INSIGHTS

Ceiling Airflow Containment and Control

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The movement of air within a space for the purpose of heating, cooling and ventilation is fundamental to the design of modern buildings.

The HVAC design of many spaces, such as hospitals, cleanrooms, areas housing sensitive equipment, senior living spaces, occupational nurses' suites, locker rooms, etc., also needs to control how air cascades through (sequences) the different rooms. The objective is to prevent cross contamination into sensitive areas. Awareness of how air moves within and between spaces is also increasing as designs look to react to the COVID-19 pandemic and prepare for the possibility of future ones and in general create healthier spaces overall. One of the methods designers use to control how air cascades between rooms and spaces is pressurization. This involves providing excess air in some spaces and a deficit in others. This pressurization, however, can create other pathways for air to travel which may not be intended such as through walls and ceilings, potentially into shared plenums and via corridors. The degree of "pressurization flow" achieved will depend on the finishes of the space including doors, ceiling tiles, wall construction etc. as well as the amount of excess or deficit air provided: e.g. the degree of pressurization of the space. The cascade air pathway will largely be dictated, but not always controlled by, the mechanical design. Air will take the easiest path to its destination. Flow will go from a high pressure zone to

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low pressure zone in a building via the route resulting in the lowest pressure loss. Therefore, while the mechanical design might assume one flow path, the air may take another.

Given that the cascade of air is important, it is useful to be confident in how that air travels from high to low pressure zones. Despite the lack of control and uncertainty described above, we can estimate that portion of the pressurization flow that exits any space via the different paths. Those paths include doors, walls and the ceiling. This means that if one pressurizes one room, with the objective that the air cascades through the door to the adjacent zone at a certain rate, it is possible to analyze the pressures and flows to confirm that the objective is achieved. This then permits one to determine how much of the excess pressurization air delivered to a space may exit via the door, ceiling or walls. It is likely that if one were to ask a mechanical designer if they thought controlling the flow cascade was a good idea for a sensitive space, they would say yes and that in fact it is practice. This then means that it is useful to understand and control unintentional flows through boundaries that are not intended to be flow pathways. This paper aims to demonstrate how improved ceiling tile construction and ceiling systems can lead to better pressure cascade via different levels of air tightness.

Building Pressurization

Ventilation systems can provide positive or negative pressurization by balancing the relative amount of air supplied versus the amount exhausted and / or returned from the space. For a positively pressurized room (Figure 1) more air is supplied than leaves. The excess air having nowhere to go, pushes on the interior of the space and the pressure in the room builds up until air begins to leak out through the ceilings, walls, under the doors, around windows and through fixtures such as lights, sprinkler piping, ductwork , conduit, etc. The opposite effects occur in a negatively pressurized space, where less air is supplied than exhausted or returned. This will decrease the pressure in the room and the exhaust system will pull on the interior of the room until air begins to leak in from the adjacent zones.

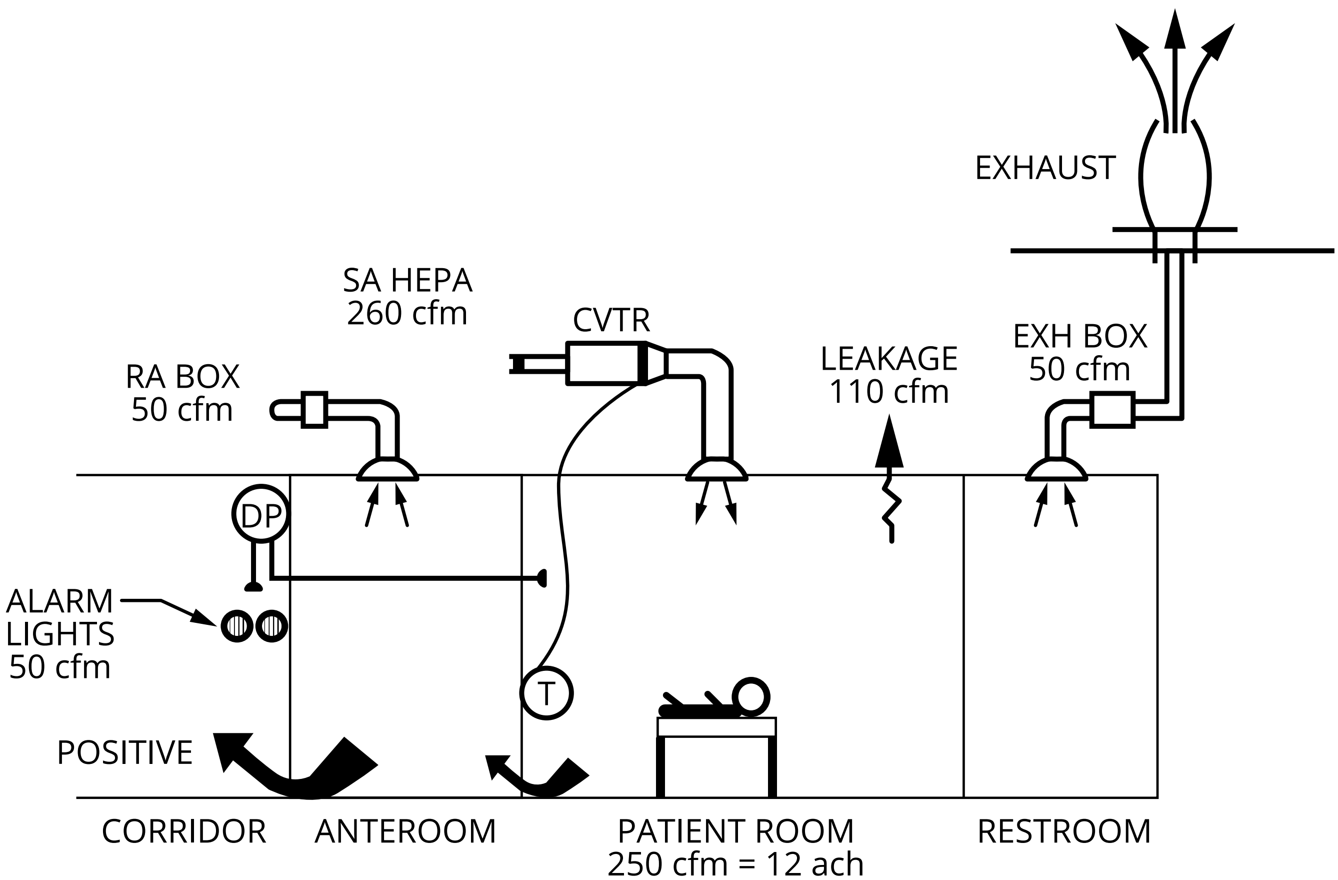

Figure 1 – Positively pressurized patient room (ASHRAE HVAC Applications 2019), supply air 250 cfm, return 50 cfm, exhaust 50 cfm, leakage to corridor 50 cfm, leakage out of room 110 cfm.

There are many different types of spaces where pressurization is required, and many more where it could be helpful. They include, clean rooms, hospitals (protective environment rooms and isolation rooms), labs, senior living spaces, occupational nurses' suites, locker rooms, manufacturing control rooms, etc. In certain climates, pressurization is used to reduce infiltration in buildings to avoid moisture problems. Pressurization in a building is useful because it gives designers a way of controlling the direction of airflow and creating an additional layer of separation. Generally, pressurization is cascaded from areas required to be clean (positive) to those that may be contaminated (negative) (Figure 2). For example, an electronic clean room that has highly sensitive equipment would be positively pressurized, whereas an underground parking garage would be negatively pressurized. In a hospital setting air would flow from protective environments (positive) where vulnerable patients are located to airborne isolation rooms (negative) where an infectious person would be located.

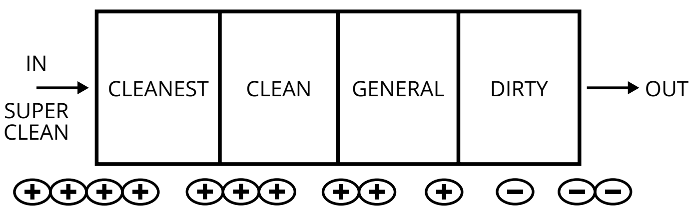

Figure 2 - Controlling Air Movement through Pressurization (ASHRAE HVAC Applications 2019)

Ideally the excess flow required to pressurize a space would be kept to a minimum. This is because more flow means, larger fans, bigger systems and more energy consumed heating / cooling and conditioning the excess air. If that excess air can be reduced, whilst achieving the pressurization and flow requirements, then energy is saved and potentially capital costs too.

The area under and around doors, small cracks around windows, small gaps or imperfections in the envelope and internal partitions, and other flow paths for the air contribute to the amount of pressurization flows. Generally speaking, the leakier an envelope around a space, the harder it is to pressurize that space. Another consequence of pressurizing a space is that there may be parasitic losses or flows that travel to unintended parts of the building, a shared plenum or corridor for example. With the current heightened awareness around the spread of infectious disease, it seems that limiting this potential spread would be beneficial, even if that benefit is not easily quantifiable.

Low leakage Ceilings

Ceiling tiles are used in most designs of public spaces when there is a desire to hide the space above suspended ceilings where ducts, piping, or other fixtures are found whilst providing convenient access to the space above. These ceiling tiles make up the leakage plane between the occupied space and the plenum above. Other elements in the ceiling plane such as lights, grills, sprinklers, etc. contribute to that overall leakage. However, the ceiling tiles present the largest surface area for potential leakage in the ceiling plane. This study was conducted to assess whether there was a beneficial impact to reducing the leakage at the ceiling plane and therefore the benefit of providing a means to decrease the leakage through the tiles by increasing the tile seal performance.

Analysis

To investigate the pressure and flow rates induced by the space pressurization, a detailed numerical tool was used. In the tool, each room or subzone within a space is modeled as a node joined by resistance to airflow across building elements (i.e., building envelope, interior partitions, doors, and ceilings). Each flow path type was represented in the model including doors, overall leakage through different construction types, gaps around sprinklers, etc. The numerical modeling tool employed in this study uses the CONTAMW solver by NIST to predict flow rates and pressures across each building element for the prescribed mechanical conditions.

Three space types were selected for the study. It should be noted that these spaces were studied in isolation and that the results presented here are demonstrative of the potential of low leakage ceilings, they may not be applicable to every design. Each design should be considered within the context of the rest of the building. The three spaces studied were an Airborne Infection Isolation room (AIIR) (Figure 3), a Protective Environment room (PER) (Figure 3), and series of adjacent rooms with ducted supply and un-ducted plenum return (Figure 4). Since the application is a health care office, the intention is to provide the plenum with an air cleaner in order to reduce the burden of potential contaminants heading towards the Air Handling Unit (AHU). However, as other industries look

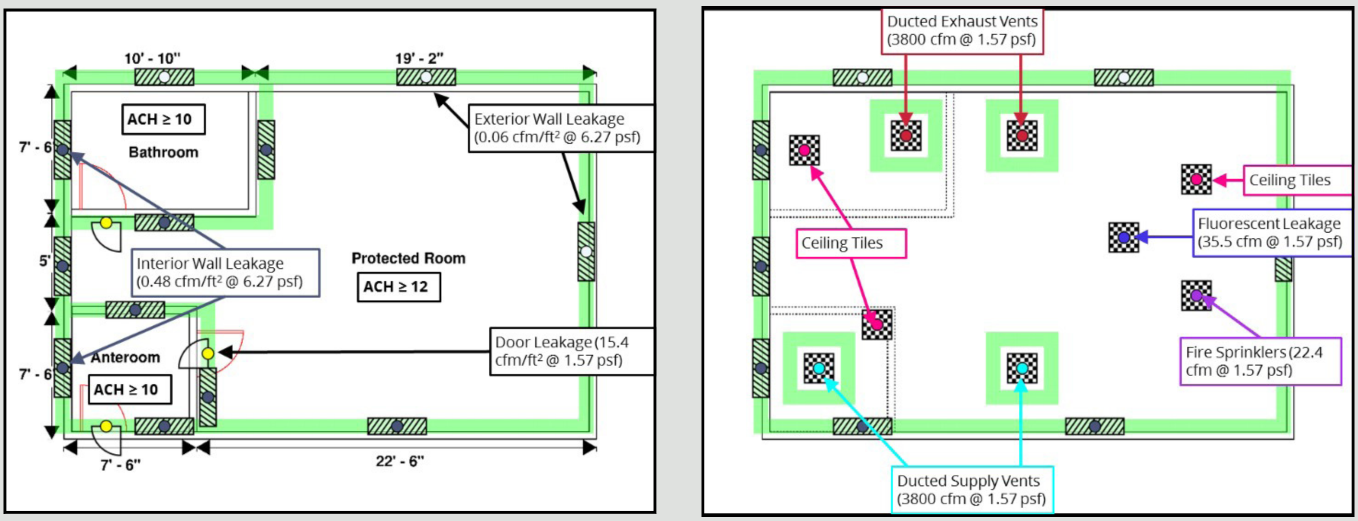

Figure 3 – Occupied Space within the Airborne Infection Isolation Room (AIIR) and Protective Environment Room (PER) (left) and their Ceiling Plenum (right)

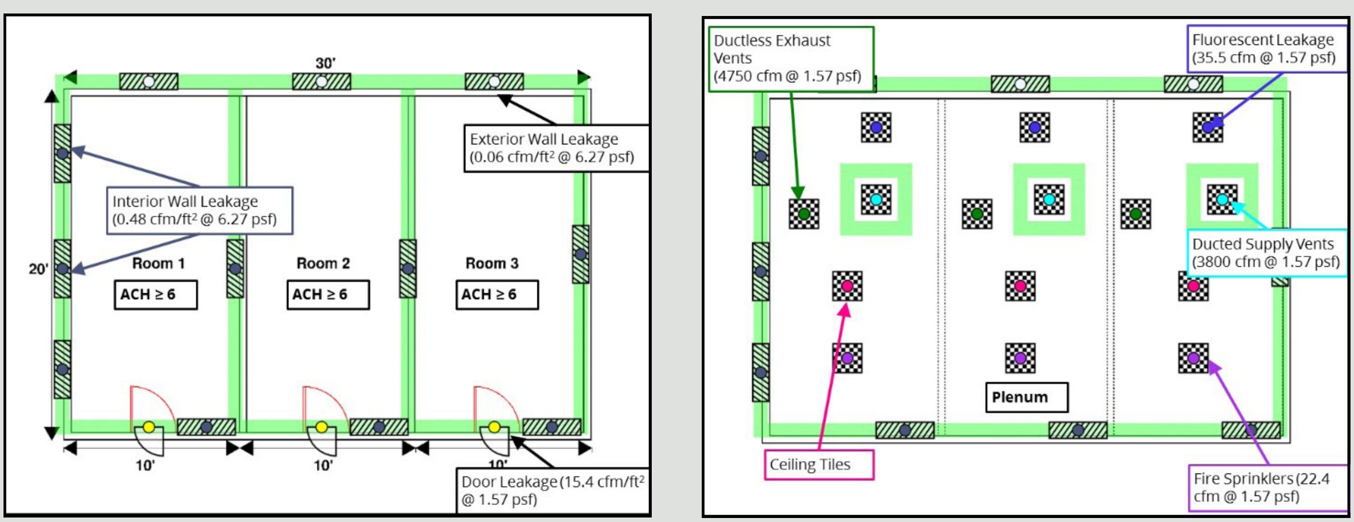

Figure 4 – Occupied Space for the Adjacent Rooms with Ducted Supply and Ductless Return (left) and Their Ceiling Plenum (right)

to healthcare for design guidance the ducted supply and un-ducted return configuration is also applicable to spaces such as nurse suites in schools or senior living facilities.

For both the AIIR and PER, the supply air and returns are ducted. However, above the patient room, washroom and the anteroom there is a shared plenum. Each isolation room was modeled as a 30’ x 20’ room with interior partitions found in a typical hospital design. The HVAC scheme applied to the AIIR and PER models were set to meet the requirements specified in ASHRAE Standard 170 –2017.

In each of the spaces, typical leakage values were used for the lights, walls, doors, sprinklers and room partitions. Leakage rates for six different ceiling tiles (Table 1) were tested, ranging from typical to low leakage ceiling tiles with gaskets, to see how the different ceiling tiles affected the pressurization performance of the spaces. All other leakage parameters were held constant. In the cases where the rooms required pressurization, the HVAC flow rates were adjusted to achieve that pressurization within a tolerance of 0.01 psf of the required value.

Table 1: Ceiling types studied and their leakage rates

Ceiling Type	Description	Leakage Rate @ 0.083 psf [cfm/ft^2]
Category 1 – Standard Ceiling Panel	Typical tile, No gasket	3.04
Category 3 – AirAssure Ceiling Panel	Low leakage tile, with gaskets	0.24
Category 3C – AirAssure Ceiling Panel + Clips	Low leakage tile with hold down clips, with gaskets	0.16

Study Results

The output of the AIIR and PER models show a range of different predicted results including: the variation in the flow through the ceiling; the HVAC flows required to meet code levels of pressurization; and the changes to the pressurization achieved in the room based on the type of ceiling tile used.

For the AIIR model the results show that as the ceiling is made tighter the flow rate through the ceiling tiles reduces (Table 2) which is an expected result. However, one of the findings is the path the air takes using the less tight

ceiling tiles (Category 1). Air travels out of the anteroom via the ceiling tiles through the plenum into the patient room and washroom, which from a design standpoint is not intended. This transfer of air via the ceiling plenum does introduce a risk of contaminants entering the ceiling void and potentially being drawn back out also.

Table 2: Summary of flow rates and pressure differences in the Airborne Infection Isolation Room (AIIR) per ceiling tile type

Ceiling Tile Type	HVAC Net Flow (cfm)	Parasitic Leakage Through Ceiling Tiles (cfm)	Pressure Difference Between Spaces ΔP (psf)
Category 1 – Standard Ceiling Panel	-65	-38	-0.056
Category 3 – AirAssure Ceiling Panel	-55	-8	-0.058
Category 3C – AirAssure Ceiling Panel with Clips	-55	-5	-0.06

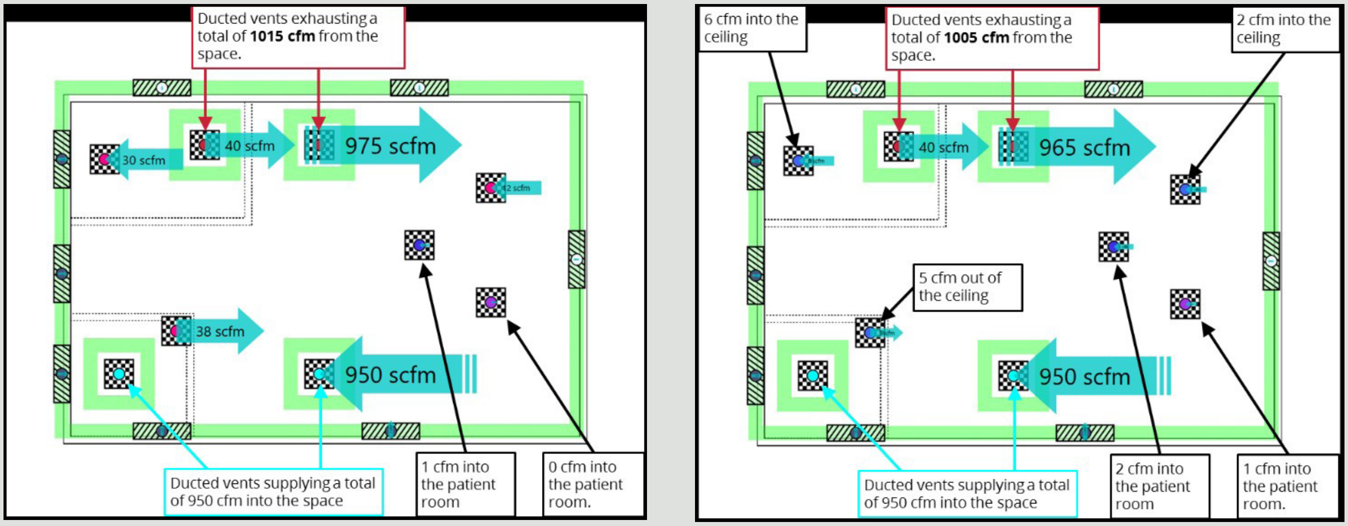

Figure 5 - Airborne Infection Isolation Room (AIIR) – Flow Rates Across the Ceiling – Category 1 – Standard Ceiling Panel (left) and Category 3C – AirAssure Ceiling Panel with Clips (right) – See Figure 3 for the Ceiling Plane Arrangement

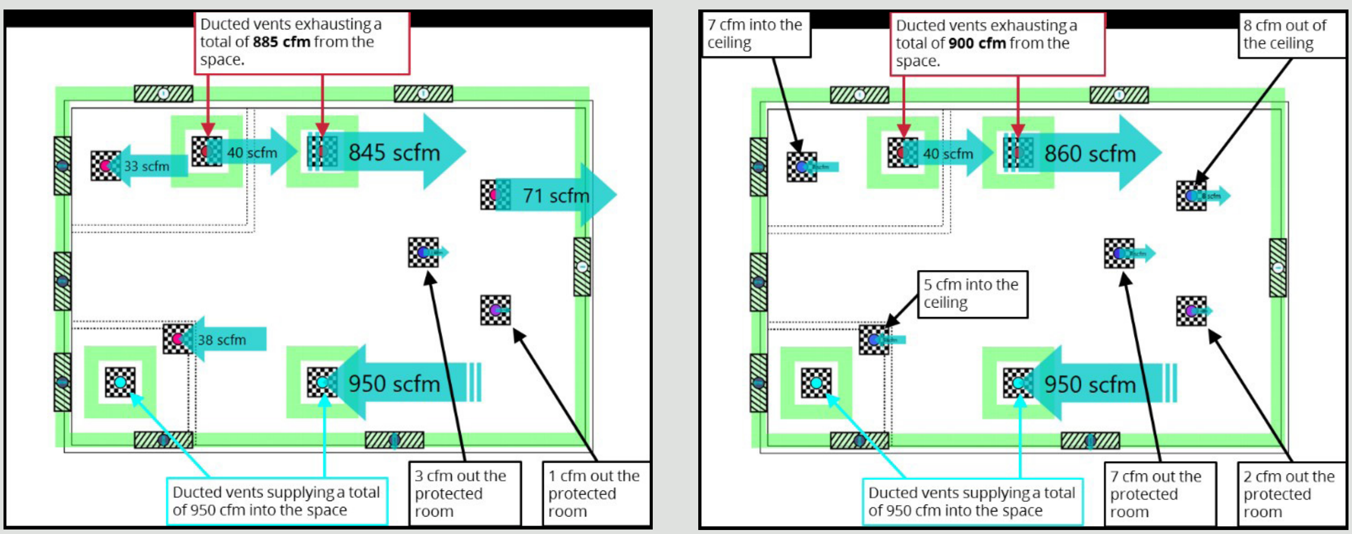

Figure 6 - Protective Environment Room (PER) – Flow Rates Across the Ceiling – Category 1 – Standard Ceiling (left) and Category 3C – AirAssure Ceiling Panel with Clips (right) – See Figure 3 for the Ceiling Plane Arrangement

With the tighter ceiling tiles (Category 3C) the airflow required to pressurize the space is reduced. The pressure in the room also increases which could justify reductions in the flow. Both the reduced ceiling leakage and mechanical flow rate results show the benefit of tightening the ceiling (Category 1 versus Category 3C) from a mechanical operation standpoint, i.e. reduced flows (ceiling league went from 38 cfm to 5 cfm) and easier pressurization (a reduction in 10 cfm HVAC flow). Figure 5 shows the flows through the AIIR for the Category 1 and 3C ceiling tile types as an example.

In the PER the results also show a reduction in the parasitic losses (71 cfm for Category 1 versus 8 cfm for Category 3C) with the tighter ceiling tiles as well as better control on the leakage paths. The leakage for the typical ceiling tiles (Category 1) are even greater compared to the corresponding AIIR leakage through the ceiling. This is because the air travels into both the washroom and the anteroom (Table 3) from the patient room via the plenum. Like the AIIR, the flows required to maintain pressurization are also reduced with the tighter ceiling (by 15 cfm). Figure 6 shows the flows through the PER for the Category 1 and 3C ceiling tile types as an example.

Table 3: Summary of flow rates and pressure differences in Protective Environment Room (PER) per tile type

Ceiling Tile Type	HVAC Net Flow (cfm)	Parasitic Leakage Through Ceiling Tiles (cfm)	Pressure Difference to Adjacent Room ΔP (psf)
Category 1 – Standard Ceiling Panel	65	-71	0.058
Category 3 – AirAssure Ceiling Panel	55	-12	0.06
Category 3C – AirAssure Ceiling Panel with Clips	50	-8	0.054

In the series of adjacent rooms with ducted supply and ductless return, there is no pressurization. However due to the ductless return there is an opportunity for air to bypass the return grilles (and filters if applicable) and leak through the ceiling into the shared plenum. The results show that the ceiling leakage flow decreases with the tighter ceiling tiles (Table 4). Figure 7 shows the flows through the PER for the Category 1 and 3C ceiling tile types as an example. In this case, the motivation for a tighter ceiling might be to ensure that air passes through the ceiling grille. For Category 1 about 68% of the flow went through the grille whereas for the Category 3C about 95% of the flow went through the grille.

Table 4: Summary of flow rates and pressure differences in the adjacent room with ducted supply and ductless return per tile type

Ceiling Tile Types	HVAC Net Flow (cfm)	Airflow Through Ceiling Tiles per Room (cfm)	Airflow Through Return Duct per Room (cfm)
Category 1 – Standard Ceiling Panel	0	-61	-136
Category 3 – AirAssure Ceiling Panel	0	-7	-189
Category 3C – AirAssure Ceiling Panel with Clips	0	-5	-191

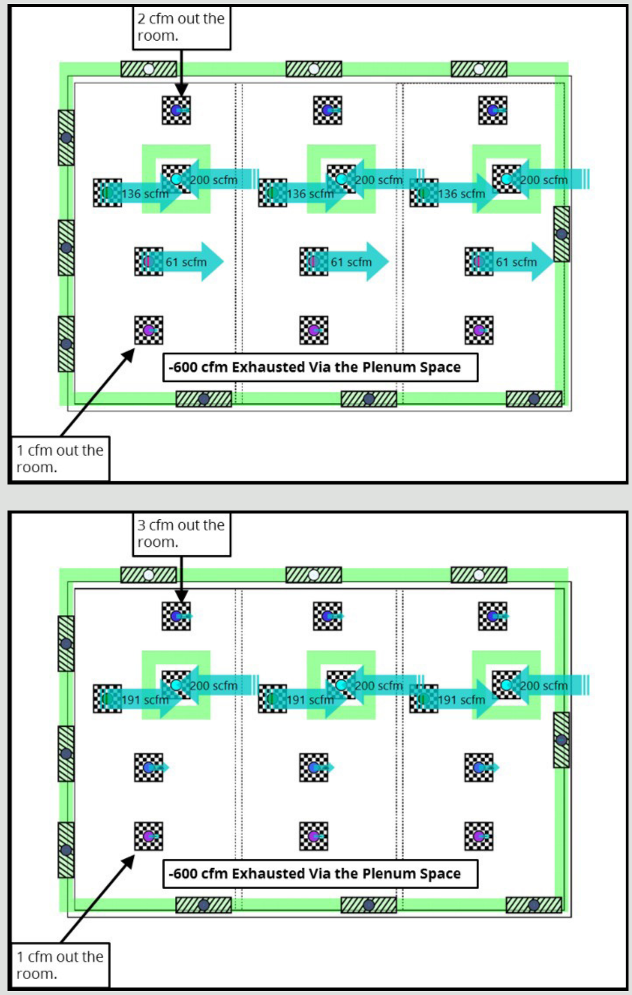

Figure 7 - Adjacent Rooms with Ducted Supply and Ductless Return – Category 1 – Standard Ceiling Panel (top) and Category 3C – AirAssure Ceiling Panel with Clips (bottom) - See Figure 4 for the Ceiling Plane Arrangement

Outcomes

Providing tighter ceiling tiles for the AIIR and PER should reduce the risk of parasitic leakage occurring through the ceiling plane. In the present study for the typical tiles (Category 1) air passed from one room to another via the ceiling tiles through the plenum and back into the occupied zone via the ceiling tiles. This leakage path was significantly reduced for the low leakage tiles (Category 3). Reducing this parasitic leakage will help keep partitioned spaces apart from a flow control perspective and reduce the risk of contaminants getting into the space above the ceiling and being drawn back later into the occupied zone. This is becoming of greater concern with the awareness of the spread of infectious disease in spaces like the COVID-19 virus.

The airtightness of the ceiling tiles is also expected to affect the net flow rates required to achieve target pressure differences between a room with special pressurization requirements and adjacent spaces. It is expected that providing tighter ceiling tiles will reduce the net flow requirements hence making pressurization more energy efficient. For the AIIR and PER scenarios studied, about 10 – 15 cfm of air was saved by utilizing tighter ceiling tiles. This 10-15 CFM represents a couple of percent of the total HVAC flow.

Providing tighter-fitting ceiling tiles for the adjacent rooms that share a ductless return is expected to reduce the air leaking into the exhaust plenum via the ceiling tiles, which means more of the exhausted air will go through the return vents instead. This improves flow control within the rooms making it easier to monitor and maintain the quality of air entering and leaving a room. This can be useful in multiple scenarios including cases when the air leaving a room needs to be cleaned before entering the plenum.

Overall, using tighter-fitting ceiling tiles with reliable, manufacturer applied gaskets (or seals) give the designer and operator more control and allows for spaces to function more easily in line with their intent. There is also the added benefit of using less energy and potentially smaller HVAC systems to serve the same purpose.

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