APPLICATION BRIEF

Modular Negative Pressure Isolation Room Design

Novel coronavirus infections are spreading quickly with each passing day. This is putting an enormous strain on healthcare infrastructures around the world, with no proven treatment in sight. There is an immediate need for easy-to-manufacture testing and isolation rooms in regions with high population densities, to prepare for a worst-case community spread scenario.

As defined by ASHRAE guidelines,[1,2] negative pressure rooms and booths are used for preventing airborne transmission of respiratory diseases in hospitals. In a negative pressure room, a mechanical ventilation system creates an operating pressure lower than the surrounding region so that there is no significant leakage of the contaminated air. Ansys Fluent computational fluid dynamics (CFD) software can be used to design a modular negative pressure room that is also easy to manufacture.

For this study, engineers created and evaluated several ventilation design concepts to identify the most effective for removing contaminated air from the isolation room and best selection for physical prototyping.

Products Used:

Ansys Fluent
Ansys SpaceClaim
Ansys VRXPERIENCE

/ Challenges

Scalable testing and isolation infrastructure are required for regions with higher population density during the community spread phase of COVID-19. A well-designed, negative pressure room, as per ASHRAE/ASHE Standard 170-2017,[1,2] and the ventilation of healthcare facilities require expensive infrastructure. These can place an enormous financial burden on the healthcare system and are difficult to build overnight. Consequently, and in light of stay-in-place virus mitigation efforts, the only feasible solution mandates the use of locally sourced materials and a quick-to-build negative pressure room design.

/ Solution

Airborne infection isolation rooms (negative pressure rooms) prevent patient-released pathogens from escaping. In this study, the construction material and basic design were inspired by the telephone-booth-style negative pressure rooms designed for mass-scale testing by South Korea.[3]

ANSI/ASHRAE/ASHE Standard 170-2008[1,2] recommends having at least 12-times air change per hour (ACH) for hospital applications, to facilitate effective ventilation.

All the ventilated air is passed through a HEPA filter to remove 95% to 99% of the contaminants before they are released to the outside ambient air. A centrifugal blower with backward-facing blades is generally used downstream of this ventilation system to create the required negative/suction pressure.

Using Ansys SpaceClaim, engineers built a CAD model that includes a patient lying on a bed in a 9 ft x 9 ft x 8 ft room. Based on research and CFD based-design optimization, the exhaust ventilation duct was placed on the wall right above the patient's head and the inlet vent was positioned in such a way that ventilation air directly sweeps the patient's head and trunk regions, and moves to the ventilation outlet. This ventilation design avoids recirculation of the contaminants in the room and makes the room safer for the medical staff and other occupants. The minimum flow rate required for 12 ACH is approximately 130 CFM for a room volume of 648 cubic feet.

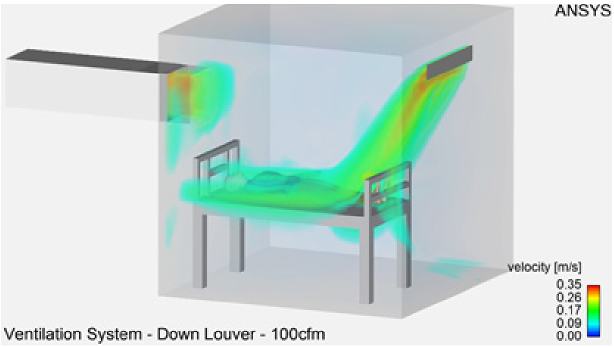

Figure 1: Computational domain and flow conditions for the CFD modeling

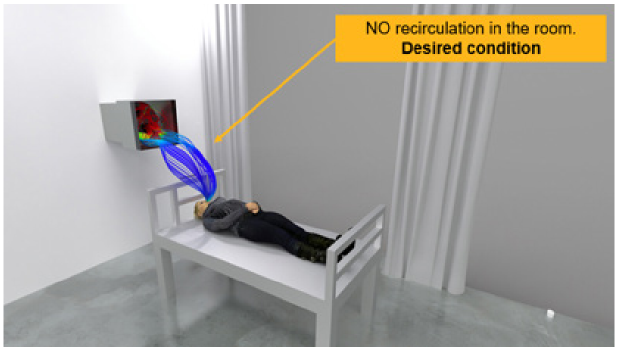

Figure 2: CFD predictions for recommended ventilation system design

Engineers meshed the model using Ansys Fluent, and prepared a CFD model by defining the floor, door and sidewalls as no-slip walls, and the outlet boundary as pressure outlets open to the atmosphere. The inlet boundary was defined as a pressure inlet open to the atmosphere and the inlet direction was set in accordance with 45-degree louver at the inlet duct. The fan was modeled using a Markov random field (MRF) model to create the required suction. The pressure drop across the HEPA filter was modeled using the porous media model.

In the simulation, massless pathlines were generated with a velocity of around 1 m/sec to compute the flow of the expelled gases from the patient's mouth. Research has shown that expelled gas velocity of around 1 m/sec from the patient nose/mouth region is a good representative value for designing a ventilation system in a negative pressure room.[4] The computational domain and flow conditions are shown in Figure 1.

The massless particle trajectories from the patient's mouth region were rendered using Ansys VRXPERIENCE, as shown in Figure 2. The massless particle trajectories are directly ventilated outside without any recirculation in the room. This shows that the combination of a flow rate in excess of 100 CFM and a 45-degree downward draft angle is recommended.

Summary

CFD simulations help with predicting and visualizing the effectiveness of a ventilation system design for a given room and patient configuration. They demonstrate the importance of optimizing flow rates, flow angles, inlet and outlet vent sizes, layouts, and fan and filter selection in the development of negative pressure isolation rooms.

References

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2. Khankari, Kishor. "Patient Room HVAC." ASHRAE Journal, Vol. 58 (6), 2016.
3. South Korean Hospital's 'Phone Booth' Coronavirus Tests
4. Airflow and AII Rooms: Why Supply and Exhaust Location Matters

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Disclaimers
These simulations were designed to replicate physical behaviors under specific circumstances. They should not be considered medical guidance and do not account for environmental variants, such as wind or humidity.