should not be used. However, the updated AIA Guidelines 2006 recommend that the high and low return/exhaust strategy is preferred [3].

### **RESEARCH**

The Memarzadeh and Manning study advanced the understanding of air flow concepts by identifying the thermal plume from the patient, doctor and nurses as a critical factor to be addressed. Assuming these findings to be accurate, it is important to note a couple of other important factors in assessing laminar flow concepts in an operating room that are often assumed to be negligible. These are the effects of the lighting and the obstructions (booms and movement of surgeons) on laminar flow systems. This study attempted to model the effect of these variables in the context of the two case studies. The assessment is done utilizing similar CFD analyses. The IES Macroflow [6] software was used. The particulate count was not addressed, rather, air flow patterns from clean to “less clean” spaces were modeled. Key model parameters and assumptions were:

- 8m x 7.7m x 4m (24 ft x 23 ft x 12 ft)
- One surgical staff members
- One patient
- One surgical stand
- Three surgical lights
- Two monitors (and stands)
- One operating table

The following sections summarize the results of the CFD studies as applied to the two field site case studies.

### UMass Memorial Case Study

The UMass Memorial air distribution concept utilizes the standard laminar downdraft flow concept delivering air at a low velocity directly above the patient area, as shown in Figure 1.

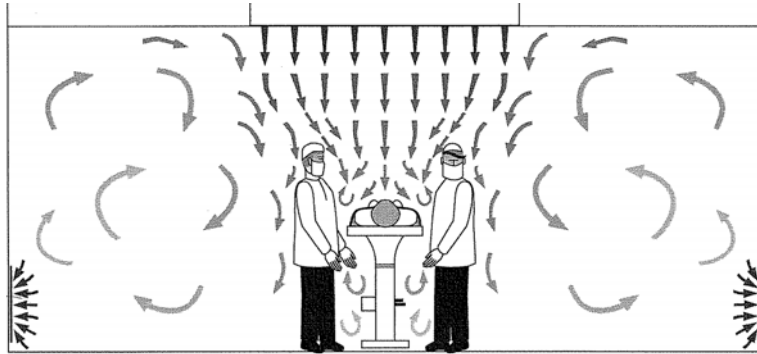


Figure 1. Standard laminar flow system concept without curtain. [2]

In addition, a linear supply air flow can be provided to apply an air curtain at the boundary of the operating area, protecting the clean area of the space from the less clean area of the space. (See Figure 2.)

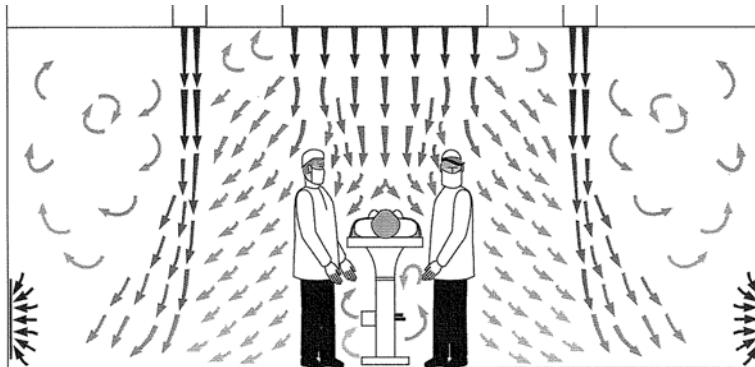


Figure 2. Laminar flow system with air curtain concept. [2]

Return grilles are located low in opposite corners of the space, and the room is under a positive pressure, consistent with the clean to less clean concept. The central air handling system has high efficiency particulate absorbing (HEPA) filters. The air is returned from the space. Of the flow needed to achieve 25 ACH; approximately 33% is brought in from the outside. This exceeds the minimum requirements of 15 ACH and 3 ACH of outside air required by the AIA Guidelines.

There are three medical booms in the laminar flow surgical area. The thermal plume from the patient is assumed to be 0.04 kW (136 Btu/hr), and the heat from the lights (which are located at the ceiling between the laminar flow diffusers and the linear, air curtain diffusers) is assumed to be radiating at 0.32 kW/m<sup>2</sup> (100 Btu/hr-ft<sup>2</sup>). The heat from the lighting on each boom is estimated at 0.41 kW/m<sup>2</sup> (130 Btu/hr-ft<sup>2</sup>).

The CFD model results (Figure 3) indicates that the particle path does flow from the clean to less clean area. The positive effect of the linear diffuser concept is clearly indicated. The air

curtain has effectively isolated the clean zone, and has also provided an increase in air change rate in the patient zone by inducing air flow away from the clean zone. This results in an increase in the effective air exchange rate within the clean zone from 25 ACH to well above 40 to 50 ACH [2]. It is important to have as little space as possible between the linear diffusers as to reduce the induction of less clean air into the airstream and to avoid stagnant or low velocity areas which will trap contaminants [2]. As noted in the reference to the ASHRAE research studies on this topic [1], this results in a reduced likelihood of patient infection.

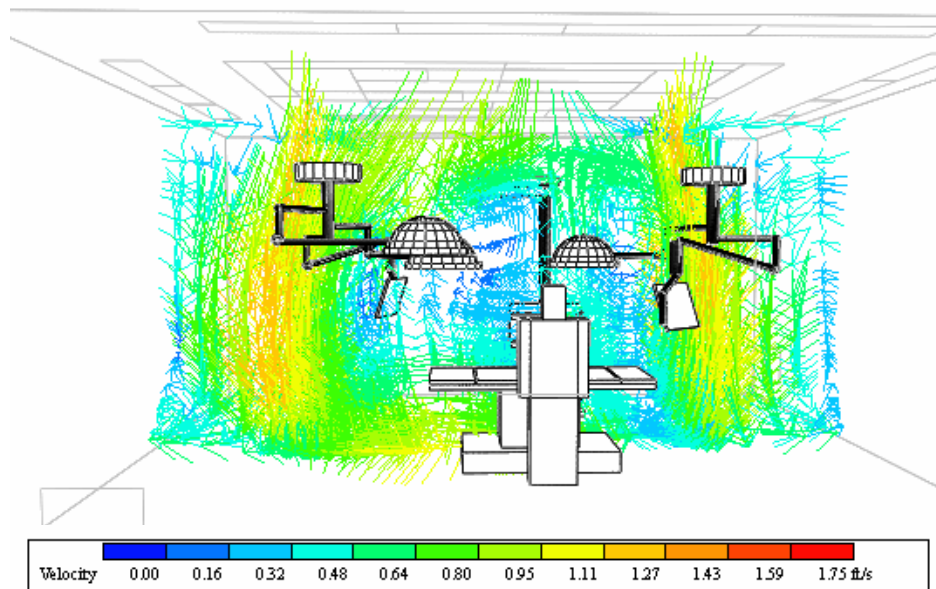


Figure 3. Velocity profile from the UMass study showing the laminar flow air curtain surrounding surgical area.

The next two figures (Figure 4 and 5) represent the particle path from the location directly above the patient to the return/exhaust location. The path shows that the particle disperses from a point directly above the patient and is trapped by the air current, flowing in a relatively linear path to the less clean zone, and then out of the room. The CFD models provide theoretical results that support the air distribution manufacturer's technical literature [2] with respect to the air curtain concept. The results further validate the ASHRAE study [1] that advocates for more than 20 ACH.

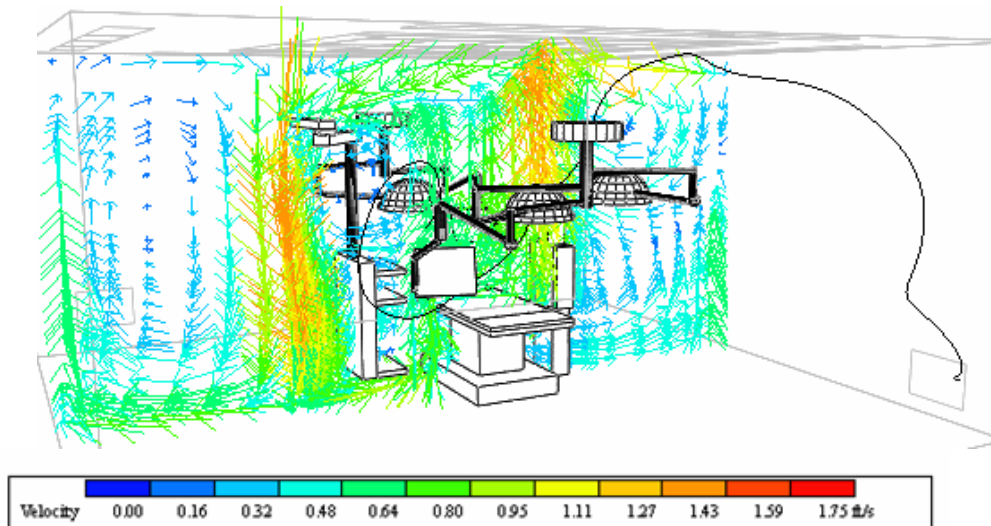


Figure 4. Velocity profile from UMass study showing particle being removed from surgical area.

### Hospital for Special Surgery Case Study

The New York City's Hospital for Special Surgery (HSS) air distribution concept is based on the laminar flow concept, but does not utilize the air curtain concept previously described. The variations include diffusers that can be adjusted to direct air flow, and an enclosed plexi-glass curtain that isolates the clean zone. The ceiling layout is altered regarding the diffuser, light and grille locations. The motorized directional vanes on the laminar flow panels are manually adjusted by the surgical team to allow for the air flow to change from the vertical direction to a 45-degree deflection. This feature is utilized when the surgical team is required to work directly above the patient and vertical laminar flow would cause for the air particles to be carried directly into the patient area. The 45 degree adjustment results in the particles to be angled away from the surgical area. The arrangement of the room, as far as equipment and people, was modeled similarly to the UMass Memorial model. However, changes were made to the supply and return diffusers as well as the lighting locations to reflect the actual room layout. The layout of the HSS (Figure 6) consists of eight 0.6m x 1.3m supply diffusers and two 0.6m x 1m supply diffusers located directly above the operation table. Surrounding the diffusers are ten 0.6m x 1.3m fluorescent lights. In addition there are three 0.3m x 0.3m fluorescent lights located in the room. The return grilles are located at opposite corners of the space.

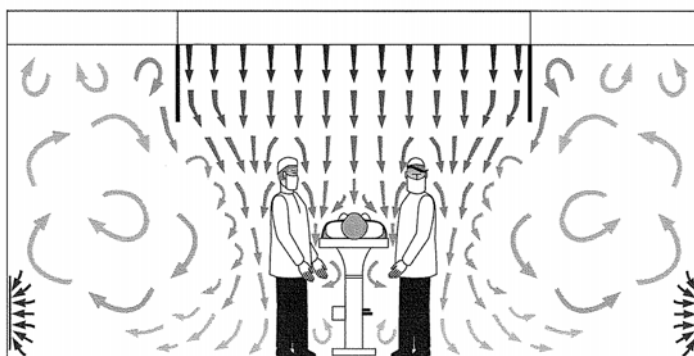


Figure 5. Laminar flow system with physical curtain [4].

The physical curtain provides a barrier between the clean zone and the less clean zone. The curtain seen in Figure 5 is a partial curtain which is used to help direct the laminar flow air towards the surgical area. As an improvement on this method, the design of HSS includes a

physical curtain which surrounds the surgical zone on all four sides. Instead of hanging from the ceiling to only a few feet below the ceiling, the design includes the curtain hanging from the ceiling to 8" above finished floor.

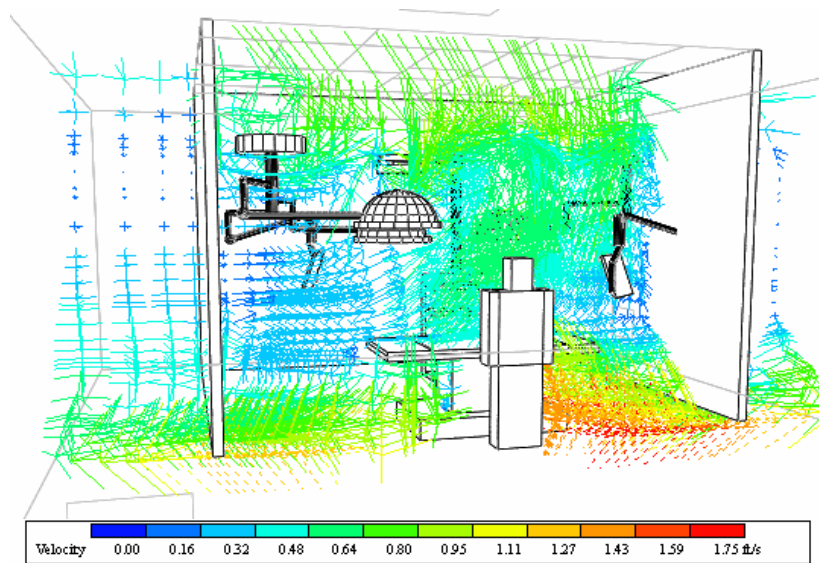


Figure 6. Velocity profile for HSS study showing general air movement coming from ceiling diffusers and under curtain and out of the surgical area.

The CFD models clearly indicate that the directional flow from the laminar diffusers creates a customized air flow dynamic in the room. There is a significant increase in velocity at the floor where the plexi-glass curtain acts in a similar fashion to a slotted return/exhaust opening. It is also evident that the equipment in the room causes turbulence that inhibits the direct removal of particles. The directional diffuser concept could be optimized by the use of similar studies.

## SUMMARY

The case studies and analyses developed based on actual operating room installations show that the theoretical air distribution will optimize the concept of maximizing air exchange rates and directing particles in the air from the critical clean area above the patient to the less clean areas at the outer parts of the room. The systems also isolate any particles already located in the less clean areas in such a way that there is a very low probability that they will be re-entrained into the critical clean zone.

## REFERENCES

1. Memarzadeh, Farhad and Andrew Manning. "Comparison of Operating Room Ventilation Systems in the Protection of the Surgical site." *ASHRAE Transactions* 108 (2).
2. "Operating Room Air Distribution" *Air Distribution Catalog – Section E – Hospital/Cleanroom Diffusers Engineering* Nailor Industries, 2005: E99-105.
3. AIA Guidelines (2006) "Guidelines for Design and Construction of Hospital and Health Care Facilities".
4. ASHRAE. *HVAC Design Manual for Hospitals and Clinics*. 2003.
5. Dooley, Bob. "Infection Control & HVAC." *ICRA Design Consultants LLC* May 2004.
6. Integrated Engineering Solutions (IES), Virtual Environment (VE), Macroflow (CFD Component), Glasgow, UK.