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FIRE CONSULTING

Leveraging Fire, Airflow & Egress Modeling to Assess the Impact of Open Doors on Stair Pressurization Systems

How Summit Fire Consulting demonstrated that simple and compensated stair pressurization systems performed equally well when considering doors opening and closing due to egress.

Stairwells are essential exit components that must be protected to allow for safe egress from a building. For high-rise buildings, which serve a floor more than 75 feet above the lowest level of fire department access, stairwells are required to be protected as smokeproof enclosures per International Building Code (IBC) 403.5.4. The objective of a smokeproof enclosure is to prevent the migration of smoke from the area surrounding the stairs into the stair enclosure. This can be accomplished through various methods, such as an outside balcony, ventilated vestibule, or stair pressurization. For the pressurization approach, IBC 909.20.5 requires that each stairwell be pressurized by mechanical fans to provide not less than 0.10 inch of water (25 Pa) and not more than 0.35 inches of water (87 Pa) in the shaft relative to the building measured with all interior exit stairway and ramp doors closed. The pressure differential creates a flow of air from inside the stair shaft to outside, thus preventing the flow of smoke from a fire floor into the stair shaft. The National Fire Protection Association (NFPA) 92, the Standard for Smoke Control Systems, requires a slightly reduced minimum pressure differential of 0.05 inch of water based on consideration of sprinkler-protected buildings. Pressure differentials are not required to be maintained at the open doors.

Summit Fire Consulting (SFC) presented a study to SFPE members that sought to understand how open doors impact the overall performance of stairwell pressurization systems. SFC's comprehensive fire, airflow and egress modeling provided actionable insights in the field of fire protection engineering and the framework for developing a more capable and reliable stairwell pressurization system.

ABOUT

SOCIETY OF FIRE PROTECTION ENGINEERS (SFPE)

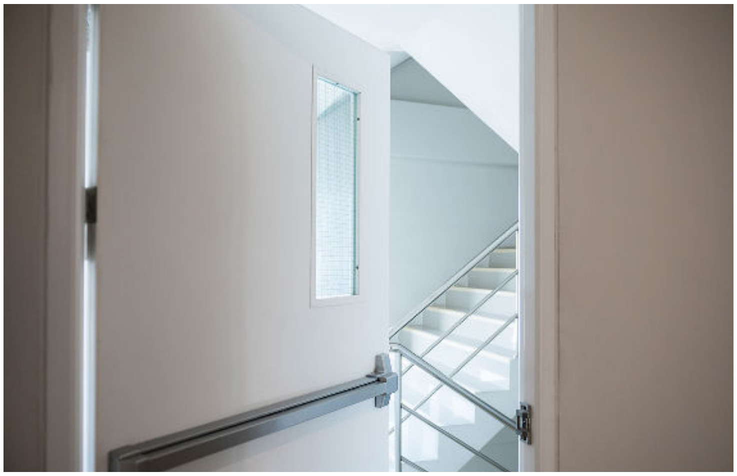
The Society of Fire Protection Engineers (SFPE) is a professional organization focused on advancing fire protection engineering. It was founded in 1950 and has grown to become an international organization with members from various backgrounds, including engineers, researchers, architects and firefighters. SFPE holds an annual conference and expo to provide members with educational and networking opportunities.

PROBLEM

Defining Open Doors

There are multiple reasons why a stair door is opened. In the event of a fire within a high-rise fire, doors are opened and closed as occupants egress from the floor into the stairwell. Even though fire-rated stairwell doors are required to have self-closing devices, they can be propped open for various reasons. For example, the door can be manually propped open with a wedge, or significant airflow in the building can keep the door ajar. Doors can also be used and propped during firefighter operations.

What is the significance of open doors? Open doors in stairs can compromise the integrity of the protected vertical exit by allowing for the infiltration of smoke, heat, and toxic gases during a fire event. Pressurization systems are designed to prevent such migration of smoke, however they are heavily dependent on how much leakage is provided into the stairwell. Leakage generally includes construction gaps through



walls and floors as well as gaps around doors and windows. When a door is open, that large amount of free area can dramatically affect the pressures within the stairwell, causing pressure spikes and drops from those doors opening and closing. Also, an exterior door can interact significantly with its surrounding environment, such as extreme temperatures and wind, which can influence the pressure within the stairwell.

How do design engineers decide how many doors to consider open and which ones? The design generally starts with the applicable codes. The IBC and the 2021 edition of NFPA 92 allow you to consider all doors closed. This edition of NPFA 92 notes that any doors on auto-openers as part of the smoke control system need to be considered open. However, this differs from previous editions, which said that open doors should be incorporated into the design but didn't note specifics for how many or which doors to be considered open.

In addition, local authorities having jurisdiction (AHJ) will have preferences based on their experience and knowledge level. They can specify certain open doors to be considered, such as an exterior discharge door and other interior doors.

Overall, it is not clearly defined as to how many and which doors to be considered open.

Compensated System Challenges

Complex pressurization systems have been utilized to compensate for the large pressure difference caused by doors opening and closing. When designing a stair pressurization system with CONTAM, considering open doors, you start the simulation with all the doors closed, resulting in high-pressure differentials. When the model is adjusted to consider two open doors, results may be closer to (or fall short of) the minimum allowable pressure differentials. Compensated systems are intended to normalize those differences.

Compensated systems are designed to provide supplemental supply air or relief venting/exhaust in specific areas to compensate for the pressure deviations. The idea is to put additional systems in place to react to the different environments caused by open doors. But in reality, this can be extremely challenging, as compensated systems are expensive and more complicated to design, test, and maintain.

The process of testing is also more complex when considering compensated systems. Compensated systems typically require extra devices, more intricate sequence of operations as well as modulation of mechanical equipment to work properly. In some situations, the systems don't perform as intended because of fan ramp-up/down delays and other interactions.

The additional devices create more failure points that could ultimately lead to catastrophic failure. For example, consider if a pressure measurement device in a compensated VAV system were to misreport low pressure within a stair enclosure signaling to the supply fan ramp up – this may yield the entire stair inaccessible due to extreme door opening forces generated so that no occupant could even open stair doors. The failure scenario in this case is more detrimental than periods of slightly lower pressure differentials common with simple pressurization systems.

Compensated systems can only perform as designed if they are regularly tested and properly maintained. During initial acceptance testing, the entire engineering and construction team share a vested interest in the system's performance in order to pass special inspections and gain the building's certificate of occupancy. However, once the building is occupied, the priority shifts, and often, smoke control systems are neglected. In addition, records of system design basis are generally not maintained within the building. It's not uncommon that even simple systems are improperly tested. With complex compensated systems, it's likely that a building's engineer or maintenance team, or even hired inspector may not fully comprehend the system's originally intended functionality.

To better understand the impact of open doors and compensated systems on stairwell pressurization, SFC conducted a study using various models.

STUDY

Using past literature studies, SFC developed a baseline scenario, considering a high-rise building that was 90 feet in height with 9 stories and 2 stairs. The team used fire and egress modeling tools to visualize the following:

- *What happened during a fire event.*
- *How the fire interacted with a stairwell pressurization system.*
- *The resulting conditions occupants would be exposed to within the stairs.*

PyroSim Graphical user interface leveraged to visualize and develop FDS simulation files. Fire Dynamics Simulator (FDS)	**Fire Dynamics Simulator (FDS)** A computational fluid dynamics software that simulates fire and smoke behavior.
Ventus Graphical user interface leveraged to visualize and develop CONTAM simulation files.	**CONTAM** Zone model that simulates the flow of air through a complex network of flow paths. Steady-state results only.
Pathfinder Simulates occupant evacuation and movement during emergencies.	

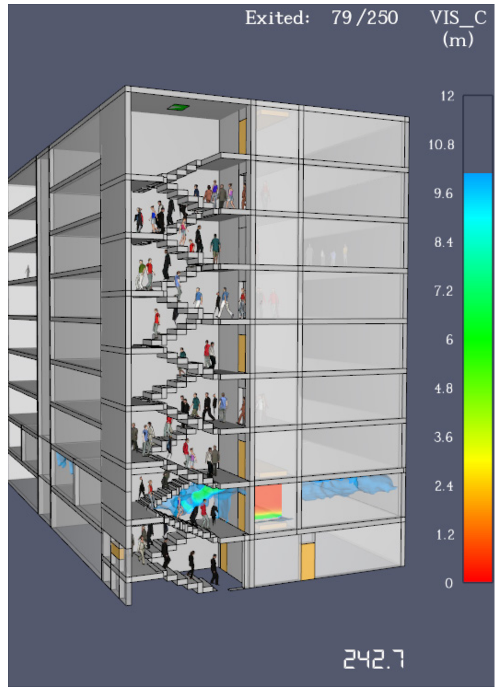
Using these programs, SFC modeled three (3) different types of systems:

1. A simple single-top injection pressurization system
2. A compensated system with multiple injections and a relief damper
3. Non-pressurized system

With these systems, the team conducted four (4) iterations:

1. All doors closed
2. Door propped on the fire floor
3. Door propped on the fire floor and the exterior door open
4. Doors opening and closing due to egress (not propped)

The study goal was to determine the impact of open doors on the different types of systems and see whether a compensated system was necessary for maintaining pressure or maintaining conditions within the stairwell.



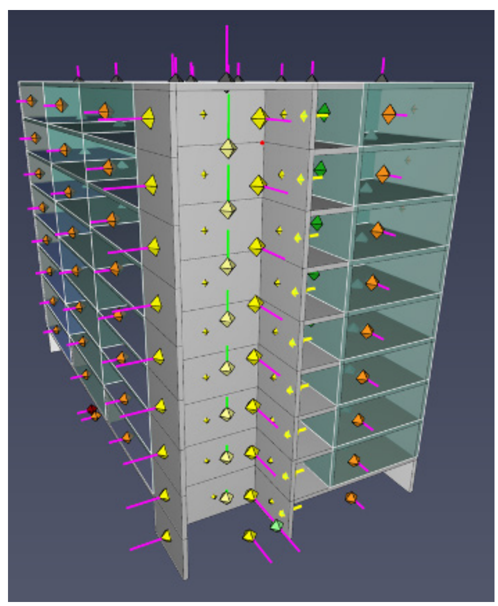
Isometric View of the Building Using FDS and Pathfinder Results

RESULTS

Fan Capacities

The first factor SFC looked at was fan capacities. This required the use of CONTAM and Ventus to determine what mechanical capacity would be required to obtain adequate pressure differentials at the stairway doors.

When sizing the systems, SFC aimed for the pressure differential to be close to 0.2 inches of water since it's in the middle of 0.1 and 0.35 inches of water. The team determined that for a simple system with all doors closed, 5,000 CFM (cubic feet per minute of airflow) would be required for the single top injection point.



A 3D Look of the Airflow Paths on the Walls and Floors

Then, when considering the door on the fire floor open and the exterior discharge door open, the system would require four times the amount at 20,000 CFM with three injection points and a 10 SF (Square Foot) relief damper on Level 1.

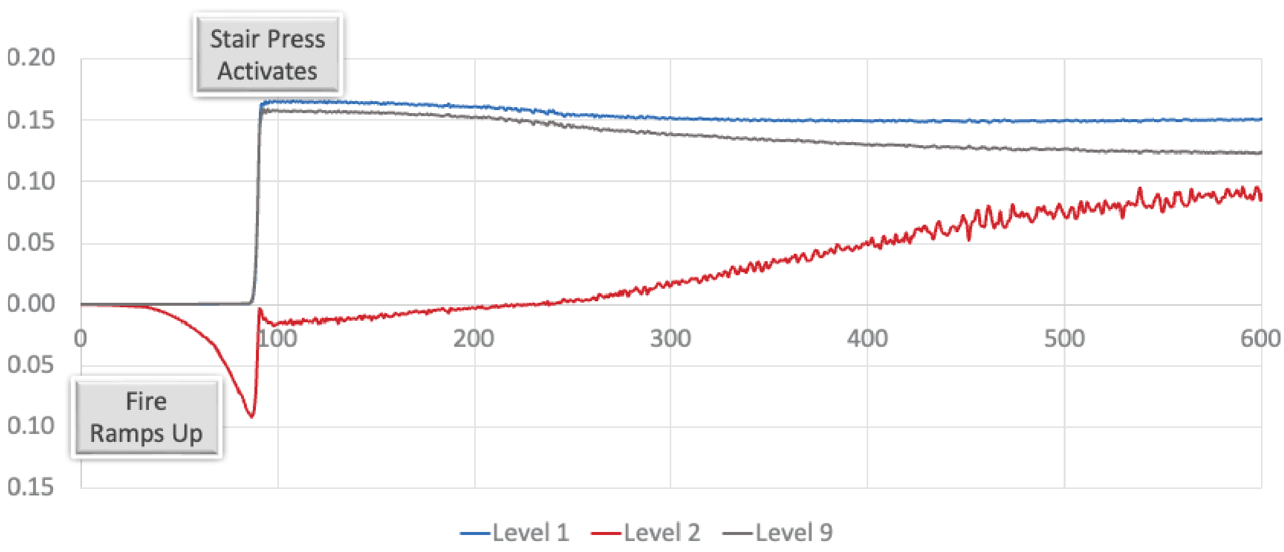
The systems were designed to achieve the same performance objectives for the same building, and the only difference in requiring greater mechanical capacity was the consideration of open doors.

Pressure Differentials

Next, SFC looked at the pressure differentials within the FDS model over time. The team used a simple system with a single 5,000 CFM injection and closed all doors to determine the pressure differentials between the stairs and the corridor over time. The baseline scenario considered a fire located on Level 2.

Stair 1 Pressure Differentials – Single Top Injection of 5,000 CFM – All Doors Closed

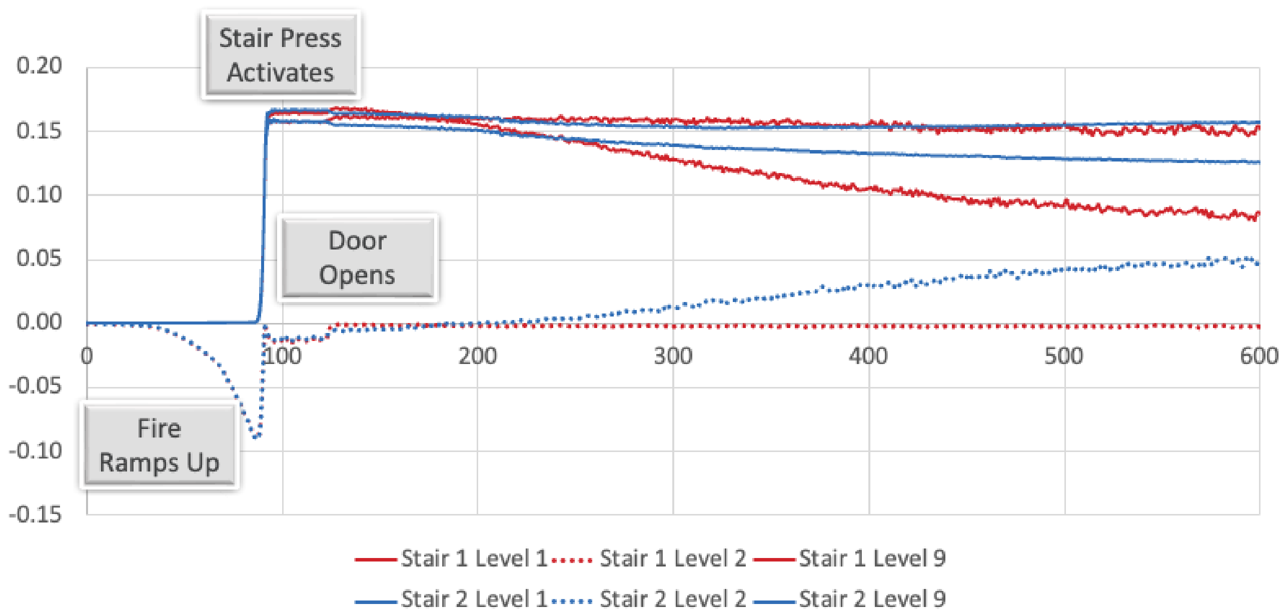
In the figure above, Level 1 and Level 9 are shown in blue and grey and increased to



approximately 0.15 after the stair pressurization was activated. Level 2, shown in red, depicted the pressure differential at the closed door on the fire floor. It initially shows a negative pressure relative to the stair enclosure due to the pressure generated by the heat release and expansion of gases caused by the fire energy. Once the stair pressurization fans are imitated, ramped up to full capacity and normalized, the pressurization system overcomes the pressure generated by the fire.

Even though the door was closed, the pressure differential was lower than the expected 0.2. Also, it's important to note that pressure changes over time. **Although CONTAM is a useful tool in the design of pressurization-based smoke control systems, it only provides a single-point-in-time (steady-state) calculation, whereas, in real life, pressures change over time.**

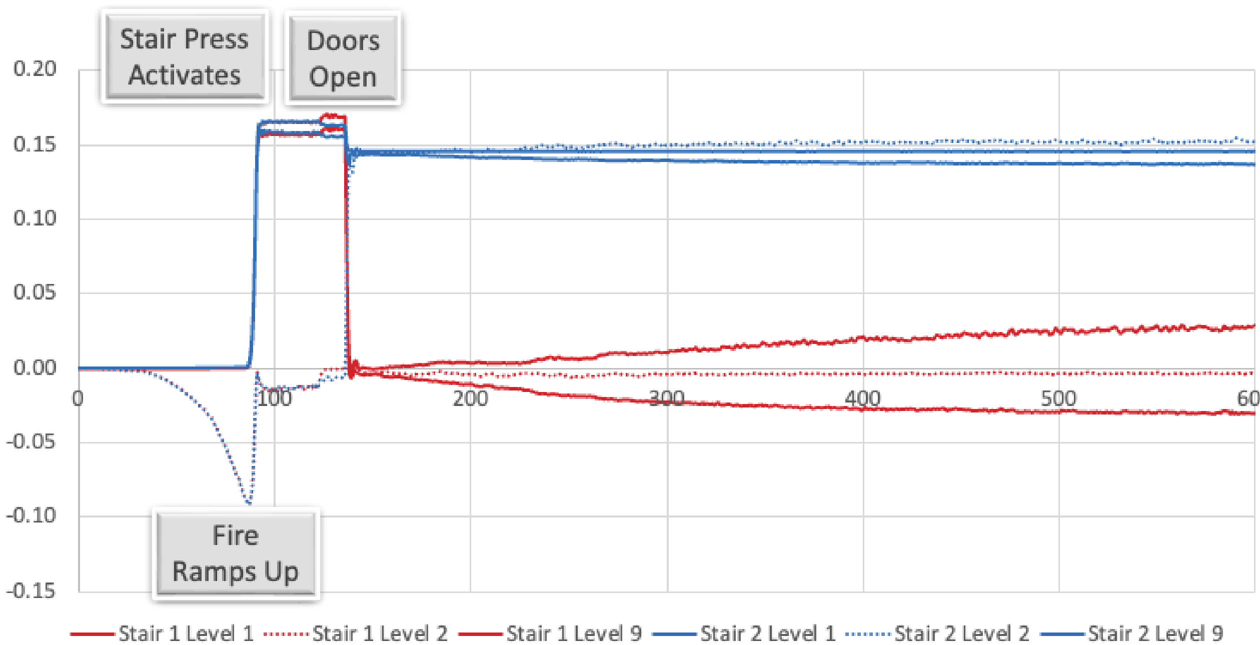
Stair 1 & 2 Pressure Differentials – Single Top Injection of 5,000 CFM – Stair 1 Door on Fire Floor Open (Stair 2 All Doors Closed)



Next, SFC looked at an iteration with a door on the fire floor open, which is represented as the red dotted line in the figure above. SFC compared Stair 1 (shown in red) that had the door on the fire floor open, and Stair 2 (shown in blue) which remained with all doors closed.

When the door on the fire floor opened, multiple changes occurred. First, the pressure differential on the closed doors of Stair 1 became more unstable and dropped over time due to the unrestricted loss of airflow out of the open door. Second, the closed door on the fire floor had a significantly reduced pressure differential, resulting from the backpressure generated on the floor by the free airflow through the open door from Stair 1. It can also be observed that no pressure differential is generated across the open door, which is expected.

Stair 1 & 2 Pressure Differentials – Single Top Injection of 5,000 CFM – Stair 1 Fire Floor & Level 1 Exterior Door Open (Stair 2 Doors All Closed)

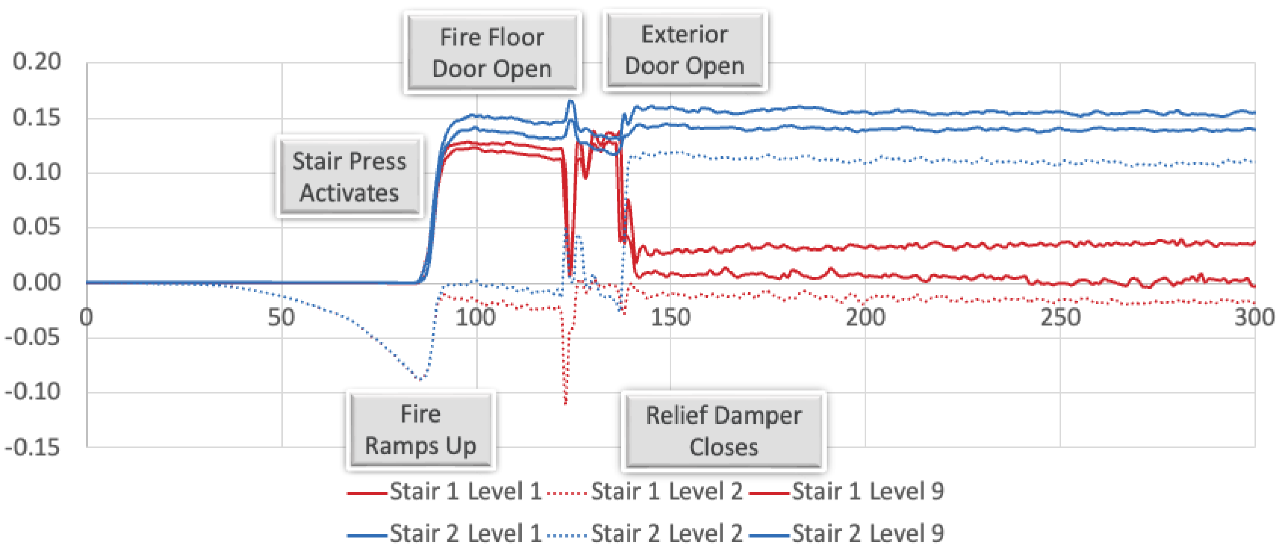


The next iteration involved both the door on the fire floor and the door on the first floor exterior open for Stair 1. Before the two doors opened, SFC saw trends similar to previous iterations. After the doors open, the doors to Stair 2 (shown in blue, which are all closed) are all around the 0.15 mark, like in the baseline case.

However, Stair 1 (shown in red, with two open doors) was below 0.05 inches of water, even at the closed door on Level 9.

These results showed that open doors significantly impact pressure differentials throughout the stair enclosure. SFC also demonstrated that pressure differentials are dynamic in nature, changing over time based on fire conditions, fan status and open doors.

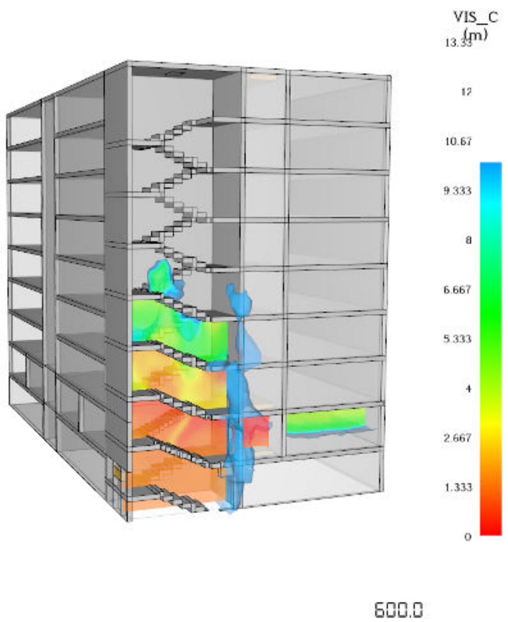
Stair 1 & 2 Pressure Differentials – Compensated Multi Injection of 20,000 CFM – Stair 1 Fire Floor & Exterior Door Open (Stair 2 Doors All Closed)



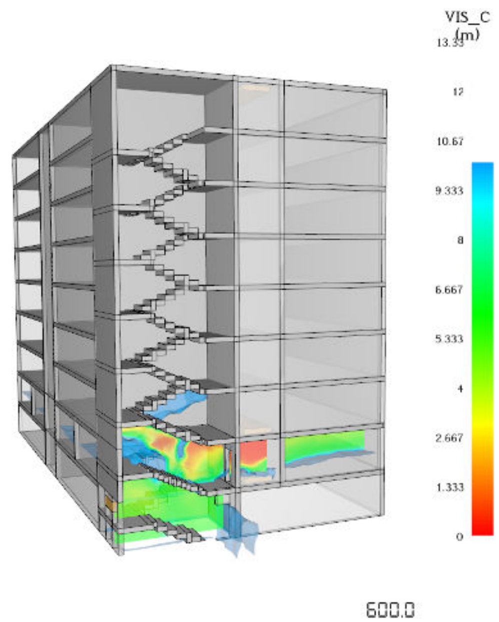
SFC next considered a compensated system, which included a multi-injection supply air with damper relief. For Stair 1, both the door on the fire floor and the door on the first floor were modeled open. The team saw similar trends as before and found that the pressures for Stair 2 (shown in blue) – which has all doors closed – were above the 0.15 range. However, even after the relief damper closed in response to the pressure drop from the doors opening, the pressure differential across the closed doors throughout the height of the stair did not maintain a pressure above 0.05.

The results showed that the simple system performed comparably to a compensated system when considering open doors. The open doors caused the pressure differentials to fall outside of the acceptable range prescribed by the code.

Stair 1 Visibility – Doors on Fire Floor & Exterior Open



The single injection system at 600 seconds.



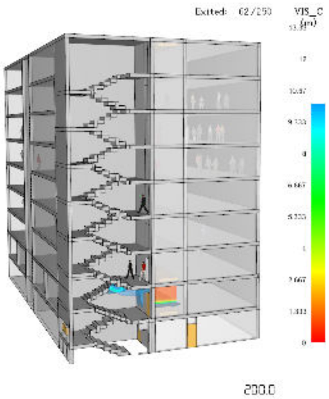
The compensated system at 600 seconds.

There are three tenability criteria that SFC generally considers when performing tenability evaluations: visibility, temperature and carbon monoxide. For this study, SFC focused on visibility because it will be the first of the three criteria to fail. The team used 10 meters as a threshold, with red being the denser smoke and blue being the smoke right at the threshold of 10 meters. Therefore, any color within the stairwell could indicate failure.

SFC compared the single injection system and the compensated system with the doors on the fire floor and exterior open. They found that both systems resulted in untenable conditions inside the stair enclosure.

Results – Doors Open Based on Egress

The No Pressurization System



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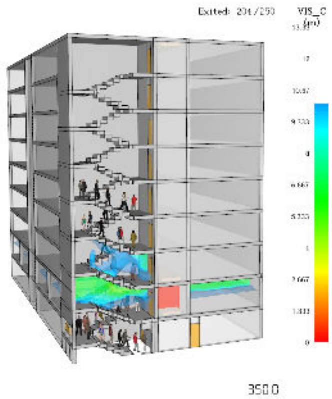

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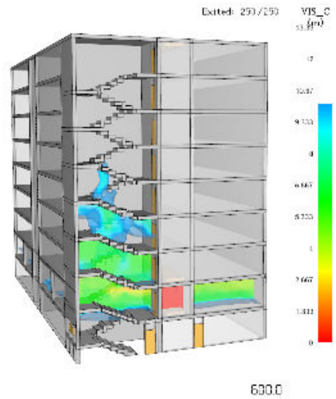

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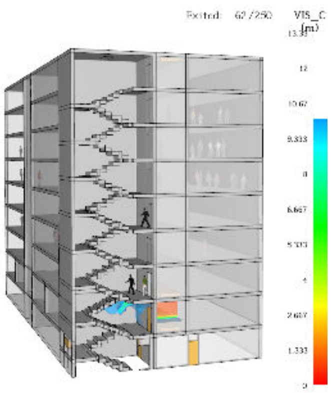
The Simple System



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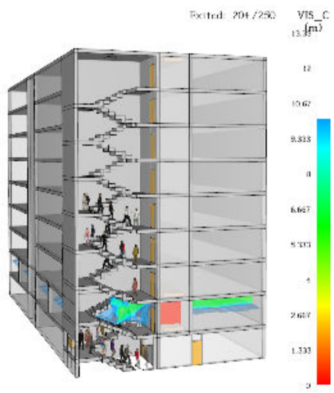

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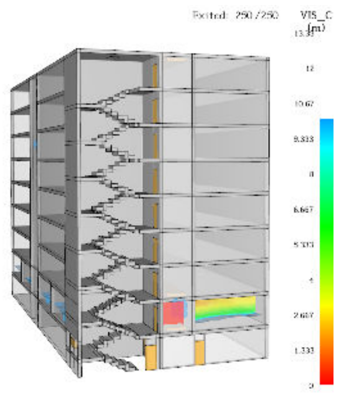

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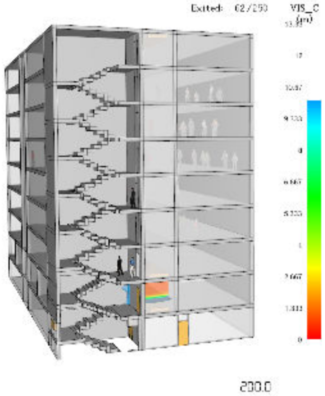
The Compensated System



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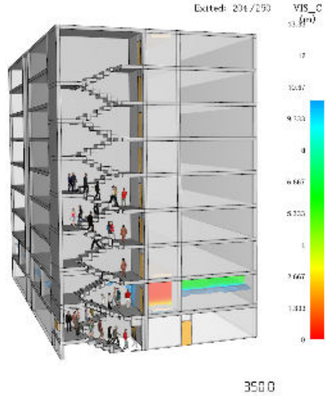

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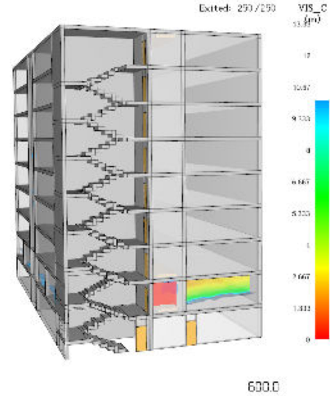

600 seconds

The Annex of NFPA 92 states that doors permanently propped open are considered a failure condition by code and are beyond the capability of a designed system. The system should not be designed for failure conditions since the unknown conditions would make any design overcomplicated, unreliable and difficult to maintain.

Using the case of only opening and closing doors due to egress, SFC compared the single injection system to a compensated system. For a baseline, the team also included a model with no pressurization.

> ***The results showed that when occupants periodically entered the stair enclosure and the door closed behind them, little smoke was allowed to infiltrate the stair enclosure. The compensated and simple systems maintained tenability in the stair enclosures.***

BOTTOM LINE

Conclusion 1

First, SFC concluded that pressure changes over time. While CONTAM is a useful tool, it only provides a one-point-in-time calculation. That's crucial to consider with compensated systems since they react and adjust based on varying conditions. For example, when a door opens, a relief damper will close, or a fan will increase. But when those adjustments happen, there can be communication delays or hardware limitations on how fast the system can adjust, and the pressure adjustment may not represent what the designer originally intended.

Conclusion 2

As a fire grows, the heat release rate increases, expanding hot gases, which generates an increased pressure. SFC's pressure differentials were slightly different (0.2 and 0.15 inches of water between CONTAM and FDS). Our conclusion is that the pressure difference observed is attributed to the fact that CONTAM does not consider the pressure created from the heat of a fire, and the delta is the result of the fire component accounted for within the FDS model.

Conclusion 3

SFC also concluded that compensated systems only limited the smoke movement into the stairs when considering propped-open doors. The annex of NFPA 92 clarifies that doors blocked open in violation of applicable codes are beyond the capability of the system. This verifies that it's not propped open doors that should be considered but rather doors opening and closing due to egress. The performance between simple and compensated pressurization systems under normal fire conditions is reasonably similar. The benefits of compensated systems might not justify their added complexity, expense, and overall increased risk of malfunction.

When you consider doors opening and closing due to egress, a simple system performed comparable to a compensated system.

Summit Fire Consulting provided valuable insights into stair pressurization for high-rise buildings that helped to drive the fire protection engineering industry forward in its quest to design better and safer systems. SFC applies these findings when engineering pressurization-based smoke control systems for its clients resulting in more resilient and efficient designs.

ABOUT SUMMIT FIRE CONSULTING

Summit Fire Consulting is a team of licensed fire protection engineers and code consultants partnering with owners, architects, and developers to solve complex code challenges, accelerate approvals, and unlock designs others say can't be built.

In addition to timed-egress evaluations, Summit Fire Consulting has experience with modeling structural fire resistance, sprinkler detection times, smoke detector spacing, device activation times and smoke and heat venting.

Going beyond compliance, Summit Fire Consulting designs safer, more efficient buildings that maximize long-term value. Backed by the strength of the full Summit Companies network, our team delivers responsive, code-aligned solutions wherever your project takes you.

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