



Rethinking OR Ventilation: Introduction to Temperature- controlled Air Flow Technology

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SAME PROBLEMS. HIGHER STAKES. BETTER SOLUTIONS.
OCTOBER 4-7, 2026 | FOXWOODS RESORT | NEHES FALL CONFERENCE

Learning Objectives

- Describe the risk factors associated with airborne microbial contamination in the operating room.
- Outline the physics of Temperature-controlled Air Flow ventilation (TcAF).
- Discuss the differences in design and performance among different ventilation alternatives.
- Characterize the process of assessing a novel ventilation technology.
- Evaluate the compliance of TcAF with ASHRAE 170.



Why change OR ventilation?

Operating Room circa 1960s



Historical Surgery Photo, Operating Room circa 1960
© 1995 – 2022 The Univ. of Texas Medical Branch, Galveston

Operating Room of Today



German Heart Center Munich, Germany, Siemens-Healthineers

Everything has changed except the ventilation!

But does ventilation really matter?

Microbiology 101: CFU/m³

- **CFU/m³: Colony-Forming Units per cubic meter of air**
 - Microbiological measure of the concentration of **viable, culturable microorganisms in air**.
 - Different than particle counting which measures all particles, not just those particles with viable microorganisms.
- **Colony-Forming Unit (CFU):** A viable microorganism—or sometimes a cluster of microorganisms— visible on an agar culture plate when incubated.
- After incubation, visible colonies are counted and standardized to the volume of air sampled:
 - $\text{CFU/m}^3 = \text{Number of colonies recovered} \div \text{volume of air sampled (m}^3\text{)}$
 - Example: 1,000 liters (1 m³) of air sampled, 20 colonies observed, result is 20 CFU/m³



Why OR ventilation matters

- Rooms with over 50 CFU/m³ are 2.6 times more likely to have SSIs than those with 10-20 CFU/m³.¹
- Airborne transmission accounts for 20%–24%, potentially up to 98% of post-operative infections.^{2, 3}
- Large, multi-center study found “*the majority of bacteria contaminating the surgical wound likely reached it by the airborne route.*”⁴

1. Lidwell OM, et al. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. *J Hosp Infect.* 1983;4(2).
2. Lidwell OM, et al. Bacteria isolated from deep joint sepsis after operation for total hip or knee replacement and the sources of the infections with *Staphylococcus aureus*. *J Hosp Infect.* 1983;4(1):19–29.
3. Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, Lowe D. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. *J Hosp Infect.* 1983 Jun;4(2):111–31.
4. Charnley, J. and Eftekhari, N. (1969), Postoperative infection in total prosthetic replacement arthroplasty of the hip-joint with special reference to the bacterial content of the air of the operating room. *Br J Surg*, 56: 641–649
5. Parvizi, J., et al. Environment of care: Is it time to reassess microbial contamination of the operating room air as a risk factor for surgical site infection in total joint arthroplasty? *Am J Infect Cont*, 45(11), 1267–1272.

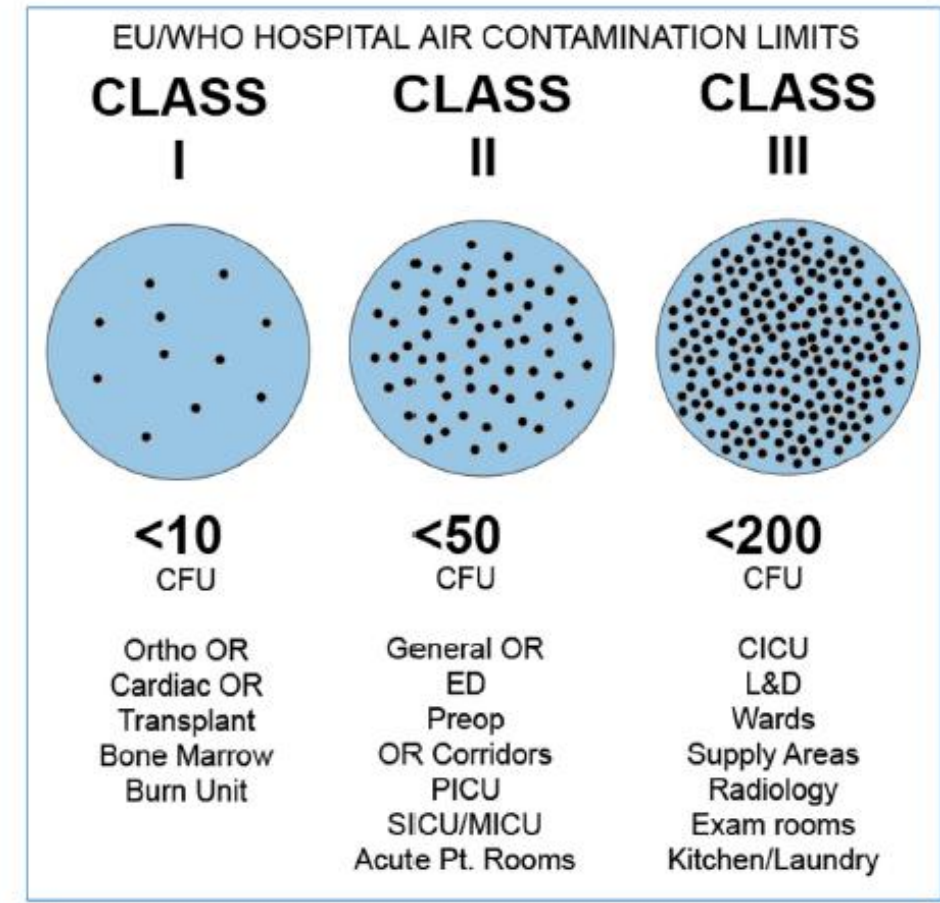
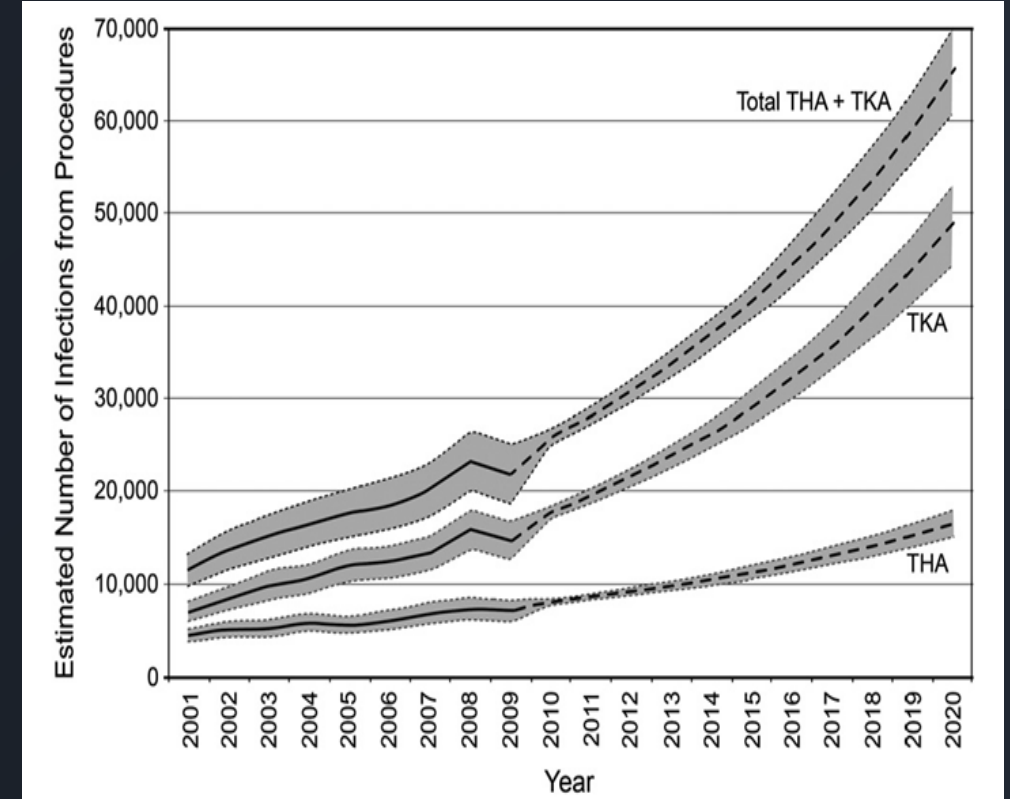


Fig 1. Propose EU-WHO standards for contamination of hospital room air: class I, <10 CFU; class II, <50 CFU; and class III, <200 CFU. Hospital OR fall within class I standards. 39 CFU, colony forming units; ED, emergency department; EU, European Union; Preop, preoperative; Pt., patient; OR, operating room pediatric intensive care unit (PICU); surgical intensive care unit (SICU); medical intensive care unit (MICU); cardiac intensive care unit (CICU) and labor and delivery (L&D). WHO, World Health Organization. 5

Surgical Site Infection is still a problem

- Volume of hip/knee arthroplasties continues to grow exponentially.¹
- Literature: 1-2% of hip and of knee arthroplasties become infected (10-20,000) **Underestimate!**²
- Cost – Infection in TKA/THA **not reimbursed**. Can be upwards of 100,000+ direct expense.³
- 5-year mortality rate TKA/THA: 16-25.9%⁴



Historical number of infected THA/TKA procedures in the United States

1. Shichman, et al. Projections and Epidemiology of Primary Hip and Knee Arthroplasty in Medicare Patients to 2040-2060. JB & JS open access, 8(1).

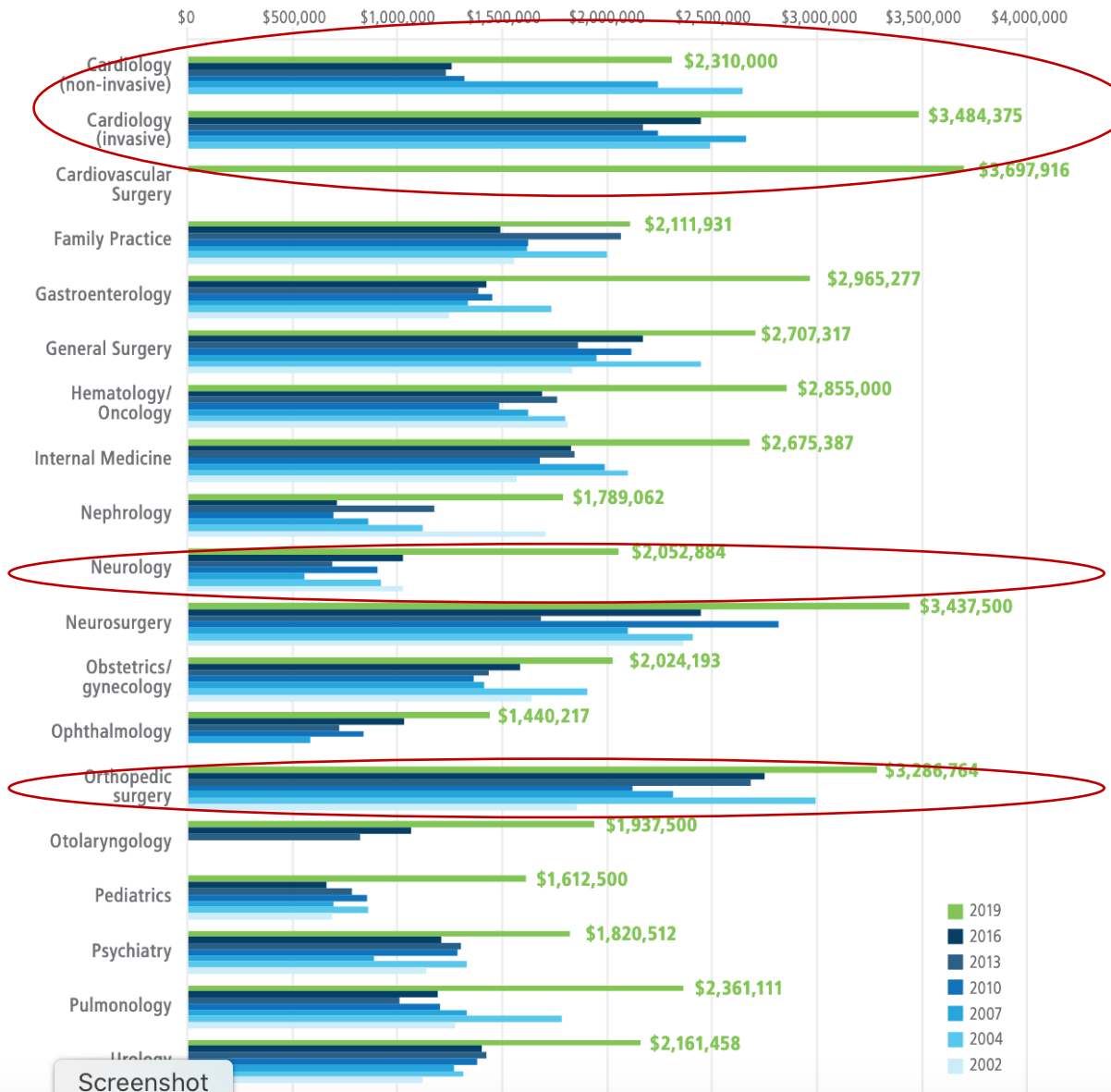
2. Folusakin A, et al. Stat Pearls, Oct 2023. <https://www.ncbi.nlm.nih.gov/books/NBK448131/>

3. Yao, J, et al. Direct Inpatient Medical Costs of Operative Treatment of Periprosthetic Hip and Knee Infections Are Twofold Higher Than Those of Aseptic Revisions. The Journal of Bone and Joint Surgery (2021) 103(4):p 312-318.

4. Yangqi X, et al. Mortality, patient-reported outcome measures, and the health economic burden of prosthetic joint infection, Effort Open Reviews. (2023) Vol 8, Issue 9.

SPECIALTY COMPARISON YEAR-TO-YEAR

The graph below shows average annual revenue generated per specialty for the seven years the survey has been conducted.



Screenshot

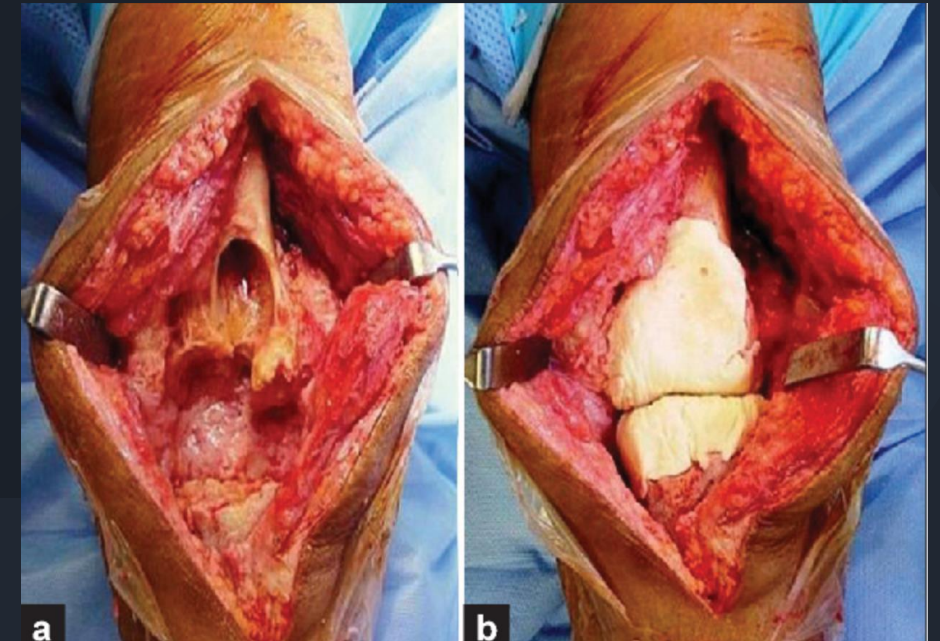
*Ophthalmology included for the first time in 2007, Cardiovascular Surgery included for the first time in 2019

3 of the top 4 generators of health system revenue...

...are Infection sensitive surgical procedures.

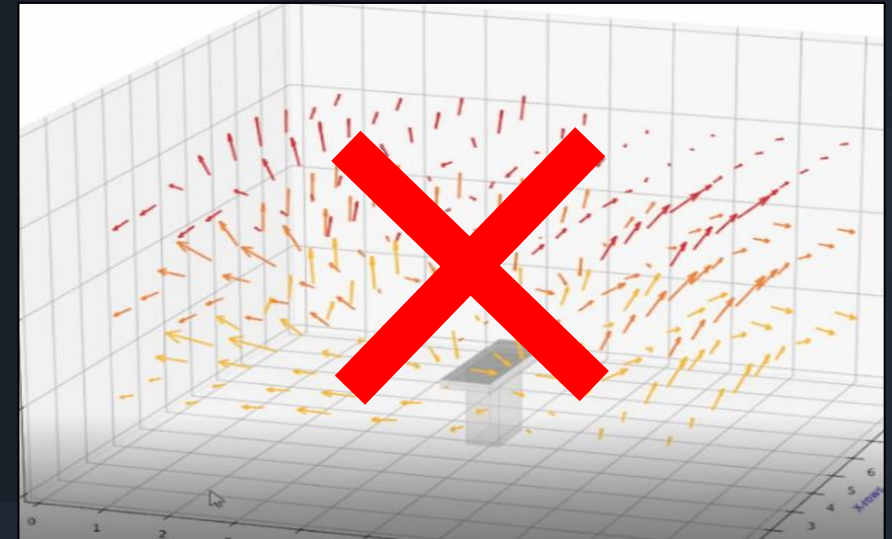
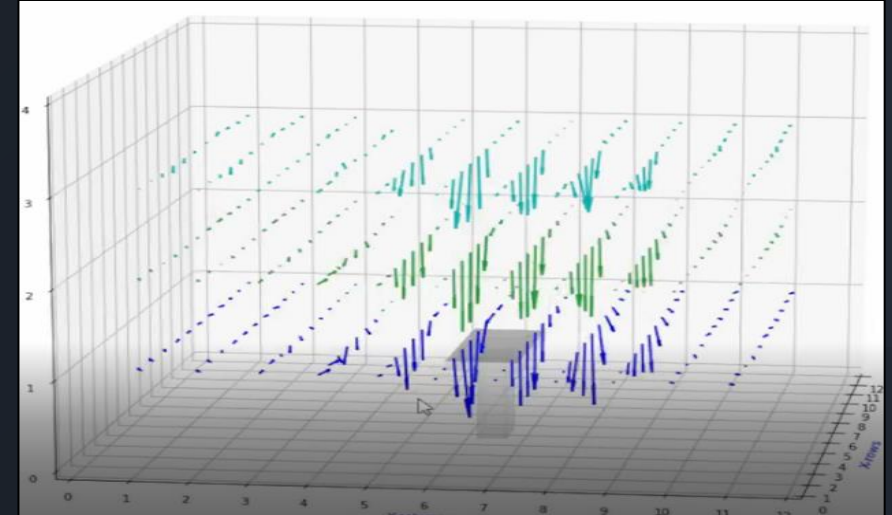
Airborne factors that contribute to infection

- Number of personnel in the room, *majority of airborne bioburden comes from the people in the room*
- Movement of personnel and equipment
- Door openings and closings
- Length and type of procedure
- Exposure of sterile instruments and implants!



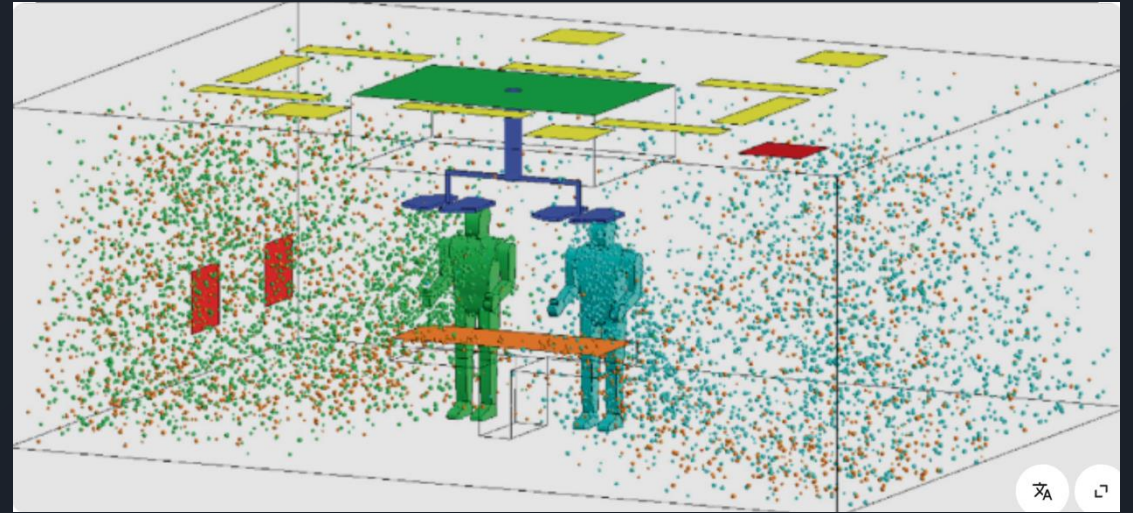
Engineering controls that minimize the presence of airborne bioburden (basis of ASHRAE 170)

- **Positive pressure:** Prevents air from contaminated areas flowing into adjacent areas
- **Direction:** Consistent, perpendicular, downward flow (unidirectional)
- **Velocity:** Driven at a speed that ensures
 - Uni-directionality
 - High enough to overcome, obstacles and heat convection
 - Minimize turbulence
- **Temperature & Humidity:** Also influence transmission



ASHRAE 170 engineering controls: What they do not tell us

- Engineering controls do not provide any information on how well ventilation systems perform against actual level of bioburden in the air.
- Controls are *prescriptive* (system must operate within specified engineering parameters), not *performance* based (airborne bioburden)
- No requirements in US for measuring ventilation *performance against airborne microbial contamination*.



Simulation of skin follicle dispersion in an OR¹

1. Rodrigues, N., Teixeira, I., Ferreira, A., Oliveira, R., Teixeira, S. (2023). Skin Follicles Dispersion Within a Hospital Operating Room—How to Predict and Reduce the Contamination. In: Arezes, P.M., *et al.* Occupational and Environmental Safety and Health IV. Studies in Systems, Decision and Control, vol 449.



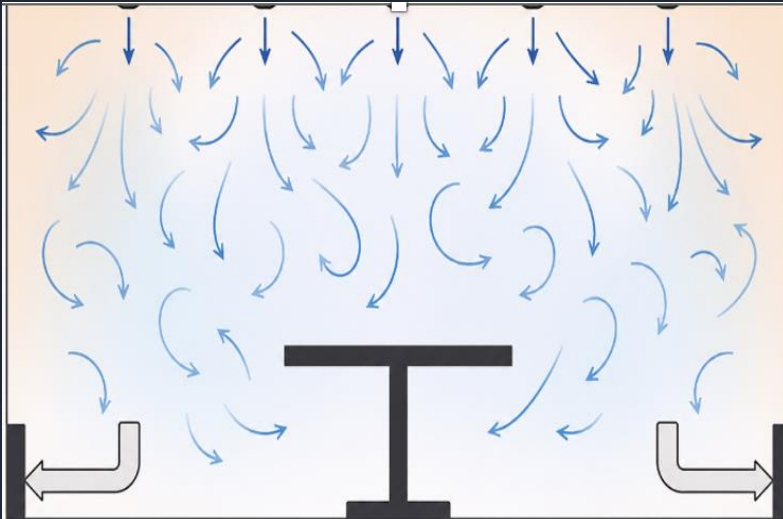
**When was the
last time**

***you measured
the airborne
microbial
bioburden***

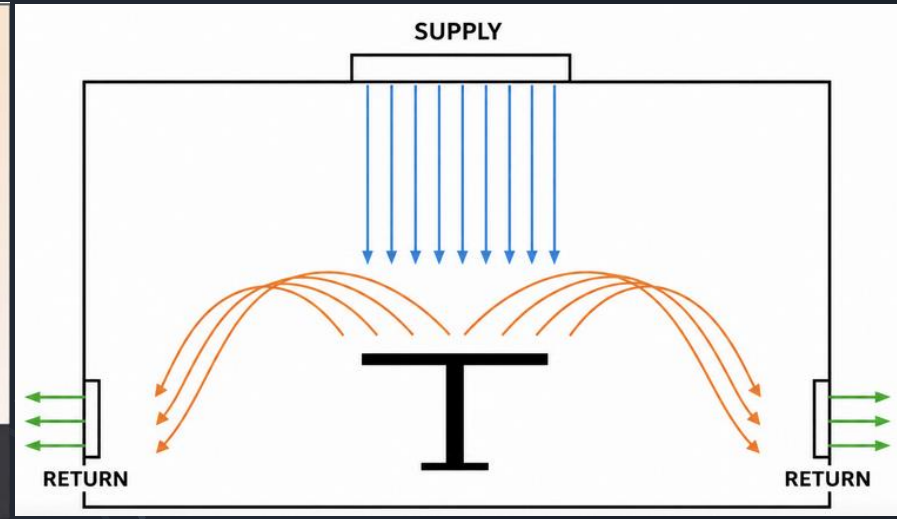
**in your operating
rooms?**



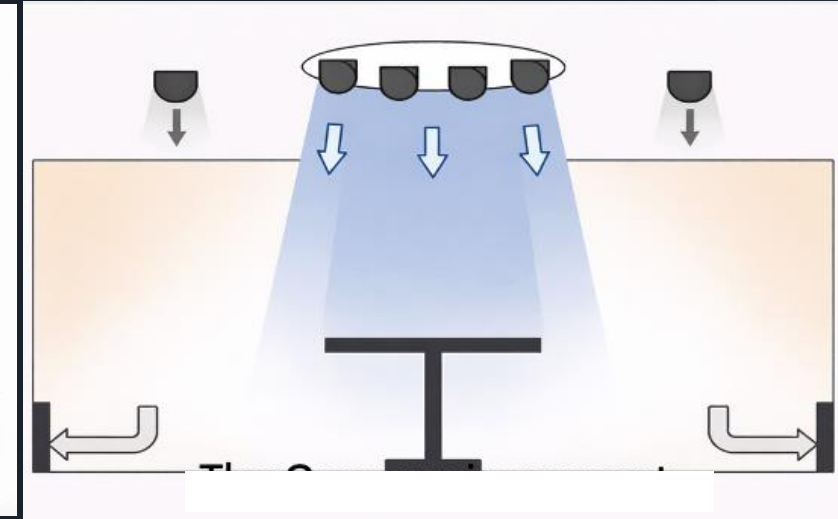
OR ventilation concepts



Turbulent Mixed Air Flow
(TMA)



Laminar Air Flow
(LAF)



Temperature controlled
Air Flow (TcAF)

Concepts differ in how air flow, direction and velocity are managed.

Conventional Laminar Air Flow (LAF)

- Designed to protect the surgical field *only* (ASHRAE 170 - 12 in. around surgical bed)
- Free shear mixing layer allows ambient room air to contaminate central sterile jet.

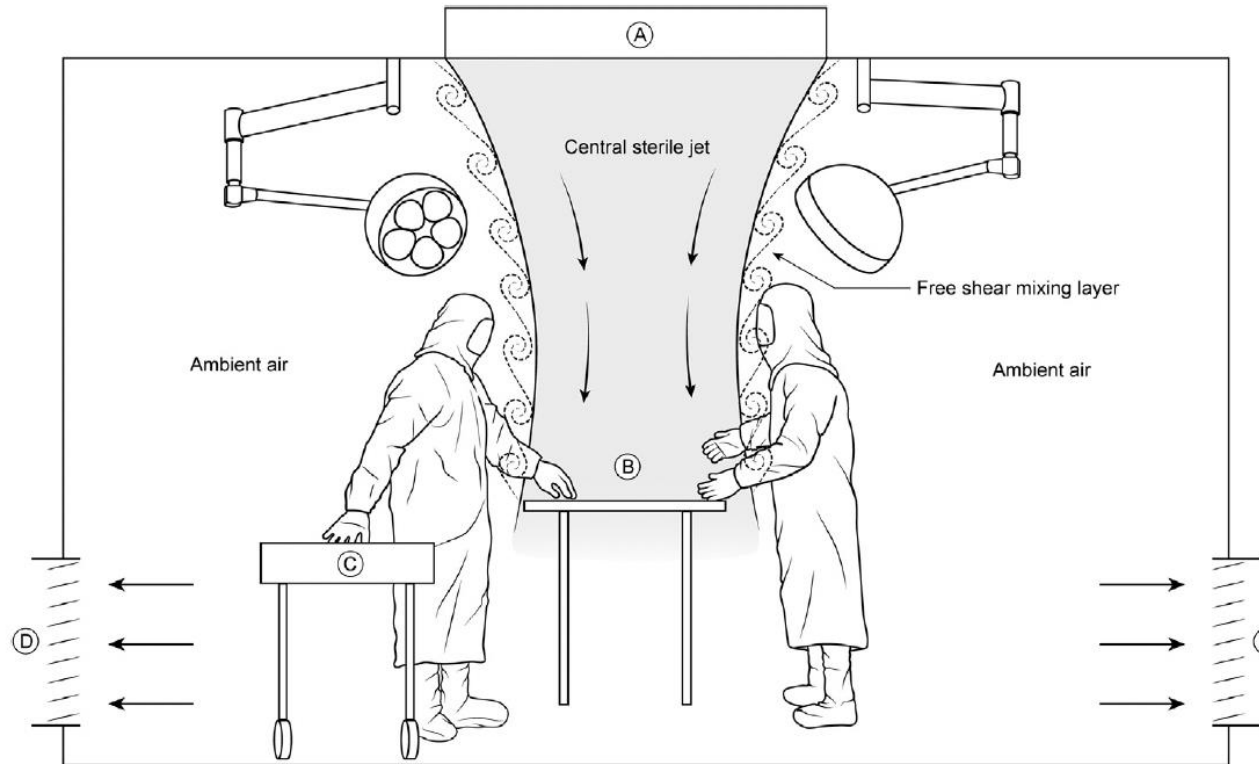
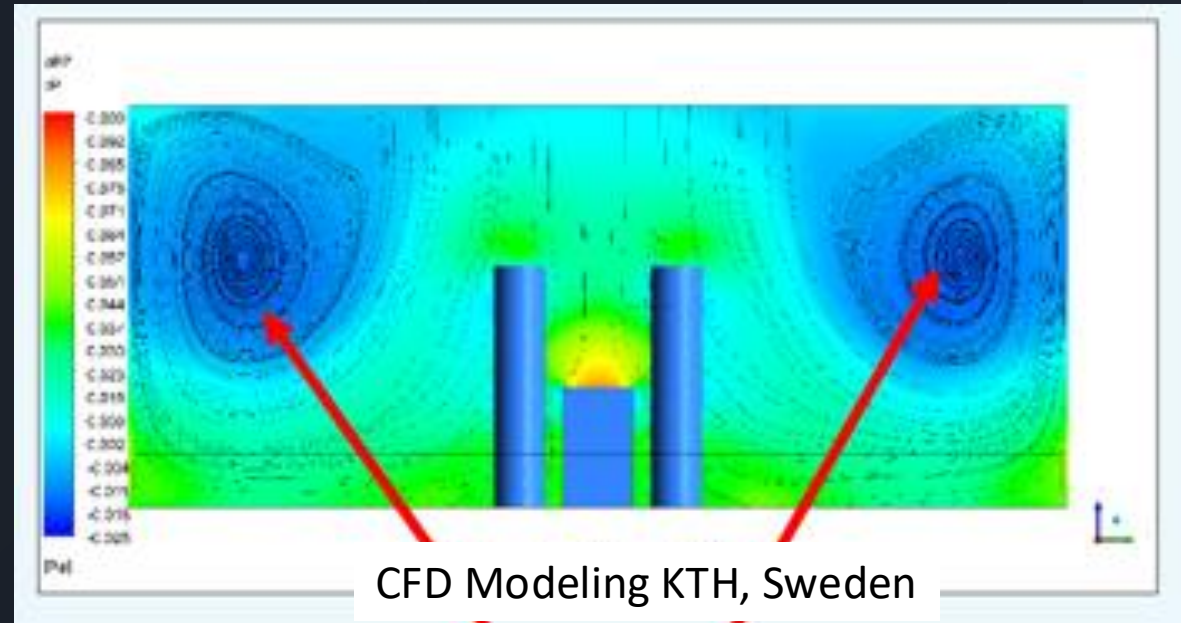
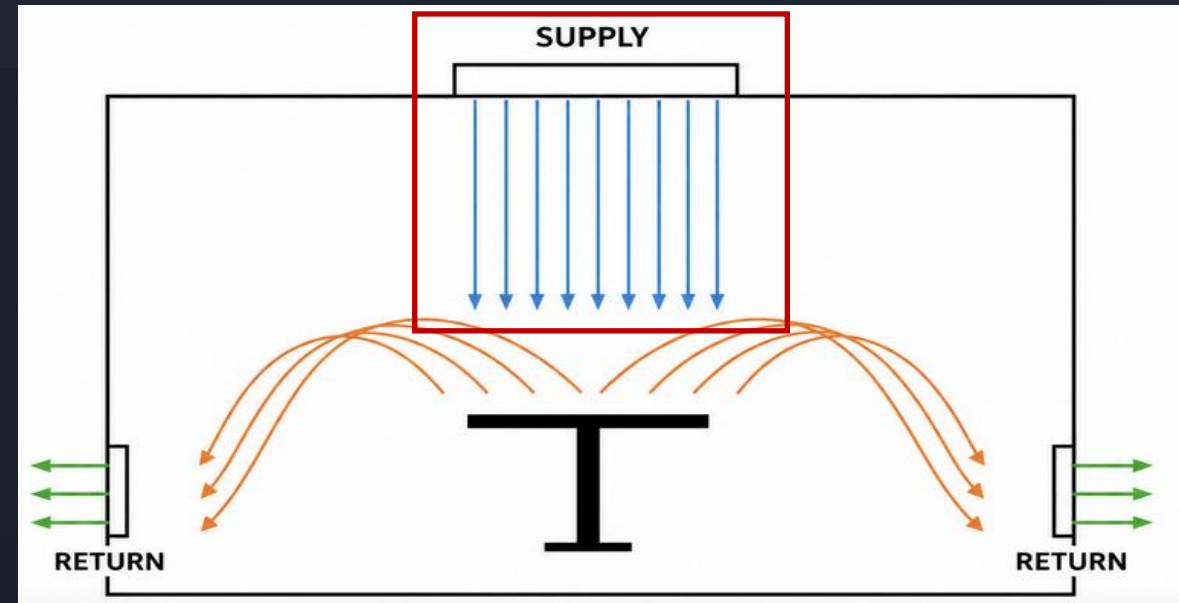


Fig 1. Schematic diagram of airflow in an operating room built to ASHRAE 170 – 2021 standards. (A) Ceiling diffusers supplying HEPA filtered air. (B) Surgical wound zone located in central jet of sterile air. (C) Back table zone for sterile instruments and supplies located in ambient air. (D) Near floor level exhaust grilles. Ambient air surrounds the central sterile jet and will contain variable amount of MCPs from personnel in room. The free shear mixing layer allows ambient room air to contaminate the central sterile jet.

Laminar Air Flow (LAF)

- Little change since the 1960s
- Designed to create a clean *zone only*
- Velocity *decreases* with distance from diffuser, can be turbulent at table level
- Airflow easily *disrupted by objects* in pathway
- *Vortices form in periphery*
- Mean values of airborne CFUs outside protected zone: *55-fold higher* than values inside ¹

Based on a growing body of evidence, LAF is no longer recommended by CDC or WHO for joint arthroplasty.^{2,3}



1. Benen T, et al. Influence of different ventilations systems upon the contamination of medical devices. Hyg Med. 2013; 38–41.
2. Berríos-Torres SI, et al. CDC Guideline for the Prevention of Surgical Site Infection, 2017. JAMA Surg. 2017;152(8):784–791.
3. Global guidelines on the prevention of surgical site infection. World Health Organization. 2016. <http://www.who.int>

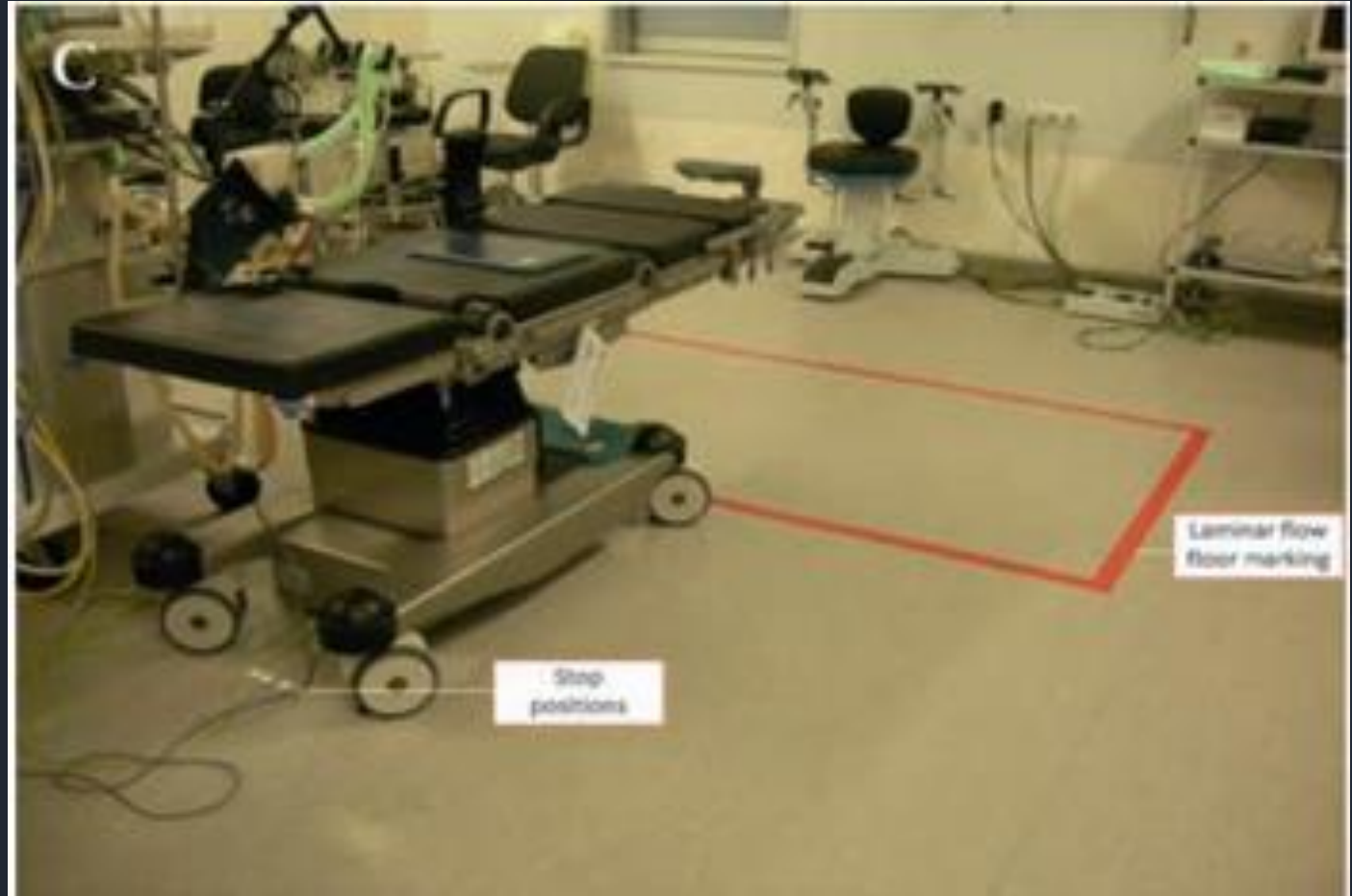
Why is the periphery important?

Surgical instruments, implants and devices should be placed within the ultraclean zone.
How often is this requirement met?

Safety by design: Effects of operating room floor marking on the positioning of surgical devices

- Before/after study using tape to mark the clean zone.
- Prior to marking, devices in the clean zone in 6.1% of surgeries.
- After marking devices in clean zone 36-52% of surgeries.

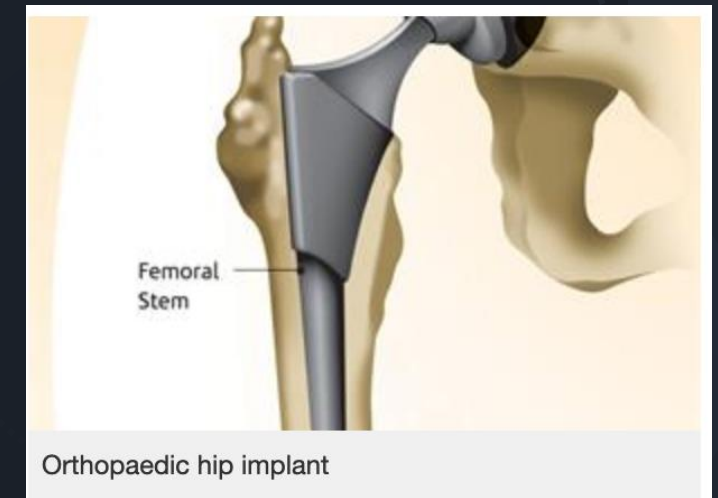
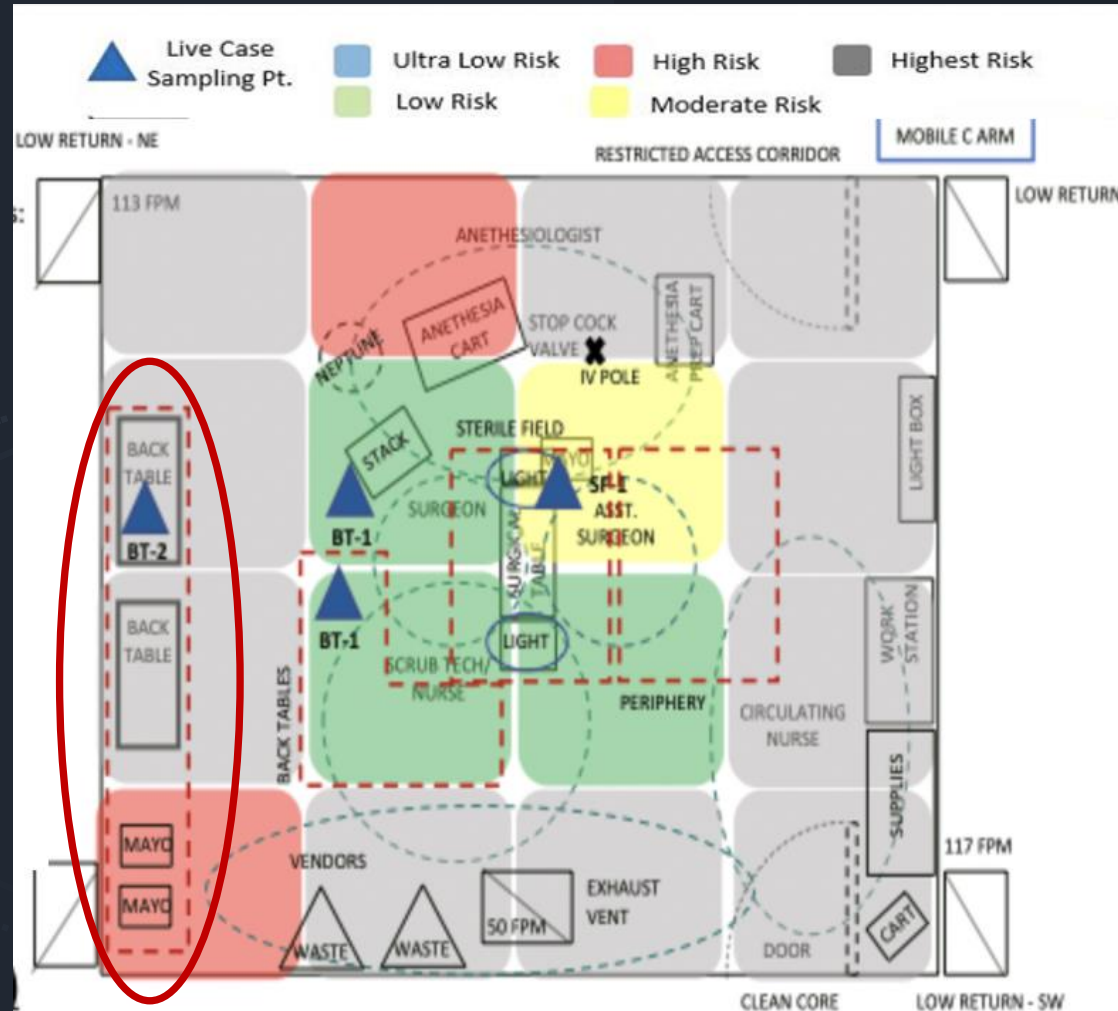
de Korne DF, van Wijngaarden JDH, van Rooij J, et al. Safety by design: effects of operating room floor marking on the position of surgical devices to promote clean air flow compliance and minimise infection risks. *BMJ Quality & Safety*. 2012;21:746-752



CFU heat map, live case with LAF

Measurements taken in 3 locations:

- Wound/surgical field
- Instrument tables
- Periphery (case carts/back tables)



Introduction to Temperature-controlled Air Flow Ventilation



Physics of Temperature-controlled Air Flow (TcAF)

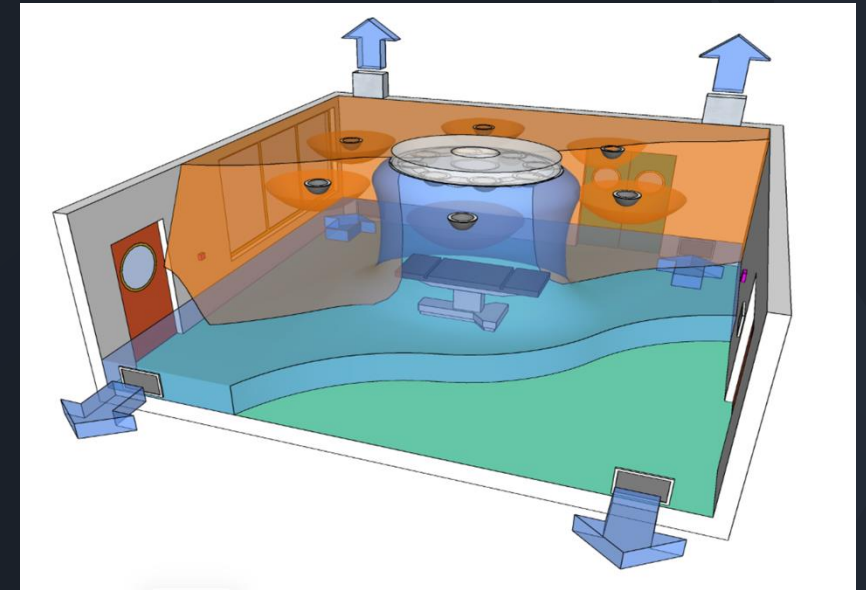
Central Zone

- HEPA filtered air released through diffusers mounted in circular platform above OT
- Air is 3-4°F cooler than ambient room temp
- Temperature differential creates gravity-driven down-flow.
- Air speed *accelerates* with gravity (cooler air is denser).



Periphery

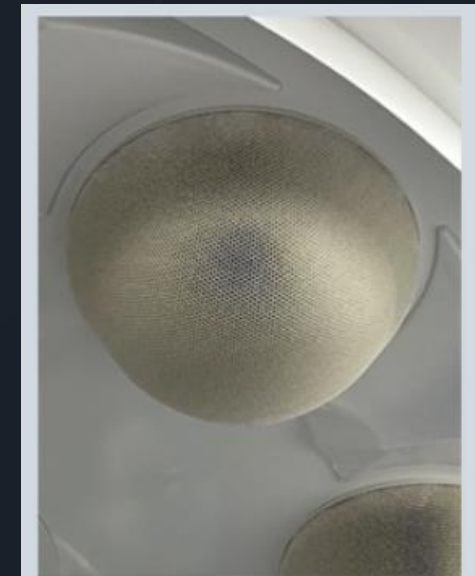
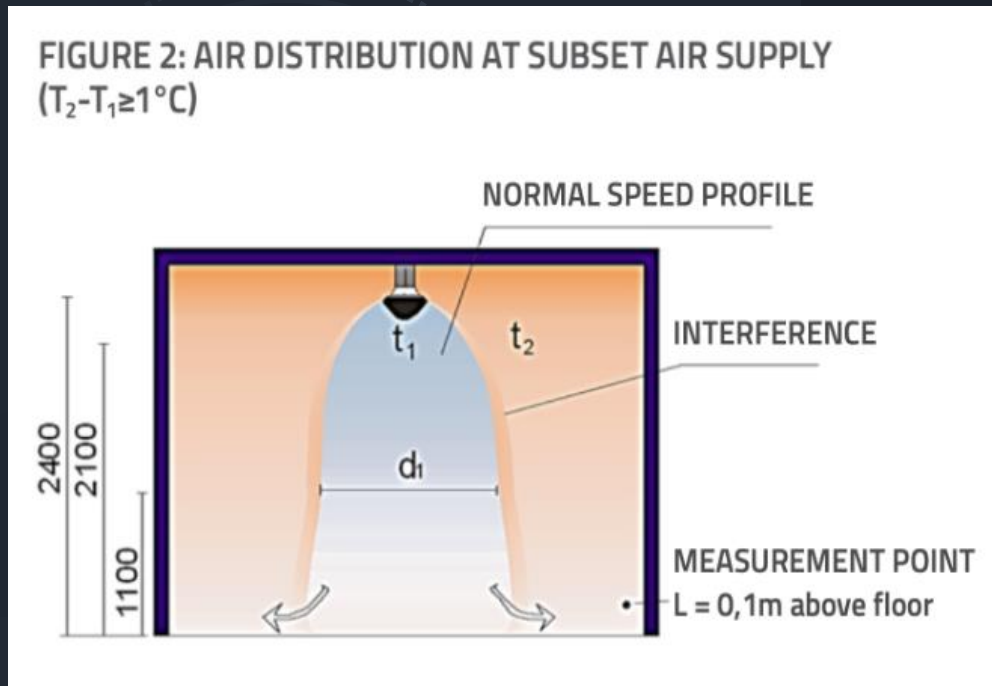
- Warmer air dispersed through additional diffusers
- Creates a low turbulent environment, prevents air from periphery returning to center



Creates ultraclean conditions ($<10\text{CFU}/\text{m}^3$) throughout *entire room*.

TcAF diffusers (air showers)

- Parabolic shape creates airflow wider in diameter than the diffuser itself
- Airflows in central unit overlap to create a unidirectional downflow
- Overlapping air from multiple diffusers creates **coverage beyond footprint of central unit**
- Diffusers in periphery prevent turbulence, allow for sedimentation
- Gravity takes over, air speed accelerates



For more information see Air Shower Technical Data Sheet

Conventional Laminar Air Flow

- Obstacles
disrupt
airflow



TcAF

- Navigates obstacles
- Maintains downward airflow throughout the room, including the periphery



TcAF

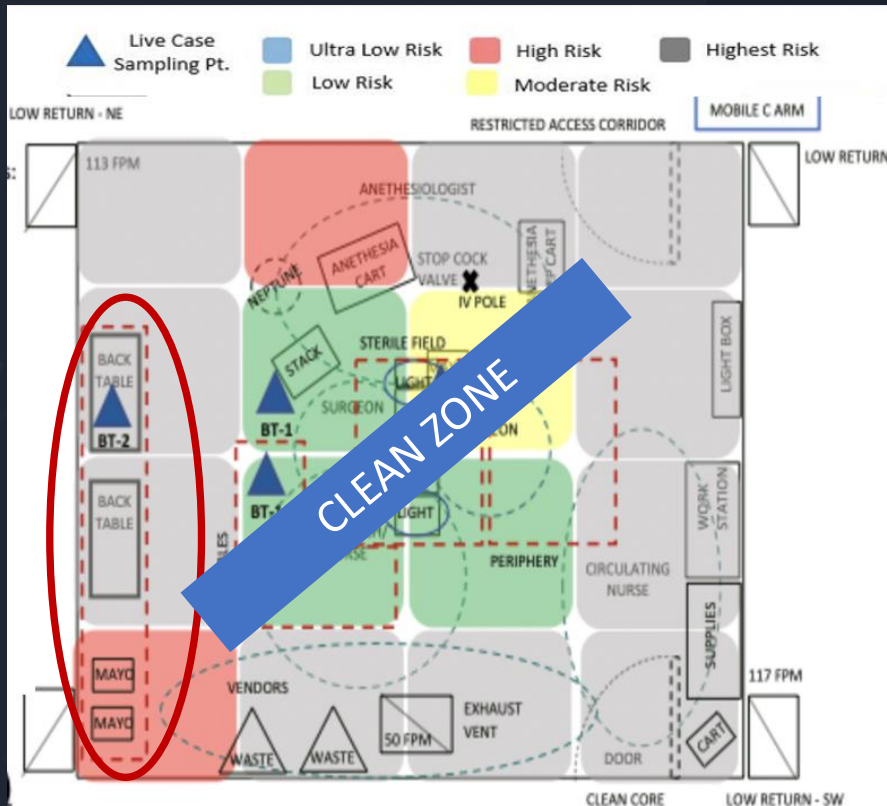
- Protects periphery of room, back tables, case carts



CFU heat maps: Live case comparison Laminar Air Flow (LAF) and Temperature-controlled Air Flow (TcAF)

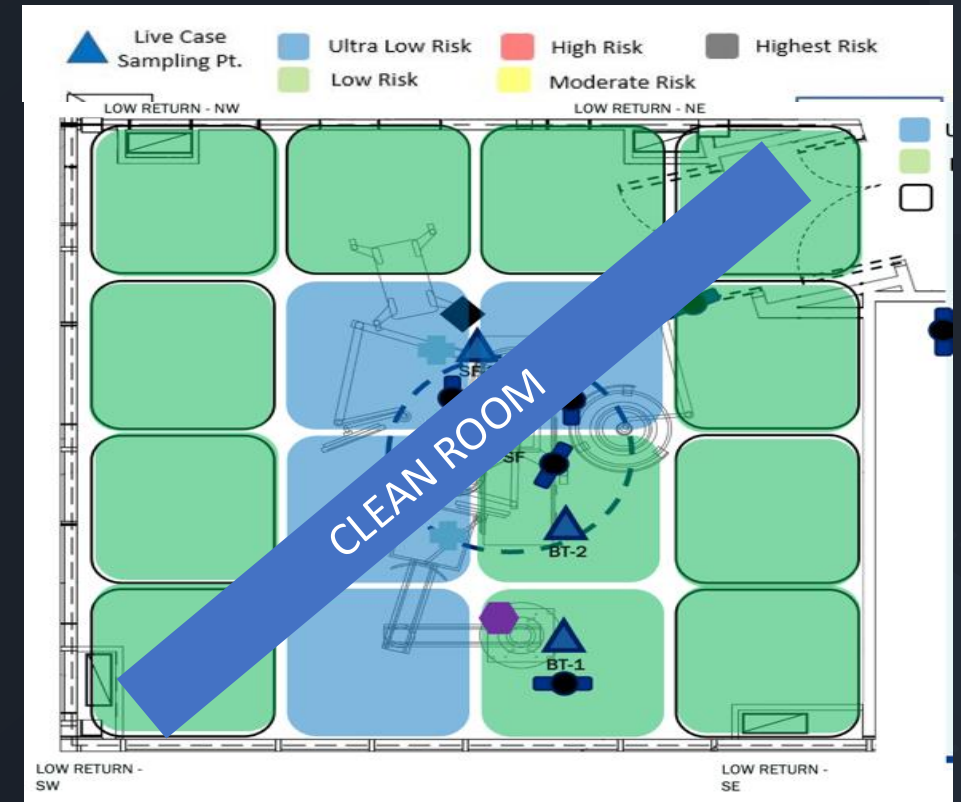


Laminar Air Flow



CFU mapping conducted during active surgery

Temperature-controlled Air Flow



*“The TcAF technology is effective at providing improved environmental quality... **<10 CFU/m³** inside the sterile field, within the footprint of the TcAF and in the periphery of the OR.”*

CFU measurements at wound, instrument table, periphery



Table 1 - Live case colony forming units per cubic meter of air (CFU/m³) for eleven samples collected (sample #7, the air pumps failed) within the sterile field at the surgical site, at the back table position during procedure, and at the location where the back table would be prepared prior to the start of the case. The medians and interquartile ranges were not significantly different between the three locations, p>.05.

Wagner J, Warye K, Greeley D. Validation of a temperature-controlled airflow ventilation system. *ASHRAE Journal*. 2025;67(6):52

Stress testing TcAF

- Leeuwarden Medical Center: 640 bed teaching hospital, specialization in cardiovascular and neurosurgery
- Building project: 12 new ORs, with 2 hybrid rooms



Purpose of study

- Measure performance of TcAF against new Dutch standard for OR air quality
 - Requires ≤ 10 CFU/m³ for “infection-prone surgery,” mean value of ≤ 5 CFU/m³
- To “test the limits” of TcAF, gauge robustness

Stress-testing TcAF: Results

Upper Leg Trauma Procedure

- 13 surgical personnel
- 2 instrument tables, 2 lamps
- Anesthesia machine, suction unit, Bair Hugger
- Equipment switched on, maximum heat loads
- C-arm brought into OR, drawn up
- Considerable movement “*not quiet*”
- 36 door openings
- Duration: 50 minutes

Results

- Average CFUs wound: 0.75 Average CFUs instrument table: 7.0



“This procedure... was an extreme example in which maximum efforts were made to defeat the system.” R. Noor MSc., CTO, Maximuse B.V.

TcAF and SSI Reduction

Clinical validation and efficacy of a temperature-controlled ventilation system (TcAF) in the OR to reduce surgical site infections

■ Objective

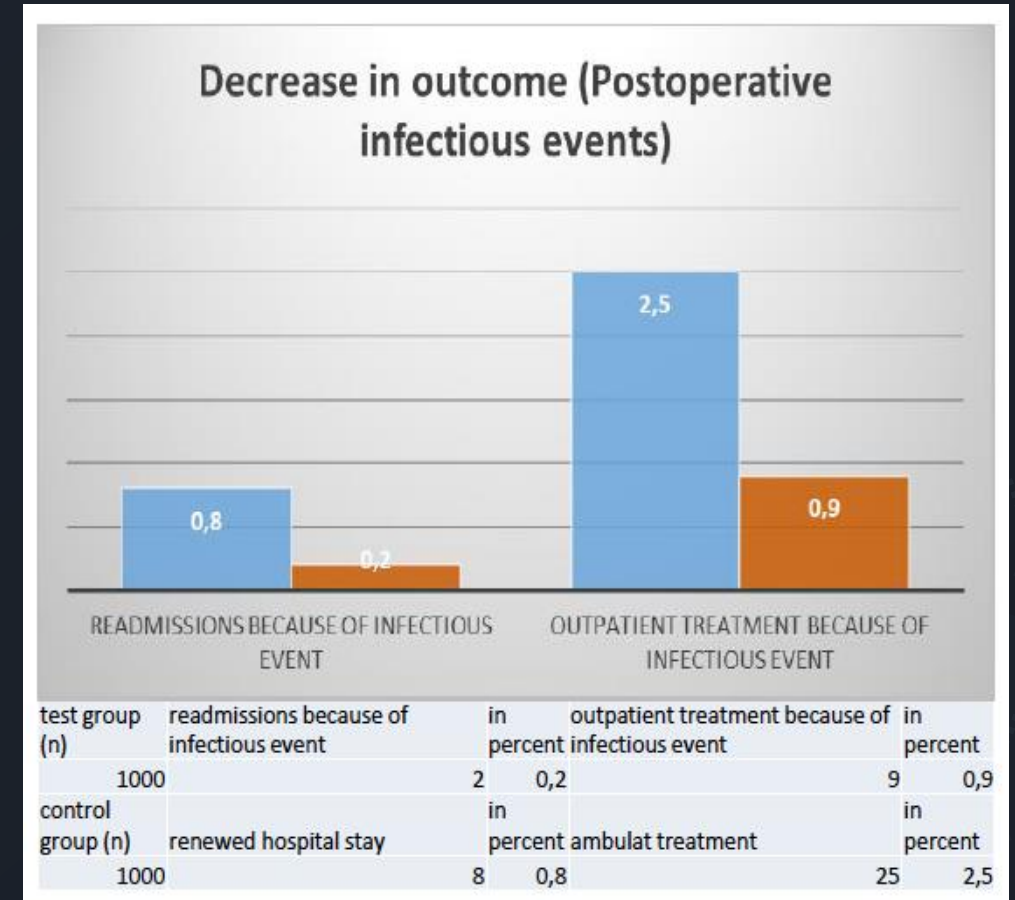
Evaluate efficacy of TcAF under routine conditions, assess impact on PJI.

■ Methods

Retrospective analysis: 1,000 consecutive cases of total joint arthroplasty before, 1,000 consecutive cases after retrofit.

■ Results

Surgical site infection rate decreased 3.1% to 1% . (OR - 0.3259 (95%CI, 0.16-0.65, $p < 0.05$).



Decrease in PJI before (blue) and after (orange) TcAF

Independent validation of TcAF

- More than 5 *independent validations performed* by both academic medical institutions and experts in operating room air quality management.
- Three published in peer-reviewed literature.



TECHNICAL FEATURE

Validation of a Temperature Controlled Airflow Ventilation System

BY JENNIFER WAGNER, PH.D., KATHY WAYNE, DANIEL GRIFFIN, P.E., NEWELL ADRIAN

Temperature controlled airflow (TcAF) has become widely accepted as best practice for reduction of contamination both inside and outside the sterile field and at the periphery of the operating room. TcAF aims to control airborne microbiological contamination by using temperature gradients to provide cool air over the sterile field and warmer air outside the sterile field. The objective of the study described in this article was to use a U.S. published methodology of studying the airborne contamination in an operating room (OR) during dynamic simulated conditions and during live surgeries¹ to validate the aseptic efficacy of a temperature controlled airflow (TcAF) system.

Background
Temperature Controlled Airflow (TcAF)

In the U.S., the general modern concept of OR air delivery requires supply air from the ceiling to flow down over the surgical field, essentially bathing the patient in clean, filtered air and washing the contaminants away from the surgical team and patient to the perimeter of the room, and out low wall returns. These systems rely on supplying the air at a certain velocity and maintaining a forced air speed until it reaches the sterile field. Most of these systems do not address the perimeter of the room, and we have found consistently that the air in the periphery is dirtier than the air within the sterile field.²⁻⁶ In Europe, TcAF has become widely accepted as best practice for reduction of contamination both inside the sterile field and at the periphery of the room. TcAF aims to control airborne microbiological contamination by using temperature gradients to provide cool air over the sterile field and warmer air outside the sterile field. The temperature

Jennifer Wagner, Ph.D., is microbiologist and managing partner and Daniel Griffin is managing partner of Grede LLC. Kathy Wayne is infection preventionist and owner of Infection Prevention Partners.

52 ASHRAE JOURNAL ashrae.org JUNE 2025

AORN Global Surgical Conference & Expo



INNOVATION IN OR VENTILATION CONCEPTS: Stress Testing Temperature-controlled Airflow

Authors
J. L. Griffin, PhD
K. Wayne, PhD
D. Griffin, P.E.
N. Adrian, PhD

Abstract
Despite 40 years of evidence supporting the controlled airflow ventilation system, the industry has not fully embraced the technology. The purpose of this study was to validate the efficacy of a temperature-controlled airflow (TcAF) system in an operating room (OR) during dynamic simulated conditions and during live surgeries. The objective of the study was to use a U.S. published methodology of studying the airborne contamination in an operating room (OR) during dynamic simulated conditions and during live surgeries¹ to validate the aseptic efficacy of a temperature controlled airflow (TcAF) system.

Methods
The study was conducted in a simulated OR environment. The TcAF system was tested under various conditions, including simulated and live surgeries. The results showed that the TcAF system effectively reduced airborne contamination in the OR.

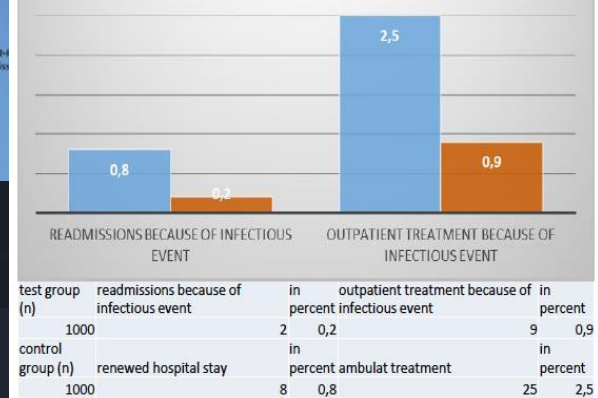
Results
The results of the study showed that the TcAF system significantly reduced the number of airborne particles in the OR, both during simulated and live surgeries. The system was found to be effective in maintaining a clean and controlled environment.

Conclusion
The study demonstrated the effectiveness of the TcAF system in reducing airborne contamination in the OR. This technology should be widely adopted to improve patient safety and reduce the risk of surgical site infections.

CURRENT DIRECTIONS IN BIOMEDICAL ENGINEERING

JOINT JOURNAL OF THE GERMAN SOCIETY FOR BIOMEDICAL ENGINEERING IN VDE AND THE AUSTRIAN AND SWISS SOCIETIES FOR BIOMEDICAL ENGINEERING

Decrease in outcome (Postoperative infectious events)





How do you evaluate the different ventilation alternatives on the market today?

What is ultraclean really?
Can they prove it?

How do you know?
Independent validation or
manufacturers' claims?





UR Medicine's new Center for Orthopaedics and Physical Performance

Univ. of Rochester Advancement



University of Rochester Medical Center *Orthopedics & Physical Performance Center*

Selection and assessment process



- A new facility with an opportunity to consider different approaches to design.
- Recognition of EU standards and different approaches in addressing microbial contamination and system design.
- Early exposure to the physics of temperature-controlled airflow ventilation. This was logical to everyone involved.
- Demonstrated differences in ventilation technology.

Why TcAF?



- Lower CFU measurements with TcAF ventilation technology.
- ISO 8 vs. ISO 6 measurements at rest.
- Reviews of reputable studies and “owner” recommendations.
- Over 300 verified installs and 900+ Microbial measurements.
- Quicker delivery of system components with superior “upfront” product engineering support.

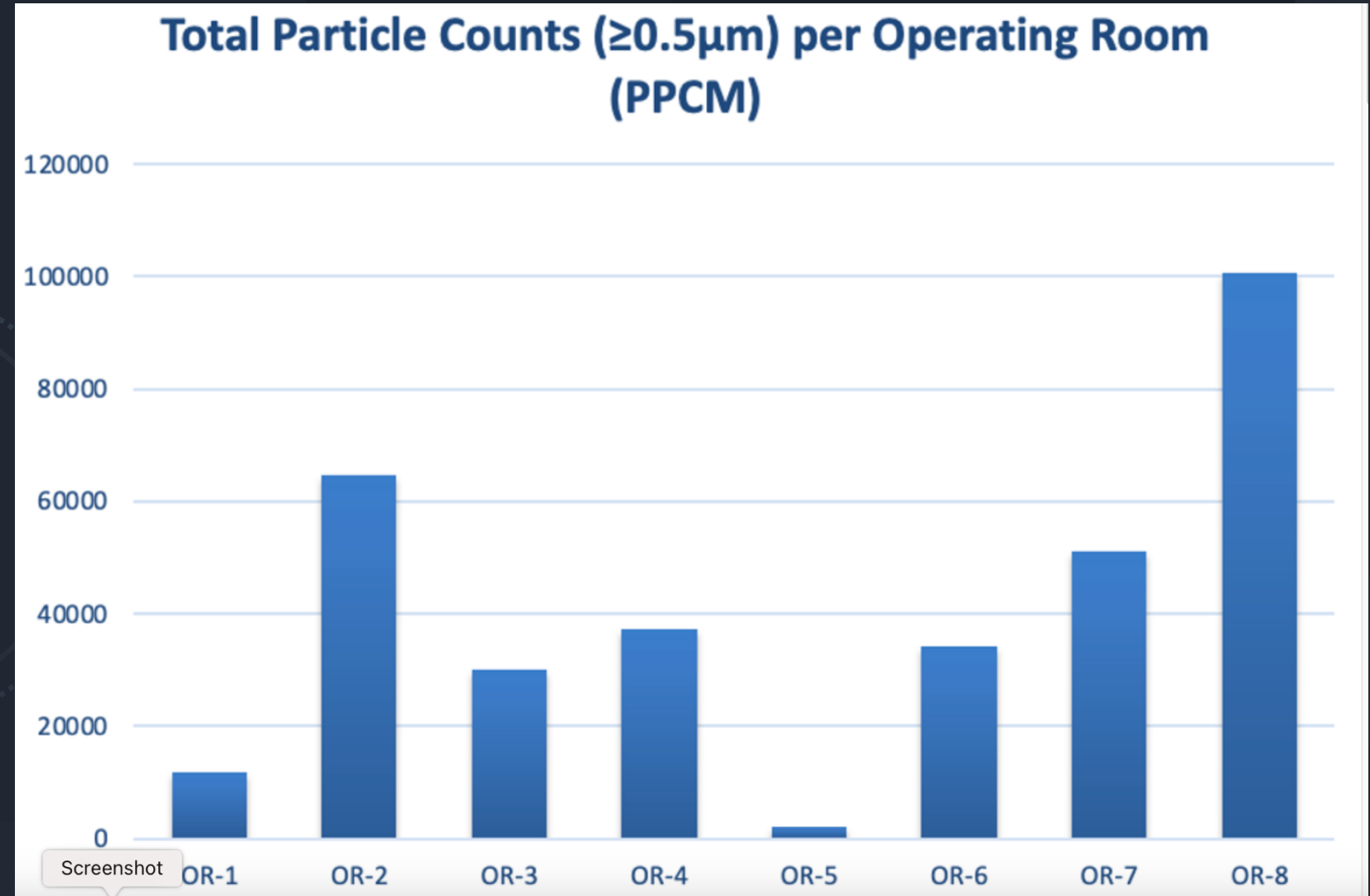
TcAF installation at URMC OR 5



Particle testing of new operating rooms



- 8 newly constructed rooms, OR 5 with TcAF
- Rooms were “broom cleaned” only prior to testing.
- Significantly lower counts in OR 5.
- “A testament to the physics of the design.”

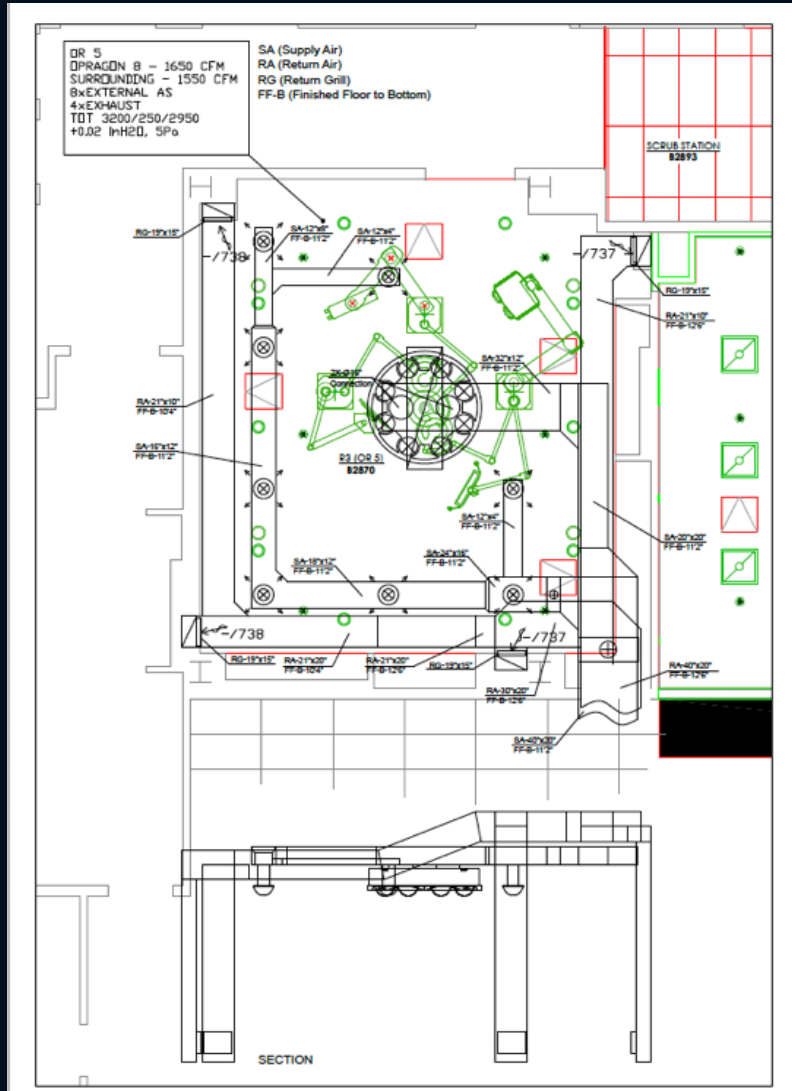




OR 5

**Orthopedics &
Physical
Performance
Center**

Strong Memorial Retrofit



ASHRAE 170 Perspective

- ASHRAE 170 does *not* dictate methods for design or prohibit design methods.
- As an American National Standards organization, ASHRAE does not “approve” products. As such, the 170 Committee is not permitted to make an official statement regarding the Opragon (TcAF).
- **4.4 Alternate Materials, Methods of Construction, or Design**
The provisions of this standard are not intended to prevent the use of any material, method of construction, design, or building system not specifically prescribed herein, provided that such construction, design, or building system has been approved by the AHJ as meeting the intent of this standard.
- Ventilation Systems for surgery are listed in Section 7.4

TcAF compliance with ASHRAE 170

- The ASHRAE 170 OR Ventilation Subcommittee thoroughly reviewed the TcAF (Opragon) and *deemed it to be compliant*.
- The review process took place over the period of 2 years (2024-2025) during which additional independent studies were undertaken to investigate compliance with key parameters of the standard such as unidirectionality and velocity.

Robert D. Booth, MPH, CIH
Oncore, Inc.
ASHRAE 170 member

Site visit: June 13, 2025 to evaluate the Opragon (TcAF) in context of ASHRAE 170 requirements



TcAF meets the ASHRAE 170 engineering parameters for OR ventilation

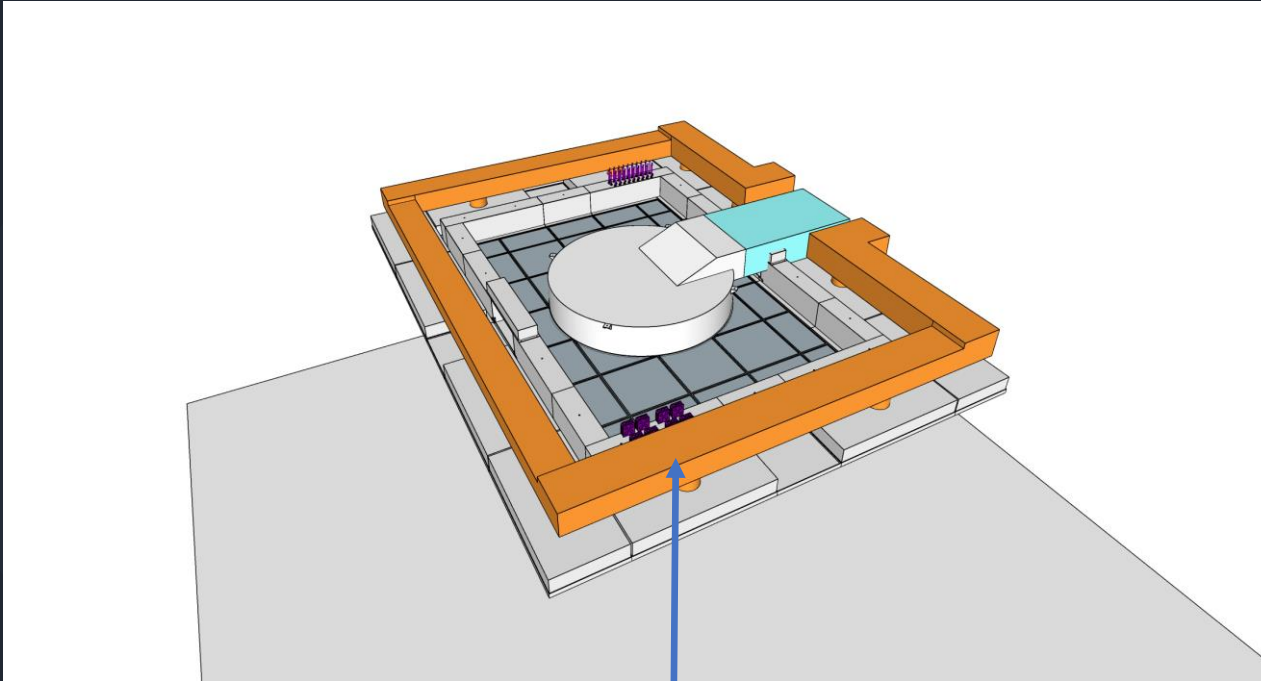
- **Positive pressure:** Prevents airflow from contaminated areas into adjacent areas
- **Direction:** Consistent, perpendicular, downward flow (unidirectional)
- **Velocity:** Driven at speed that ensures
 - Uni-directionality
 - High enough to overcome, obstacles and heat convection
 - Minimize turbulence

Several members of the OR Ventilation Subcommittee are available upon request to answer compliance related questions.

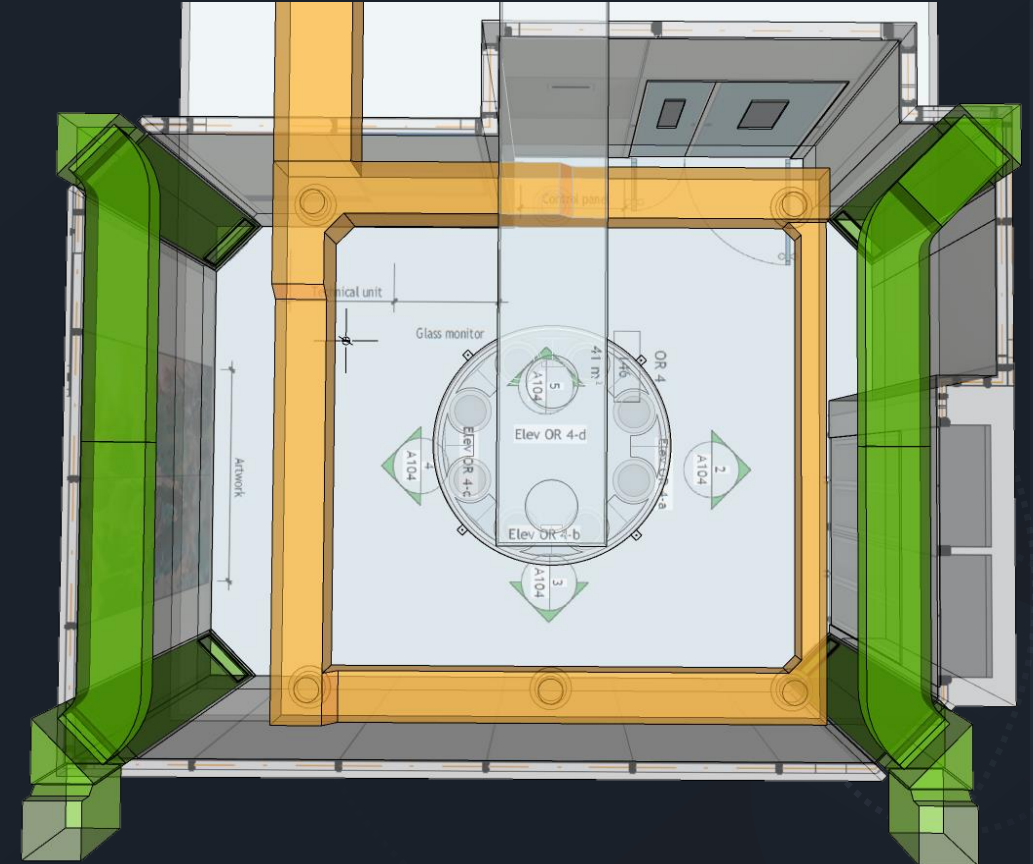


TcAF Design and Configuration

Sample designs: Standard OR



Additional duct work



Hybrid configurations

- Numerous hybrid installations with leading imaging companies
- Combines state of the art imaging with the safety of ultraclean air throughout the space



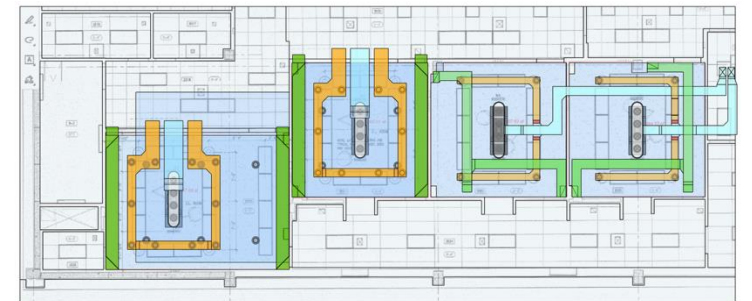
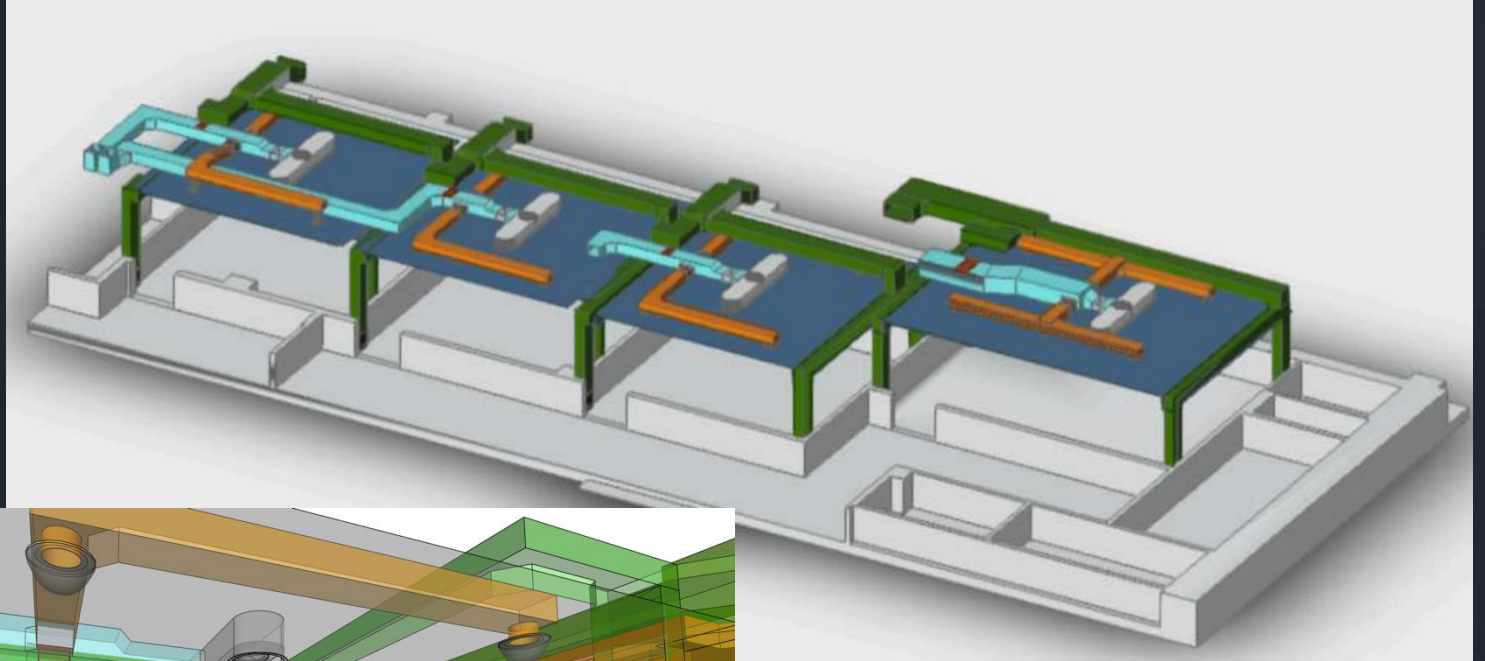
Flexible design for congested hybrid ceilings



Flexible design for difficult retrofits

Bonner General Health Retrofit Sandpoint, Idaho

- 4 small ORs, 450-500 sq ft
- Constraints required design with fewer diffusers than standard design
- Demonstrates flexibility of design
- Construction 2026



Beyond the OR: Flexible configuration enables installation in any location where minimizing airborne contamination is a priority



Figure 1: C

Operating Room Configurations



Hybrid OR



Surgical Prep



Sterile Processing Dept.



Radiology



Pharmaceutical Laboratory

Global movement to performance-based standards

Country	CFU Limits	ISO Clean Room	Document	Comments
Australia	Class 6, ISO 14644-1	ISO Class 6	ANZ/NZS ISO 14644-1	
Sweden	≤10 CFU/m³ for procedures utilizing implants	TcAF designed to meet most rigorous standards	Standards Institute Teknisk Specification SIS-TS 39	
Netherlands	≤10 CFU/m³ for procedures utilizing implants			Mean value of ≤5 CFU/m ³ targeted, to ensure ≤10 CFU/m ³
Germany	Recommended <4 CFU/m ³ , limit of <10 CFU/m ³		Standard DIN 1946-4-2008 Standard VD 2167	3 classes of rooms
Switzerland	<10, 50 & 200/CFU/m ³ depending on risk			3 classes of rooms by risk
France	≤20 CFU/m ³		NF S 90-351	2 classes of rooms
UK	≤35CFU/m ³ rooms at rest, <10 for ultraclean rooms, not to exceed 180CFU/m ³ for more than 5 min		British Standard 52-95-1	
Wales	<10 CFU/m ³		HTM 03-1	
Italy	<180 CFU/m ³		ISPESL 2010	
Russia	<5 CFU/m ¹ at OT, <20 CFU/m ¹ periphery		GOST R 52539	5 classes of rooms including CFU limitations in ED
South Africa		Class 5, ISO 14644-1	Design of mechanical installations (Core Standards 2006)	

What we covered

- The risk factors associated with airborne microbial contamination in the operating room.
- The physics of temperature-controlled airflow ventilation.
- The differences in design and performance among different ventilation alternatives.
- One institution's process of assessing a novel ventilation technology.
- Compliance of TcAF with ASHRAE 170.



QUESTIONS



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