Smoke-Control Systems

CHAPTER 5

Provided in this chapter is information intended to assist the registered design professional (RDP), the commissioning agent, the authority having jurisdiction (AHJ), and the installing contractor in the proper commissioning of smoke-control systems. It presents information needed for the development of the basis of design (BOD), for the submission of plans and calculations during the permitting process, and for inspections and tests required to verify system performance. The RDP, commissioning agent, and/or AHJ can use this information to develop the system-specific commissioning requirements, methods, and procedures for a project specification.

OVERVIEW

General*

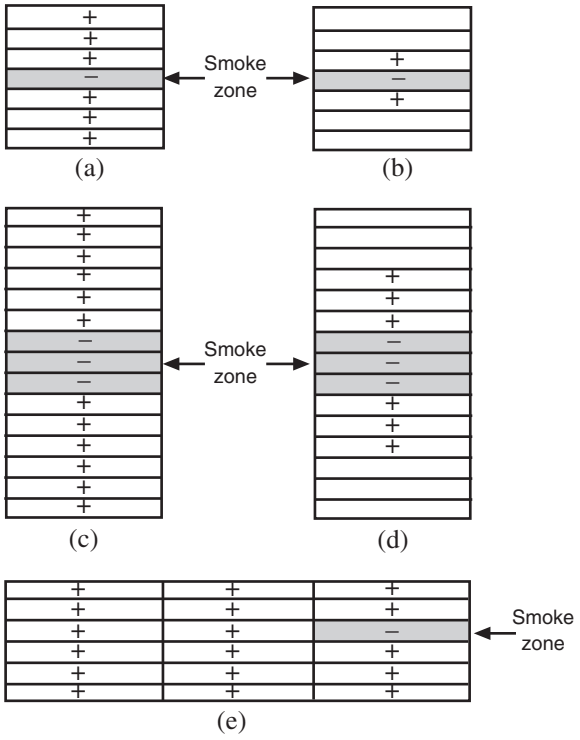
Smoke will readily travel beyond the compartment of fire origin due to several factors, including:

- Stack effect — the vertical airflow within a building caused by pressure differences between the building interior and exterior
- Temperature effect of the fire — the energy (buoyancy) of the heated smoke, which causes it to move
- Weather conditions — wind direction and velocity as well as temperature conditions
- Mechanical air-handling systems

These factors create pressure differences across barriers (e.g., walls, doors, floors) that result in the spread of smoke. The primary means of controlling smoke movement is by developing pressure differences across these barriers that overcome the energy of the smoke and confine the smoke to the compartment of origin. The basic principle is to develop higher pressures in the areas of the building (zones) adjacent to the compartment of fire origin, thereby confining the smoke to the zone of fire origin. In Exhibit 5.1, smoke zones are indicated by a minus sign, and pressurized spaces are indicated by a plus sign. Each floor can be a smoke-control zone, as in (a) and (b), or a smoke zone can consist of more than one floor, as in (c) and (d). All of the non-smoke zones in a building could be pressurized, as in

* The following general information on smoke-control systems is reproduced by permission from Wayne G. Carson and Richard L. Klinker, *Fire Protection Systems: Inspection, Test & Maintenance Manual,* third edition, NFPA, Quincy, MA, 2000, pp. 345–346.

EXHIBIT 5.1 Smoke Zones



Source: Fire Protection Systems: Inspection, Test & Maintenance Manual, *NFPA, 2000, Figure 19-1.*

(a) and (c), or only nonsmoke zones adjacent to the smoke zone could be pressurized, as in (b) and (d). A smoke zone can also be limited to part of a floor, as in (e).

The tightness (completeness) of the construction is a significant issue in the effectiveness of a smoke-control system. Openings around penetrations or poor construction may permit excessive leakage so that adequate pressure differences cannot be established.

Airflow (air velocity) can also be used to confine smoke movement through an opening. This method can be used to control the movement of smoke through an open doorway. Because relatively large quantities of air are required to prevent smoke movement through an opening, this method is not the most practical.

Smoke-control systems are designed to limit the flow of smoke into the means of egress and to confine smoke to one area of the building. Limiting the size of the fire and therefore the amount of smoke production by the installation of automatic sprinklers is generally considered necessary for effective and economical smoke control. The activation of sprinklers cools the atmosphere and takes energy from the smoke, thereby reducing its ability to move. Other protection techniques may be appropriate in different, specific situations.

Where a smoke-control system is provided, it should be activated early in the fire development to limit smoke spread. Smoke-control systems are intended to control the migration of smoke, and it should not be assumed that such systems will get rid of all of the smoke in a compartment. The smoke-control system should be coordinated with the other fire safety systems in the building to provide a unified fire safety system for the building.

Smoke-Control System Defined

A smoke-control system can be defined as an engineered system that uses mechanical fans to produce pressure differences across smoke barriers to inhibit smoke movement. A smoke-control system is used to achieve one or more of the following design objectives:

- Inhibit smoke from entering stairwells, means of egress, areas of refuge, elevator shafts, or similar areas
- Maintain a tenable environment in areas of refuge and means of egress during the time required for evacuation
- Inhibit the migration of smoke from the smoke zone
- Provide conditions outside the fire zone that enable emergency response personnel to conduct search-and-rescue operations and to locate and control the fire
- Contribute to the protection of life and to the reduction of property loss

The document used for the design of smoke-control systems is NFPA 92, *Standard for Smoke-Control Systems*. It is important that the RDP and owner establish the desired performance characteristics for these systems in the basis of the design documentation described in Part I. This information must be clearly defined in the basis of design in order to allow meaningful acceptance tests to be performed.

Quality Assurance for Smoke-Control Systems Scope

Scope

The commissioning concepts discussed in this book can be used to meet the requirements for a quality assurance program for smoke-control systems. *NFPA 5000®*, *Building Construction and Safety Code®*, establishes minimum requirements for a quality assurance program and further requires performance testing of these systems. The test procedures outlined in NFPA 92 should be used to comply with these requirements.

> A quality assurance program for the installation and operation of smoke control systems shall be prepared by the RDP responsible for design. [NFPA 5000-12: 40.6.1]
>
> Special tests and inspection of smoke control systems shall include testing during erection and prior to concealment of ductwork for the purposes of identifying leakage and recording the actuating device location. [NFPA 5000-12: 40.6.1.1]
>
> Prior to occupancy and after substantial completion, pressure difference testing, flow measurements, and detection and control verification shall be performed. [NFPA 5000-12: 40.6.1.2]

5000

Qualifications

> Testing and inspection agents for smoke control systems shall have expertise in fire protection engineering and mechanical engineering and shall be certified as air balancers. [NFPA 5000-12: 40.6.2]

5000

DESIGN PARAMETERS

The design parameters should be outlined in the basis of a design document. In addition to the owner and RDP, the approving authority should be involved in the development of the basis of design for input related to system performance and acceptance testing.

Design Objectives

> The methods for accomplishing smoke control shall include one or more of the following:

92

92

(1) The containment of smoke to the zone of origin by establishment and maintenance of pressure differences across smoke zone boundaries
(2) The management of smoke within a large-volume space and any unseparated spaces that communicate with the large-volume space [NFPA 92-12: 4.1.1]

The specific objectives to be achieved over the design interval time shall include one or more of the following:

(1) Containing the smoke to the zone of fire origin
(2) Maintaining a tenable environment within exit stairwells for the time necessary to allow occupants to exit the building
(3) Maintaining a tenable environment within all exit access and smoke refuge area access paths for the time necessary to allow occupants to reach an exit or smoke refuge area
(4) Maintaining the smoke layer interface to a predetermined elevation in large volume spaces [NFPA 92-12: 4.1.1]

Design Basis

92

A smoke control system in a given building designed to contain smoke to a given zone or keep smoke from entering another zone. [NFPA 92-12: 4.2.1]

A smoke control system in a given building designed to contain smoke to a given zone or keep smoke from entering another zone. [NFPA 92-12: 4.2.1.1]

The performance objective of automatic sprinklers installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems,* is to provide fire control, which is defined as follows: limiting the size of a fire by distribution of water so as to decrease the heat release rate and pre-wet adjacent combustibles while controlling ceiling gas temperatures to avoid structural damage. A limited number of investigations have been undertaken involving full-scale fire tests in which the sprinkler system was challenged but provided the expected level of performance (Madrzykowski and Vettori [29]; Lougheed, Mawhinney, and O'Neill [26]). These investigations indicate that, for a fire control situation, although the heat release rate is limited, smoke can continue to be produced. However, the temperature of the smoke is reduced, and the pressure differences provided in this document for smoke control systems in fully sprinklered buildings are conservative. In addition, with the reduced smoke temperatures, the temperature requirement for smoke control components in contact with exhaust gases can be limited. [NFPA 92-12: 4.2.3.1]

A The temperature ratings for the equipment used for smoke control systems shall be based on the expected temperature experienced by the equipment while the equipment is intended to be operational. [NFPA 92-12: A.4.2.1]

Temperature ratings shall be based on the following:

(1) Proximity to the fire
(2) Effects of dilution of the smoke and hot gases by entrained air [NFPA 92-12: 4.2.3.2]

Design Approaches

92

The design approach for smoke containment systems shall be one of or a combination of the following:

(1) Stairwell pressurization
(2) Zoned pressurization
(3) Elevator pressurization
(4) Vestibule pressurization
(5) Smoke refuge area pressurization [NFPA 92-12: 4.3.1]

Tenability

92

Where the design of the smoke control system is based on the potential for occupants being exposed to smoke, the tenability conditions shall be assessed. [NFPA 92-12: 4.5.1.1]

Egress Analysis

92

Where the design of the smoke control system is based on occupants exiting a space before being exposed to smoke or before tenability thresholds are reached, there shall be sufficient time for the movement of the occupant as determined by a timed egress analysis. [NFPA 92-12: 4.5.1.2]

Design Considerations

92

Designs shall incorporate the effect of openings and leakage areas in smoke barriers on the performance of the smoke-control system. [NFPA 92-12: 4.4.4.3]

A In the design of smoke-control systems, airflow paths must be identified and evaluated. Some leakage paths are obvious, such as gaps around closed doors, open doors, elevator doors, windows, and air transfer grilles. Construction cracks in building walls and floors are less obvious but no less important. The flow area of most large openings can be calculated easily. The flow area of construction cracks is dependent on workmanship — for example, how well a door is fitted or how well weather stripping is installed. Typical leakage areas of construction cracks in walls and floors of commercial buildings are listed in NFPA 92 (2012) Table A.4.4.4.3 [Exhibit 5.2]. Doors open for short periods of time result in a transition condition that is necessary in order to provide egress from or access to the smoke zone. [NFPA NFPA 92-12: A.4.6.1]

Designs shall incorporate the effect of outdoor temperature and wind on the performance of systems. [NFPA 92-12: 4.4.1]

A The temperature differences between the exterior and the interior of the building cause stack effect and determine the stack effect's direction and magnitude. The stack effect must be considered when selecting exhaust fans. The effect of temperature and wind velocity varies with building height, configuration, leakage, and openings in wall and floor construction. One source of weather data is the *ASHRAE Handbook of Fundamentals*, Chapter 26, Climatic Design Information. It is suggested that the 99.6 percent heating dry bulb (DB) temperature and the 0.4 percent cooling DB temperature be used as the winter and summer design conditions, respectively. It is also suggested that the 1 percent extreme wind velocity be used as the design condition. If available, more site-specific wind data should be consulted. [NFPA 92-12: A.4.4.1]

Except as specified by 4.4.2.1.2, the pressure differences in NFPA 92 (2012) Table 4.4.2.1.1 [Exhibit 5.3] shall be used for designs that are based on maintaining minimum pressure differences between specified spaces. [NFPA 92-12: 4.4.2.1.1]

Where the system designer has determined that a higher minimum pressure difference is necessary to achieve the smoke control system objectives, the higher minimum pressure difference shall be used. [NFPA 92-12: 4.4.2.1.2]

The minimum allowable pressure difference shall restrict smoke leakage during building evacuation to a level that maintains a tenable environment in areas outside the smoke zone. [NFPA 92-12: 4.4.2.1.3]

The minimum pressure difference for smoke control systems shall be established at a level that is high enough that it will not be overcome by the forces of wind, stack effect, or buoyancy of hot smoke. [NFPA 92-12: 4.4.2.14]

The calculations shall take into account the design number of doors to be opened simultaneously. [NFPA 92-12: 4.4.2.1.4]

EXHIBIT 5.2 Typical Leakage Areas for Walls and Floors of Commercial Buildings.

Construction Element	Tightness	Area Ratio[a]
Exterior building walls (includes construction cracks and cracks around windows and doors)	Tight[b]	0.50×10^{-4}
	Average[b]	0.17×10^{-3}
	Loose[b]	0.35×10^{-3}
	Very loose[b]	0.12×10^{-2}
Stairwell walls (includes construction cracks, but not cracks around windows and doors)	Tight[c]	0.14×10^{-4}
	Average[c]	0.11×10^{-3}
	Loose[c]	0.35×10^{-3}
Elevator shaft walls (includes construction cracks, but not cracks and gaps around doors)	Tight[c]	0.18×10^{-3}
	Average[c]	0.84×10^{-3}
	Loose[c]	0.18×10^{-2}
Floors (includes construction cracks and gaps around penetrations)	Tight[d]	0.66×10^{-5}
	Average[e]	0.52×10^{-4}
	Loose[d]	0.17×10^{-3}

[a] For a wall, the area ratio is the area of the leakage through the wall divided by the total wall area. For a floor, the area ratio is the area of the leakage through the floor divided by the total area of the floor.
[b] Values based on measurements of Tamura and Shaw (1976), Tamura and Wilson (1966) and Shaw, Reardon, and Cheung (1993).
[c] Values based on measurements of Tamura and Wilson (1966), and Tamura and Shaw (1976).
[d] Values extrapolated from average floor tightness based on range of tightness of other construction elements.
[e] Values based on measurements of Tamura and Shaw (1978).

Source: NFPA 92, 2012, Table A.4.6.1.

EXHIBIT 5.3 Suggested Minimum Design Pressure Differences Across Smoke Barriers

Building Type	Ceiling Height (ft)	Design Pressure Difference* (in. w.g.)
AS	Any	0.05
NS	9	0.10
NS	15	0.14
NS	21	0.18

For SI units, 1 ft = 0.305 m; 0.1 in. w.g. = 25 Pa.
AS: Sprinklered. NS: Nonsprinklered.

Notes:
(1) The table presents minimum design pressure differences developed for a gas temperature of 1700°F (925°C) next to the smoke barrier.
(2) For design purposes, a smoke-control system shall maintain these minimum pressure differences under specified design conditions of stack effect or wind.

*For zoned smoke-control systems, the pressure difference shall be measured between the smoke zone and adjacent spaces while the affected areas are in the smoke-control mode.

Source: NFPA 92, 2012, Table 5.2.1.1.

DOCUMENTATION

The testing documentation and owner's manuals and instructions should be kept on file for the intended service life of the system.

Documentation Required

The following documents shall be generated by the designer during the design process:

(1) Detailed design report
(2) Operations and maintenance manual [NFPA 92-12: 7.1]

Detailed Design Report

The detailed design report shall provide documentation of the smoke control system as it is designed and intended to be installed. [NFPA 92-12: 7.2.1]

The design report shall include the following elements, if applicable:

(1) System purpose
(2) System design objectives
(3) Design approach
(4) Design assumptions (building height, ambient conditions, reliance on other fire protection systems, leakage, etc.)
(5) Location of smoke zone(s)
(6) Design pressure differences
(7) Building use limitations that arise out of the system design

92

92

(8) Design calculations
(9) Fan and duct specifications
(10) Damper specifications
(11) Detailed inlet or exhaust inlets site information
(12) Detailed method of activation
(13) Smoke control system operation logic
(14) System commissioning procedures [NFPA 92-12: 7.2.2]

Operations and Maintenance Manual

92

The operations and maintenance manual shall provide the requirements to ensure the proper operation of the system over the life of the building. [NFPA 92-12: 7.3]

The operations and maintenance manual shall include the following:

(1) The procedures used in the initial commissioning of the system as well as the measured performance of the system at the time of commissioning
(2) The testing and inspection requirements for the system and system components and the required frequency of testing (see NFPA 92, Chapter 8)
(3) The critical design assumptions used in the design and limitations on the building and its use that arise out of the design assumptions and limitations
(4) The purpose of the smoke control system [NFPA 92-12: 7.3.1]

Copies of the operations and maintenance manual shall be provided to the owner and the authorities having jurisdiction. [NFPA 92-12:7.3.2]

The building owner shall be responsible for all system testing and shall maintain records of all periodic testing and maintenance in accordance with the operations and maintenance manual. [NFPA 92-12: 7.3.3]

The building owner shall be responsible for limiting the use of the space in a manner consistent with the limitations provided in the operations and maintenance manual. [NFPA 92-12: 7.3.4]

TESTING PROCEDURES

General

92

A Some smoke control systems are designed to limit smoke migration at the boundaries of a smoke control area using pressure differences. A stairwell pressurization system is used to limit smoke movement from the floor area into the stairwell and thus provide a tenable environment during egress. For zoned smoke control, pressure differences are used to contain smoke within the smoke zone and limit the migration of smoke and fire gases to other parts of the building. Testing appropriate to the objective of the system consists of measuring the pressure difference between the smoke zone and the adjacent zones. The testing procedures provided in Section 8.4 are based on the measurement of pressure differences and door-opening forces under the design conditions agreed on with the authority having jurisdiction.

An understanding with the authority having jurisdiction on the expected performance of the system and the acceptance test procedures should be established early in the design. (Detailed engineering design information is contained in ASHRAE/SFPE Principles of Smoke Management [21] and the NFPA publication Smoke Movement and Control in High-Rise Buildings [49]).

Absence of a consensus agreement for a testing procedure and acceptance criteria historically has created numerous problems at the time of system acceptance, including delays in obtaining a certificate of occupancy.

92

It is recommended that the building owner, the designer, and the authority having jurisdiction meet during the planning stage of the project to share their thoughts and objectives concerning the smoke control system and agree on the design criteria and the pass/fail performance tests for the systems. Such an agreement helps to overcome the numerous problems that occur during final acceptance testing and facilitates obtaining the certificate of occupancy. [NFPA 92-12: A.8.1]

Preliminary Building Inspections

92

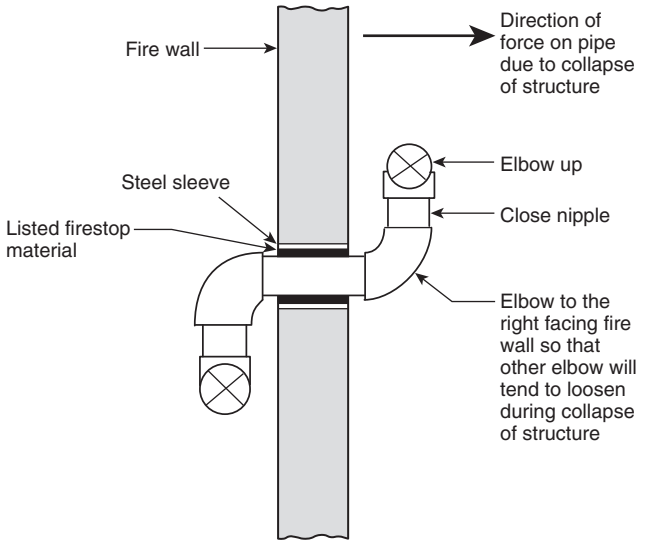
Prior to testing, the party responsible for testing shall verify completeness of building construction. [NFPA 92-12: 8.2.1]

The following architectural features, where applicable, shall be inspected:

(1) Smoke barriers, including joints therein
(2) Shaft integrity
(3) Firestopping
(4) Doors/closers
(5) Glazing, including that enclosing a large-volume space
(6) Partitions and ceilings [NFPA 92-12: 8.2.2]

The verification suggested in this section should be in the form of an inspection report or punch list for incomplete installations. The inspection should include each wall or floor penetration to verify that a fire stop, or a rated fire penetration sealing material, has been installed (see Exhibit 5.4). This verification should include a review of the specified materials, the approved product data submittals, and installation plans or sketches.

EXHIBIT 5.4 Pipe Penetration



Source: NFPA 221, 2000, Figure A.6.1.

OPERATIONAL AND ACCEPTANCE TESTING

Operational Testing

The project specifications and basis of design should clearly spell out the objectives of operational testing. Prior to performing any tests, an inspection of the completed system should be made and documented in an inspection report verifying the completeness of

the installation. The inspection report can also include a punch list of incomplete items. The inspection is also an opportunity to revise installation plans to include any field changes, thus allowing the installation plans to be updated to as-built status.

92

A The intent of component system testing is to establish that the final installation complies with the specified design, is functioning properly, and is ready for acceptance testing. Operational testing of system components should be completed during construction. These operational tests normally are performed by various trades before interconnection is made to integrate the overall smoke control system. It should be documented in writing that each individual system component's installation is complete and the component is functional. Each component test, including items such as speed, volume, sensitivity calibration, voltage, and amperage, should be individually documented. [NFPA 92-12: A.8.3]

An operational test of each smoke control system component and subsystem shall be performed prior to the acceptance test. [NFPA 92-12: 8.3.1]

Operational tests shall be performed prior to interconnection of individual components and subsystems to the smoke control system. [NFPA 92-12: 8.3.2]

Smoke control system operational testing shall include all subsystems to the extent that they affect the operation of the smoke control system. [NFPA 92-12: 8.3.3]

A Systems that could affect or be affected by the operation of the smoke control system include the following:

(1) Fire alarm system (see *NFPA 72®*)
(2) Energy management system
(3) Building management system
(4) Heating, ventilating, and air-conditioning (HVAC) equipment
(5) Electrical equipment
(6) Temperature control system
(7) Power sources
(8) Standby power
(9) Automatic suppression systems
(10) Automatic operating doors and closures
(11) Other smoke control systems
(12) Emergency elevator operation
(13) Dampers
(14) Fire fighters' control station (FFCS) [NFPA 92-12: A.8.3.3]

Requirements and responsibilities for each component test shall be identified in the design documentation. [NFPA 92-12: 8.3.4]

All documentation from component system testing relative to the smoke control system shall be included in the final testing documentation. [NFPA 92-12: 8.3.5]

Acceptance Testing

92

Acceptance testing shall demonstrate that the final integrated system installation complies with the specific design and is functioning properly. [NFPA 92-12: 8.4.1]

Where appropriate to the design, all parameters shall be measured during acceptance testing. [NFPA 92-12: 8.4.2]

The locations for measurement of the parameters identified in 8.4.2 shall be in accordance with nationally recognized methods. [NFPA 92-12: 8.4.3]

The acceptance testing shall include the procedures described in 8.4.4.1 through 8.4.4.4. [NFPA 92-12: 8.4.4]

Prior to beginning acceptance testing, all building equipment shall be placed in the normal operating mode, including equipment that is not used to implement smoke control. [NFPA 92-12: 8.4.4.1]

92

If standby power has been provided for the operation of the smoke control system, the acceptance testing shall be conducted while on both normal and standby power. [NFPA 92-12: 8.4.4.2]

The acceptance testing shall include demonstrating that the correct outputs are produced for a given input for each control sequence specified. [NFPA 92-12: 8.4.4.3]

The complete smoke control sequence shall be demonstrated for the following:

(1) Normal mode
(2) Automatic smoke control mode for first alarm
(3) Transfer to standby power if provided.
(4) Return to normal [NFPA 92-12: 8.4.4.4]

SUMMARY

Commissioning of smoke-control systems must be based on the BOD and the performance of the system described therein. *NFPA 92, Standard for Smoke-Control Systems,* contains prescriptive measures for the testing of these systems. The procedures outlined in Part I should be followed to establish the BOD and the submission of plans, calculations, and project closeouts.