PROPER SMOKE CONTROL SYSTEM DESIGN: PROTECTING FANS AND DUCTWORK FOR PRESSURIZATION SYSTEMS

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Introduction

SMOKE CONTROL SYSTEM OVERVIEW

When it comes to improving building safety in the United States, smoke control systems are employed less frequently than other fire and life systems. Unlike fire sprinkler and alarm systems, which are installed in at least some capacity for almost any structure built today, the principals of active smoke control only apply to a specific subset of facilities. Typically, more complex building designs require intricate and detailed integration of various fire and life safety systems for smoke control purposes. This contributes to the protection of life and reduces the potential for property loss.

The International Building Code (IBC)[1] requires smoke control systems for atriums, assembly seating, underground buildings, detention and correctional occupancies, large stages, and high-rise buildings. Though actual smoke control methods may vary by facility, they all encompass one or more of the following purposes:

+ Inhibit smoke from entering enclosed means of egress and fire department access routes
+ Maintain tenable conditions in the means of egress to allow safe evacuation
+ Inhibit the migration of smoke from the smoke zone
+ Provide conditions outside the smoke zone that enable emergency responders to conduct operations.

Smoke control systems can generally be categorized into either "smoke containment systems" or "smoke management systems". Smoke containment systems keep smoke from entering specific areas using pressurization and passive barriers. Smoke management systems maintain tenable environments in the means of egress from large volume spaces or prevent the movement of smoke into surrounding spaces.

Although these smoke control methods seem quite different, they use the same underlying design fundamentals. This includes the use of well-established engineering principles, detailed analysis to support methods, coordination of various disciplines involved and commitment to continued reliable performance.

[1] All references to the International Building Code (IBC) make reference to the 2021 Edition for clerical purposes. The requirements discussed in this paper are consistent between the 2015 IBC, 2018 IBC, and 2021 IBC.

SMOKEPROOF ENCLOSURES

The common life safety approach for multi-story buildings is for occupants to traverse safe, but possibly unprotected, egress paths until they reach exit stairway enclosures. At this point, there should be a protected path through the stair to the exit discharge. The IBC essentially provides three different levels of protection for exit stairways.

Stairways connecting less than four stories require a one-hour fire-resistance-rated (FRR) enclosure, while stairways connecting four or more stories require a two-hour FRR enclosure. Once the building reaches a high-rise designation, smokeproof enclosures are added into the design. This provides a place of safe egress for occupants in tall buildings where immediate total evacuation cannot be readily accomplished. In such situations, exit stairways also provide access for fire-fighting purposes.

Smokeproof enclosures in high-rise buildings are prescriptively required for enclosed exit stairways serving floors more than 75 feet above the lowest level of fire department access. These upper floors are where stack effect is more of a factor and the resulting spread of smoke will be the greatest. Stairways serving the low-rise portion of the building (less than 75 feet) do not require such systems.

The IBC allows one smokeproof enclosure to discharge into a ground floor lobby, or similar area, where the exits to the outside are readily apparent. If a smokeproof enclosure does not terminate at an exit discharge, it can be extended via an exit passageway. The exit passageway is an extension of the smokeproof enclosure and, as such, is also required to meet the pressurization requirements.

For fully sprinklered buildings, mechanical ventilation equipment provides supply air to create a pressure differential between the stairway and the adjacent spaces when the stair doors are closed. In theory, the positively pressured shaft will prevent smoke from entering the enclosure providing a safe area to egress the high-rise building.

GENERAL SMOKE CONTROL DUCTWORK

The mechanical equipment plays a major role in the effectiveness of a smoke control system. Since the ducts are ultimately responsible for transporting supply and/or exhaust air to different smoke zones, maintaining the integrity of the ductwork is a critical issue that must be addressed in every smoke control system design. The applicable mechanical code must be reviewed to ensure smoke control ducts are properly designed with regard to pressure classification, materials, joints, supports, mechanical protection and weather protection.

The IBC provides requirements that specifically address fire exposure to smoke control ducts and air leakage into other smoke zones. The ducts must be capable of withstanding the probable temperatures and pressures to which they are exposed and be supported directly from FRR structural elements by substantial, noncombustible supports. The ducts must be leak tested to 1.5 times the maximum design pressure in accordance with nationally accepted practices without a leakage exceeding 5 percent of design flow.

If the installation of a fire damper in a smoke control duct will interfere with the smoke control system's operation, approved alternative protection must be provided. Additionally, smoke dampers are not required at penetrations of shafts where ducts are used as part of an approved mechanical smoke control system and where the smoke damper will interfere with the system's operation.

SHAFT PRESSURIZATION DUCTWORK

Supplemental passive fire protection requirements are provided in IBC Sections 909.20 and 909.21 for the ductwork and ventilation equipment serving smokeproof enclosures and elevator hoistway pressurization systems, respectively. For hoistway pressurization, a separate fan system must be used for each elevator hoistway. The fan system and any duct system that is part of the pressurization system must be protected with the same FRR required as the elevator shaft. For smokeproof enclosures, the equipment must be independent of other building ventilation systems and be located on the exterior of the building or in a two-hour FRR enclosure inside the building. The ductwork serving the system must be protected using one of the following methods:

+ Locating on the exterior of the building
+ Locating within the smokeproof enclosure
+ Two-hour FRR shaft enclosure from the smokeproof enclosure to the exterior

In cases where a two-hour FRR enclosure is provided for ducts and/or fans, openings into the FRR construction must be limited to those needed for maintenance and operation of the system, since it is an extension of the stair envelope. This required level of protection also applies to the control and power wiring serving the smokeproof enclosure ventilation equipment. Additional options for wiring other than FRR enclosures are permitted which allow for the use of a two-hour rated cable, encasement with not less than two inches of concrete, or a listed two-hour electrical circuit protective system.

Challenges for Code Compliance

ENGINEERING ANALYSIS

All smoke control systems are subject to numerous code provisions that indicate the need for performance-based evaluations rather than the typical application of prescriptive requirements. For instance, IBC Section 909.2 states, “Buildings, structures or parts thereof required by this code to have a smoke control system or systems shall have such systems designed in accordance with the applicable requirements of Section 909 and the generally accepted and well-established principles of engineering relevant to the design.” This results in a subjective review and acceptance of smoke control system designs including the protection of ductwork.

RATING CONTINUITY

For stair pressurization systems, IBC requirements intend to protect all necessary equipment for a minimum two-hour duration when the components are exposed to the standard fire curve. Generally, the required protection is limited to those components specifically identified in the code which include power and control wiring, ductwork, and fans. However, careful consideration should be given to the FRR continuity requirements in the IBC and how that may impact the fire-resistance of other components. Some specific examples of IBC provisions that do not align with the two-hour FRR survivability concept include the separation of fire command centers, the separation of standby power equipment, and the roof construction for high-rise buildings.

New high-rise buildings must have a fire command center containing the main fire alarm control panel, the fire fighter’s control panel, and other contents and features. All smoke control systems must have a standby power source separated from the normal power transformers and switch gears. IBC Sections 909.11.1 and 911.1.2 specifically call for minimum one-hour FRR enclosures to isolate these spaces from other areas of the building such that the critical contents of the room are provided with some level of passive fire protection. Depending on the specific arrangement of providing power and control over system equipment, the 1-hr FRR rooms could be weak spots in the two-hour FRR survivability concept of smokeproof enclosures.

Generally, high-rise buildings are of noncombustible, fire-resistive construction and encompass Type IA, IB, and IIA construction in the IBC. Type IA construction, which is the most protected construction type, specifically calls for the roof construction and associated secondary members to be 1.5-hour FRR. A common design method is to locate stair pressurization fans and other mechanical equipment outside the building envelope on the roof. If this is the approach, the planned structural system and roofing materials do not need to be upgraded, since the equipment is on the exterior of the building as permitted.

Some may say there is a code conflict , but they are not since there is a hierarchy for ICC, codes that the specific code requirements trump the general code requirements. Another example of this, the IBC requires fire command center to have a 1-hour FRR rating, even though every high-rise building is required to have a fire fighters smoke control panel and fire alarm panel within the fire command center, which are both required to meet 2-hour survivability requirements for wiring. Pressurization Fan Location

The IBC requires pressurization fans to be enclosed with two-hour FRR construction or located on the exterior of the building. Uncertain conditions may arise in cases where fans are located in areas of the building that are not fully enclosed such as mechanical spaces with grated or louvered screens or inside penthouses on the roof. A determination must be made regarding the exterior building envelope to ensure FRR separation is not required between stair pressurization equipment and other building equipment.

Outside air inlets for stair pressurization fans must be located in a way that minimizes the potential for introducing smoke or flame into the building. Since a prescriptive separation distance is not provided in IBC Section 909.10.3, the adequacy of the locations should be addressed in the rational analysis. This may align with the limitations of the applicable mechanical code or be determined using other engineering practices.

COMPLEX DUCT ROUTING

A one-size-fits-all approach does not exist for stair pressurization system design. The factors impacting the performance of these systems include building height, stairwell height, floor plans, flow areas, atmospheric pressure, building temperature, outdoor temperature, ventilation systems and wind effects.

If a building is on the short side of the high-rise threshold, has a compact floor plan with a single smoke control system, and is in a mild climate zone, the design should be relatively straightforward for an experienced professional. Simple single-point injection systems like these can use roof or exterior wall-mounted propeller fans which require minimal, if any, ductwork inside the building.

For tall stairwells, single injection systems will not work as they cannot provide the needed pressure differentials on all floors without creating excessive stair door opening forces that exceed the IBC maximum of 30 lb. Multiple injection systems, which are common for stair pressurization systems, may consist of one fan supplying air through a duct with multiple supply outlets into the stairway for more efficient distribution of the air. Figure 1[2] below shows examples of a single-point injection system, a multiple-point injection system using a single fan, and a multiple-point injection system using multiple fans.

[2] Image Source: NFPA 92 Handbook, 2015 Edition

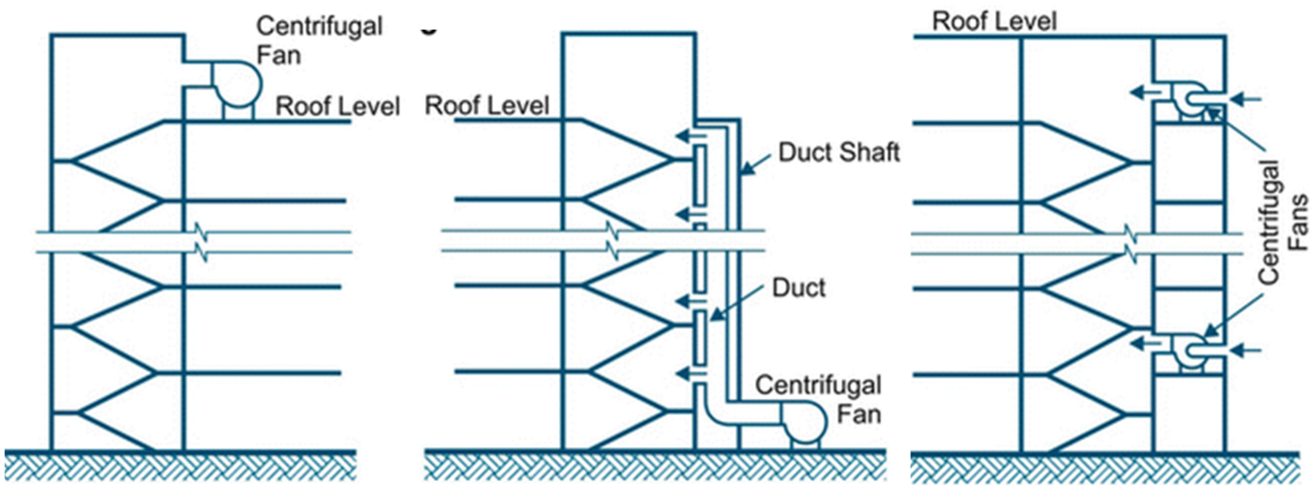

Figure 1: Example of Single-Point Injection and Multiple-Point Injection Fans

Just because multiple-point injection systems are used, does not necessarily mean that protection of ducts will be problematic. For vertical duct sections, numerous listed shaft wall assemblies can be used to provide two-hour protection. Furthermore, if ductwork is located in the stairway, additional shaft construction is not required, but oftentimes the ductwork is protected with non-rated gypsum to create a more aesthetic visual appearance in the stair. There are still potential coordination issues that must be reviewed. The ductwork must be routed in the stairway such that it does not obstruct the egress path, and the potential for damage to the exposed ductwork due to unrestricted access must be mitigated.

The protection of horizontal ductwork can be challenging when fans are located on the interior of the building and serve ductwork traversing the floor plans to the pressurized enclosure. Horizontal jogs of the stairway and the use of exit passageways to extend the stairway to a discharge point may also create situations where a simple ductwork path is not feasible and horizontal duct transitions are required.

HORIZONTAL DUCT PROTECTION

IBC Section 717.1.1 addresses the protection of ducts transitioning horizontally between shafts. Provided that the duct penetration into each associated shaft is protected with dampers complying with Section 717, a horizontal duct will not typically require a shaft enclosure. For typical air ventilation ducts, the configuration shown in Figure 2 below is acceptable[3]

[3] Image Source: Significant Changes to the International Building Code 2015 Edition.

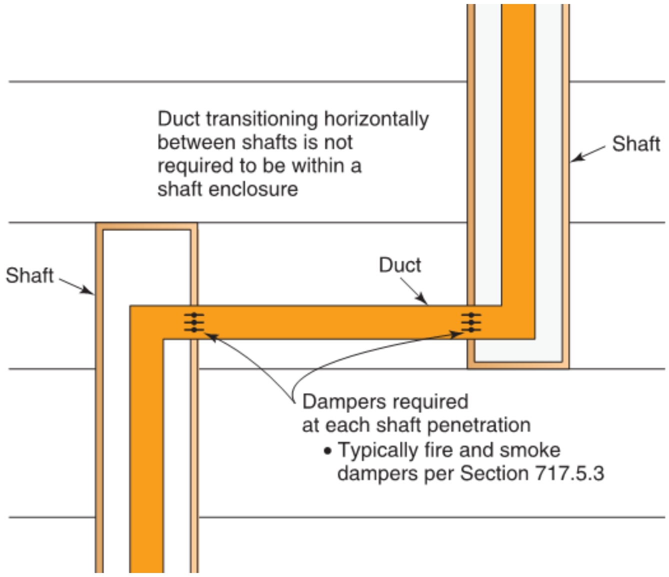

Figure 2: Horizontal Transition Between Shafts for Normal HVAC Ducts

Because the ducts will be protected with dampers at both shafts, an appropriate separation between stories can be maintained if the duct fails due to fire exposure. Since the intent of protecting stair pressurization equipment is to maintain the operation of the system for a certain duration, this configuration will not be acceptable.

There are limited listed assemblies that provide horizontal fire-resistance-rated duct continuity using gypsum. Using gypsum in a horizontal, non-floor condition is difficult for code compliance and constructability concerns, since there are no ASTM E119 test criteria for a non-load-bearing horizontal assembly or a horizontal assembly hung by a vertical fire-resistance-rated assembly[4].

FIRE-RATED DUCTS

FRR duct assemblies may be used as both a common alternative to gypsum assemblies protecting horizontal ducts and as a method to omit fire dampers in smoke control ducts. However, there is no IBC clear prescriptive code path for using FRR duct assemblies unless they are tested as shaft enclosures using the fire exposure and acceptance criteria specified in ASTM E119. The ICC has established Acceptance Criteria, known as AC179, which provides guidance for demonstrating the safety of FRR duct enclosure systems as an alternative to provide an equivalent level of safety. Unfortunately, there are no products currently available that meet the criteria and have an ESR report. Nevertheless, it is important to recognize the industry's current approach to FRR duct assemblies as it relates to test standards, terminology, and relevance to applicable IBC requirements.

AC179 Section 3.6 establishes the equivalence of duct fire protection systems to the level of protection provided by required fire dampers, horizontal ducts penetrating fire-resistance-rated fire barriers, fire partitions and/or smoke barriers, and vertical ducts that connect multiple stories. Section 3.7 establishes the equivalence of duct fire protection systems that are part of elevator hoistway pressurization systems or stair pressurization systems.

If AC179 (or other future acceptance criteria) is referenced to specify or approve FRR ducts, the intended use and configuration of the mechanical system should first be examined. Just because ductwork is part of a stairway or elevator hoistway pressurization system does not mean it is exempt from using a product that is

[4] Information regarding horizontal fire-resistance-rated shaft enclosures can be found in the paper "Consideration of Protection for Horizontal Fire-Resistance-Rated Enclosures" written by Arthur Gager from Jensen Hughes.

tested from the inside and outside. Pressurization ducts that penetrate a FRR assembly or extend through multiple floors, are subject to the requirements of Section 3.6 if the protection is being evaluated using AC179.

The pertinent fire-resistance rating requirements from the IBC used as the basis for an equivalency or code modification should be sufficiently outlined such that the prescriptive requirements including FRR continuity, test methods, and symmetry can be compared to the protection offered by the FRR duct.

FIRE DAMPER OMISSION

In complex facilities where horizontal stair pressurization ductwork traverses the floor area, there is potential for the ducts to cross FRR separations such as fire walls, fire barriers, smoke barriers or horizontal exit boundaries. Typically, these penetrations require a fire damper to prevent the spread of flames from one part of the building to another through the building's ductwork. IBC Section 717.3.3.1 permits a maximum 350°F operating temperature for fire damper actuation devices where the ductwork serves a smoke control system. This is more often seen in below grade smoke control systems that utilize the normal HVAC supply and return/exhaust as part of the smoke control system.

Best Practices for Fire Protection of Ductwork

COORDINATED DESIGN

Professionals involved with the design of a smoke control system should be engaged as early as possible. For buildings that are relatively complicated, a CONTAM analysis of the pressurized stairwells is often needed to not only determine if the stairwell system arrangement is capable of being balanced to perform as intended, but also size the fans for the system.

The model results will provide sufficient information to size supply air ducts and locate injection points early in the design process. Additionally, the model may justify the use of a single-point injection system which is much simpler than multiple-point injection systems.

As it relates to the ductwork design, the pressurization of exit passageways and horizontal offsets should be included in these early coordination efforts as this is the most likely situation that will require horizontal ductwork runs through the building.

COMPLIANCE APPROACH

Since gypsum is the only prescriptively acknowledged shaft protection, use of any FRR ductwork requires AHJ approval as an alternate means and methods or as a code modification. The pertinent fire-resistance rating provisions from the IBC should be identified such that methods proposed to protect the ductwork can be reviewed for compliance. This should include requirements for the minimum fire endurance, acceptable test standards, assembly continuity, rating symmetry, and duct penetrations. Specific criteria for the smoke control system that may impact the fire protection of the ductwork should be accounted for.

Where the review of the applicable requirements, proposed design, and listed assemblies points to an alternative code approach as the most favorable option, a code path to get the solution approved should be established with the AHJ. This may be an alternate means and methods approach in accordance with IBC Section 104.11 or a code modification under IBC 104.10.

In cases where a listed gypsum assembly is not feasible due to the ductwork configuration, alternative fire-rated products not prescriptively permitted by the IBC may be considered. These products must be reviewed and substantiated by an appropriate design professional using test data that fully supports the engineering analysis.

An alternate means and methods approach in accordance with IBC Section 104.11 can be used to justify that a gypsum assembly utilized outside of its listing parameters, or a FRR duct assembly listed and the need to address equivalent fire-resistance or a potential code modification under IBC 104.10.[5]

ADDRESSING SCENARIOS

A rational analysis must be prepared for all smoke control systems. The analysis should include the types of smoke control systems being employed, their methods of operation, the systems supporting them and the methods of construction being utilized.

The rational analysis should also document the impact of stack effect, temperature effect of fires, wind effect, HVAC systems, climate, duration of operation and smoke control system interaction. The project's complexity and the smoke control system will dictate the level of analysis performed in addressing the various scenarios the system might encounter. In all cases, the requirement for smoke control ducts to withstand the probable temperatures and pressures to which they are exposed should be assessed.

Since the assemblies enclosing the pressurization ducts prescriptively require a two-hour FRR from tested with fire from both sides, the use of FRR duct assemblies listed only for outside fire exposure should be submitted typically as a code modification in accordance with IBC 104.10[6], and rationale and justification should be provided as part of this process. This will require additional discussion and analysis. Even though these assemblies do not provide "equivalent fire-resistance," a building official may potentially accept this if appropriate rationale and justification are provided as part of the submitted variance package. An acceptable approach could be the analysis of fire scenarios in each compartment containing openings to the pressurization duct and addressing the fire scenario within the stair enclosure and would require approval of the building official.

Looking Ahead

Documentation and early coordination among disciplines needs to be emphasized in smoke control system design. There are many factors that could alter the effectiveness of a smoke control system. These factors must be considered in the smoke control rational analysis report (SCRAR) that will be referenced by the design team and smoke control special inspector.

Alternate duct protection under IBC 104.10 or 104.11 should be submitted to the building official for review. If approved by the building official, it will become part of the overall stair pressurization code approach. In addition to considerations from the design team, the smoke control special inspector should be aware of all methods used to protect the ductwork as well as the approvals received from building officials and third-party reviewers. Providing appropriate fire-rated protection for ducts and fans associated with the pressurization system is a critical part of the overall smoke control system and must not be overlooked to maintain reliability.

[5] Information regarding the alternate means and methods process specific to fire-resistance-rated ducts can be found in the paper "Fire Resistance Rated Ducts as Alternatives to Shaft Enclosures" written by Samuel Flibbert from Jensen Hughes.

[6] Information regarding the non-symmetrical wall construction can be found in the paper "Guidance on Fire-Resistive Duct Assemblies" written by Timothy LaRose and Chares Mason from Jensen Hughes.