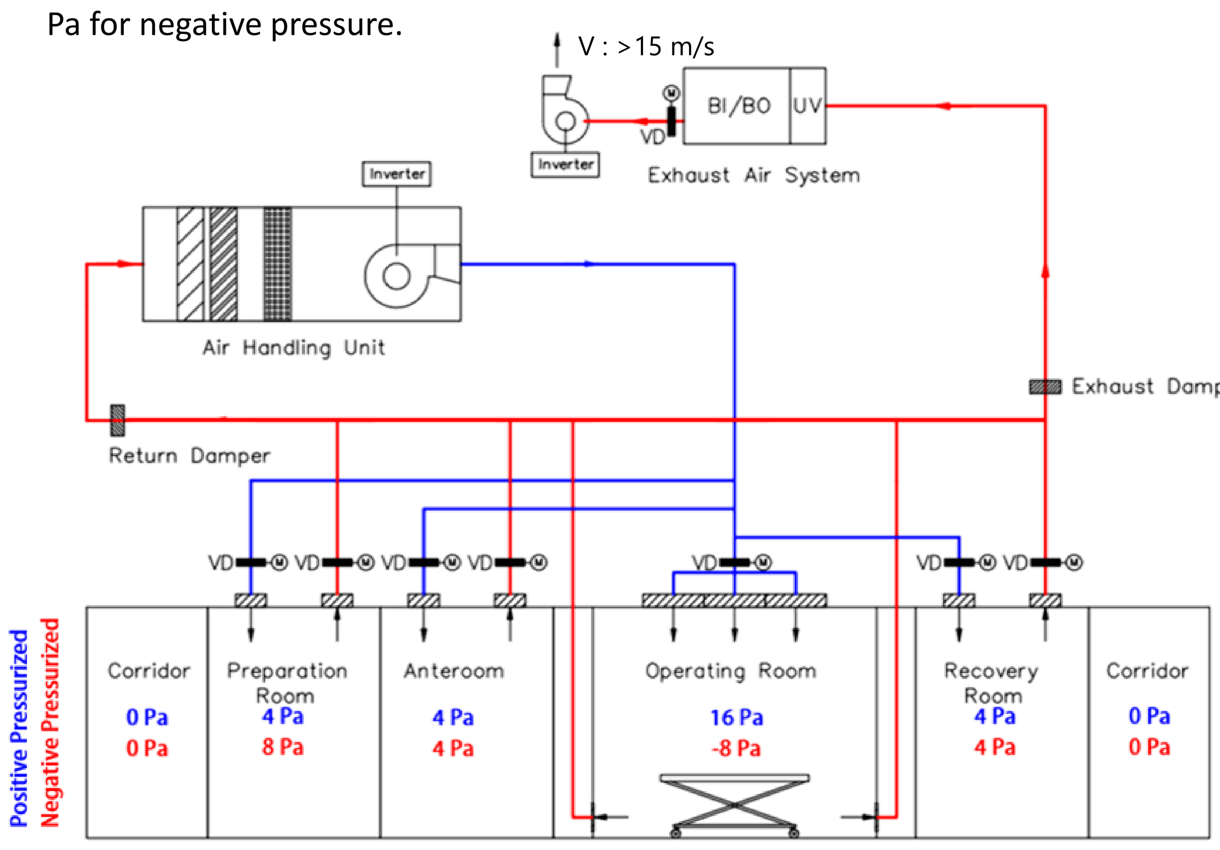
Performance Investigation of a Novel Positive and Negative Pressurized Operating Room for Infection Control

INTRODUCTION

The operating room is generally categorized as a positive pressurized bio-cleanroom that ensures a critical environment for thermal comfort and infection control concerns. However, the coronavirus disease 2019 (COVID-19) outbreak necessitates the construction of a negative pressurized operating room specific for contagious patients. The heating, ventilation, and air conditioning (HVAC) system has been conducted to meet the dual function of the positive and negative pressurized operating room. Filtration, pressurization, and dilution are implemented in the HVAC system for this operating room. Field measurements also have been conducted comprehensively to validate the simulation results. Computational Fluid Dynamics (CFD) simulation was conducted to simulate and compare the air distribution between the positive and negative pressurized operating room and its ability to remove the airborne contaminants. Air curtain was added to enhance the design improvement for contamination control and its ability to remove airborne particles. The performance of contamination control can be comprehensively evaluated by the distribution of airflow and the concentration profile under different air curtain velocities.

SYSTEM DESCRIPTION

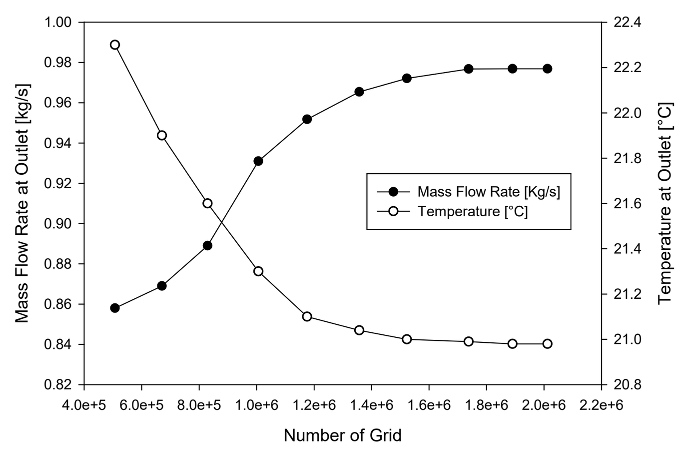
According to ISO 14644-1, there are 2 categories of cleanroom classes. The operating room is classified as class 10,000 (ISO class 7), while the preparation room, anteroom, and recovery room are classified as class 100,000 (ISO class 8). Specified design conditions are temperature 22±2°C, relative humidity 30-60%, and pressurization 16 Pa for positive pressure, -8 Pa for negative pressure.



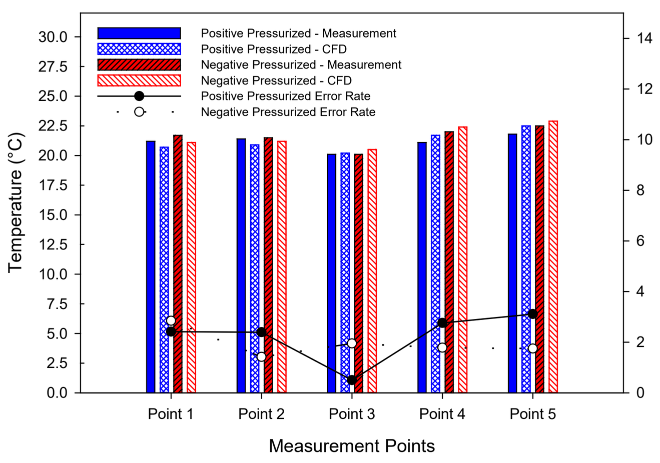
METHODOLOGY

Field Measurement Test

Grid Independence Test & Validation



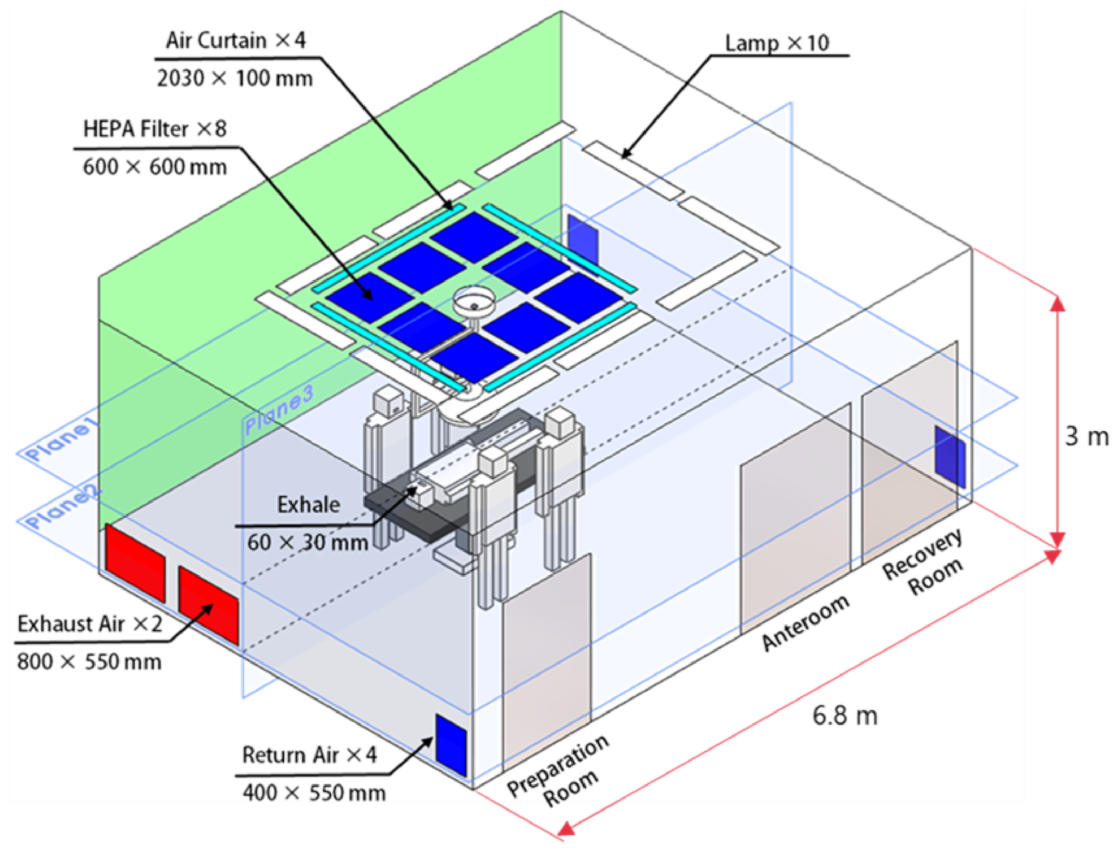
Grid Independence Test
The mass flow rate (kg/s) and temperature at the outlet in the operating room are chosen to assess the number of grids. A total of 10 grids are selected for comparison to verify the accuracy of the simulation. The grid number of 1,787,762 was chosen as a follow-up numerical simulation.



Validation
Validation requires the estimation process for error, and uncertainty must occur on both sides, field measurement test and numerical simulation. This process does not assume that the field measurements are more accurate than the computational results but only asserts that the experimental measurements are the most faithful reflections of reality for validation.

CFD Simulation & Improvement Strategy

The CFD simulation was performed by using the Ansys Fluent, Workbench 2020 R2. The full-scale geometry of the investigated operating room was created based on the actual size and situation of the operating room. The study also aims to investigate the performance of the positive and negative pressurized operating room for infection control in order to prevent bacteria or even fungi from entering the patient's body undergoing the surgical process. In addition, enhancing airflow patterns and surgical site infection is essential to protect the surgeon from the contagious patient and the patient from the contaminant. Air curtain around the HEPA filters coverage with different velocities (0.50 m/s, 0.75 m/s, and 1.0 m/s) is implemented to investigate the performance improvement of the airflow distribution and contamination control.

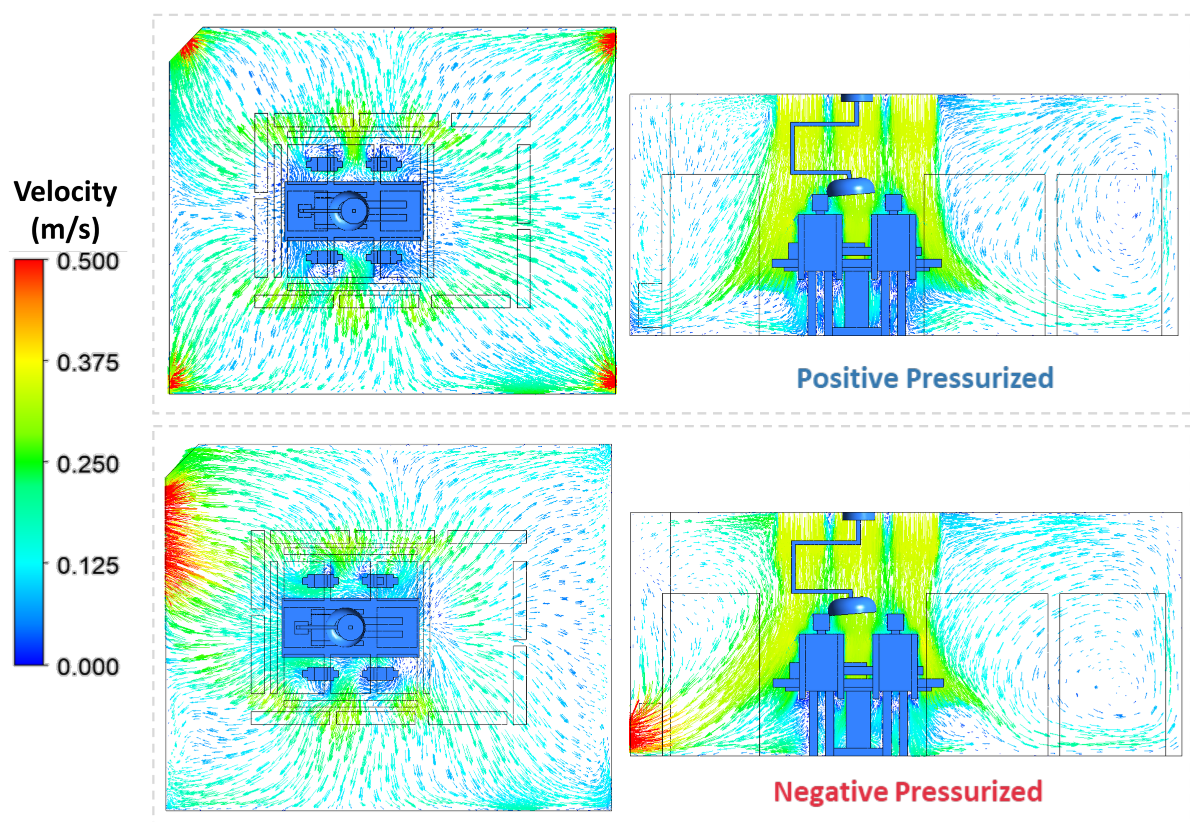


Boundary Conditions

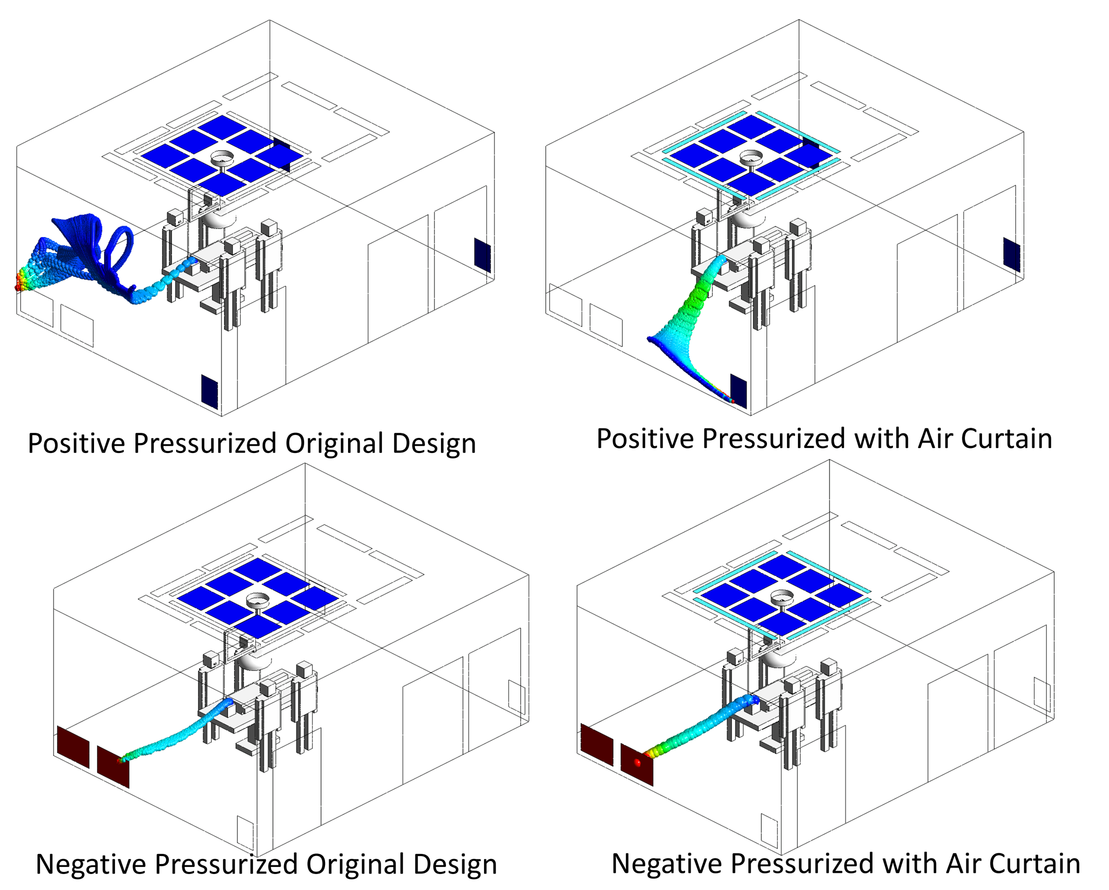
Parameters	Type	Value
HEPA	Velocity Inlet	Velocity: 0.245 m/s Temperature: 18.6°C Concentration: 400 ppm
Return Air	Pressure Outlet	Pressure: 16 Pa
Exhaust Air	Pressure Outlet	Pressure: - 8 Pa
Air Curtain	Velocity Inlet	Velocity: 0.5 m/s; 0.75 m/s; 1.0 m/s Concentration: 400 ppm
Exhaled	Velocity Inlet	Velocity: 0.17 m/s CO_2: 38,000 ppm
Surgeon [19]	Wall	Heat flux: 33.55 W/m²
Patient [19]	Wall	Heat flux: 17.45 W/m²
General Lighting	Wall	Heat Flux: 288 W/m²
Operating Lighting	Wall	Heat Flux: 320 W/m²

RESULTS & DISCUSSION

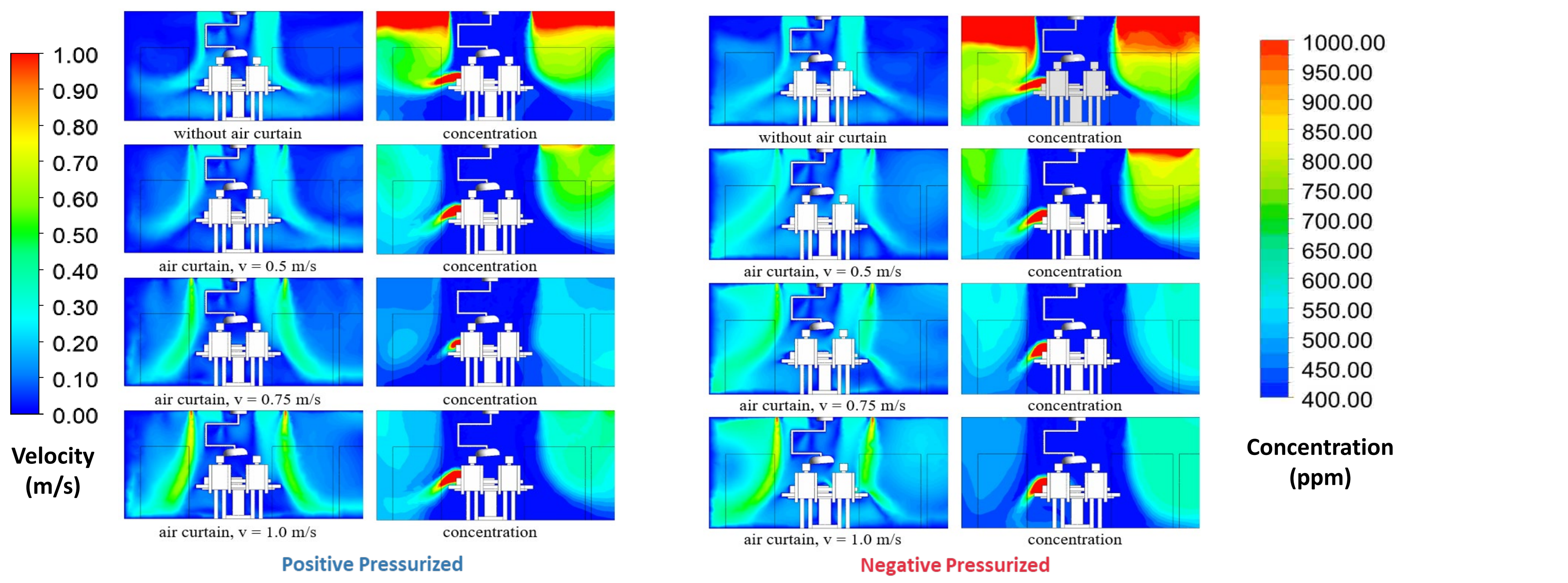
Airflow Distribution



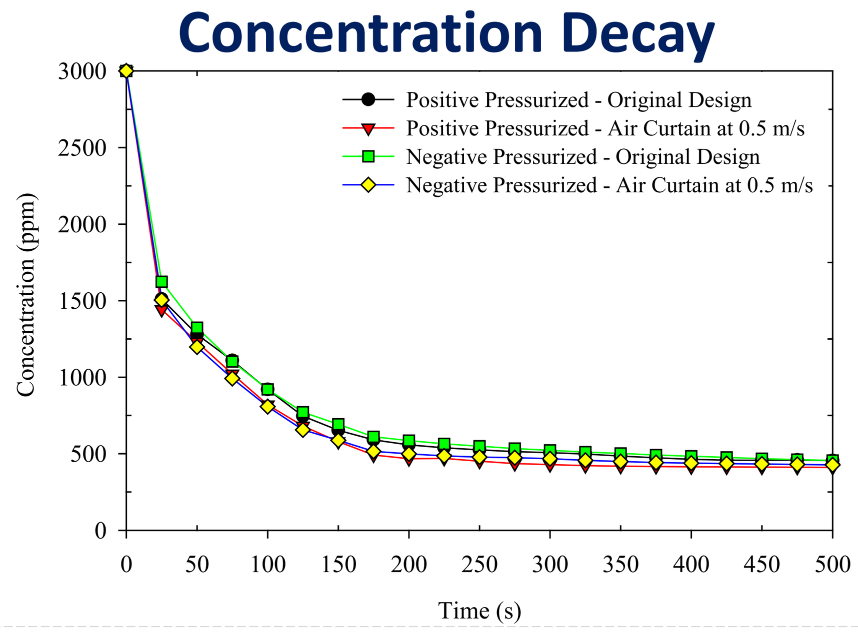
Flow Path of Airborne Contaminants



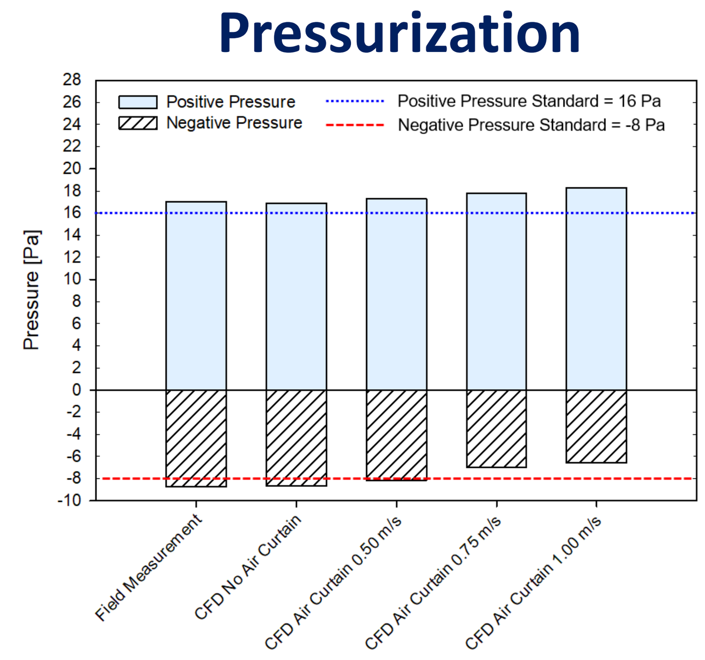
Concentration Distribution



Concentration Decay



Pressurization



Ventilation Efficiency

Case Study		Concentration Average (ppm)	Ventilation Efficiency (%)
Positive Pressurized	Original Design	455	82.91
	Air Curtain 0.50 m/s	411	92.73
	Air Curtain 0.75 m/s	404	95.15
	Air Curtain 1.00 m/s	408	93.75
Negative Pressurized	Original Design	467	80.60
	Air Curtain 0.50 m/s	427	90.74
	Air Curtain 0.75 m/s	414	94.29
	Air Curtain 1.00 m/s	421	92.86

CONCLUSION

The positive pressurized operating room has a better airflow pattern in removing overall concentration because of the arrangement of the outlet air in a four-way corner. However, the negative pressurized effectively removes airborne infection and prevents transmission to other rooms or personnel. The exhaust air grilles behind the operating bed make contaminants easily dilute and remove. The air curtains around the HEPA filter can improve airflow pattern distribution, contamination control, and ventilation efficiency by around 10% both on the positive and negative pressurized operating room. The air curtain velocity at 0.5 m/s could be implemented because it could conform to the design requirements. Thus, the improvement by adding the air curtain was feasible to reduce contamination levels inside the operating room.

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ASHRAE HVAC&R STUDENT COMPETITION 2022