

NFPA® 92B

Standard for Smoke Management Systems in Malls, Atria, and Large Spaces

2009 Edition



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NFPA® 92B

Standard for

Smoke Management Systems in Malls, Atria, and Large Spaces

2009 Edition

This edition of NFPA 92B, *Standard for Smoke Management Systems in Malls, Atria, and Large Spaces*, was prepared by the Technical Committee on Smoke Management Systems. It was issued by the Standards Council on May 30, 2008, with an effective date of July 18, 2008, and supersedes all previous editions.

This edition of NFPA 92B was approved as an American National Standard on July 18, 2008.

Origin and Development of NFPA 92B

The NFPA Standards Council established the Technical Committee on Smoke Management Systems in 1985 and charged it with addressing the need for guidelines and materials on building fire smoke management. The Committee's first document, NFPA 92A, *Recommended Practice for Smoke-Control Systems*, was published in 1988 and addressed smoke control utilizing barriers, airflows, and pressure differentials so as to confine the smoke of a fire to the zone of fire origin to maintain a tenable environment in other zones. The complex problem of maintaining tenable conditions within large zones of fire origin, such as atria and shopping malls, represented a more difficult issue in terms of the physics involved and thus was reserved for the document, NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*. The first edition was published in 1991; the second edition was published in 1995.

The 2000 edition was a substantial rewrite of the document to reflect the best current information on smoke management in malls, atria, and other large spaces. Major changes included new and updated definitions, additional data on the impact of sprinklers on smoke management, extensive discussion on basic principles and limitations, additional information on estimating heat release rates of fires, and new criteria for system verification.

The 2005 edition was a major revision from the previous edition. The document was rewritten as a standard with mandatory provisions regarding the design, installation, and testing of smoke management systems. In addition, the document was reorganized to comply with the *Manual of Style for NFPA Technical Committee Documents*. Some technical changes included the revision of some equations used to determine the minimum number of exhaust inlets and the introduction of advisory information on how to calculate smoke temperature when plugholing is being considered. Text was also revised to clarify the application of certain equations and to provide guidance on determining the effective smoke layer interface and the application of virtual origin concept. Example problems were revised to reflect changes made in the standard.

The 2009 edition includes changes that specify design criteria to maintain tenable spaces, provision for plume design for a variety of geometrics, and a method to calculate smoke densities. This edition also incorporates the Tentative Interim Amendments (TIAs) issued for the 2005 edition, which modified a number of the equations.



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Committee Scope: This Committee shall have primary responsibility for documents on the design, installation, testing, operation, and maintenance of systems for the control, removal, or venting of heat or smoke from fires in buildings.



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Changes other than editorial are indicated by a vertical rule beside the paragraph, table, or figure in which the change occurred. These rules are included as an aid to the user in identifying changes from the previous edition. Where one or more complete paragraphs have been deleted, the deletion is indicated by a bullet (•) between the paragraphs that remain.

A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex J. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced publications can be found in Chapter 2 and Annex J.

Chapter 1 Administration**1.1* Scope.**

1.1.1 This standard provides methodologies for estimating the location of smoke within a large-volume space due to a fire either in the large-volume space or in an adjacent space.

1.1.1.1 These methodologies comprise the technical basis for assisting in the design, installation, testing, operation, and maintenance of new and retrofitted smoke management systems for the management of smoke within the space where the fire exists or between spaces not separated by smoke barriers.

1.1.1.2 Buildings within the scope of this standard include those with atria, covered malls, and similar large-volume spaces.

1.1.1.3 This standard is not intended to apply to warehouses, manufacturing facilities, or other similar spaces.

1.1.1.4 This standard does not provide methodologies to assess the effects of smoke exposure on people, property, or mission continuity.

1.1.2 The algebraic approaches to smoke management contained in this standard assume either that the smoke removal will be by mechanical means or that the smoke will fill the large space.

1.2 Purpose.

1.2.1* The purpose of this standard is to provide requirements for implementing smoke management systems to accomplish one or both of the following:

- (1) Maintain a tenable environment in the means of egress from large-volume building spaces during the time required for evacuation
- (2) Control and reduce the migration of smoke between the fire area and adjacent spaces

1.2.2 Specific design objectives are established in other codes and standards.

1.3 Retroactivity.

1.3.1 Unless otherwise noted, the provisions of this standard are not intended to be applied to facilities, equipment, structures, or installations that were existing or approved for construction or installation prior to the effective date of this standard.

1.3.2 In those cases where the authority having jurisdiction determines that the existing situation involves a distinct hazard to life or property, retroactive application of the provisions of this standard shall be permitted.

1.3.3 Where a smoke management system is being altered, extended, or renovated, the requirements of this standard shall apply only to the work being undertaken.

1.3.4 Verification is required to ensure that new or modified systems do not adversely affect the performance of existing smoke management systems.

1.4 Equivalency.

1.4.1 Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard.

1.4.2 Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

1.4.3 The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 70®, *National Electrical Code*®, 2008 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2009 edition.

2.3 Other Publications.

2.3.1 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ANSI/UL 555, *Standard for Fire Dampers*, 2006.

ANSI/UL 555S, *Standard for Smoke Dampers*, 2006.

ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems*, 2006.



2.3.2 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA 101®, *Life Safety Code*®, 2009 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities*, 2009 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.4* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.2.7 Standard. A document, the main text of which contains only mandatory provisions using the word “shall” to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

3.3 General Definitions.

3.3.1 Atrium. A large-volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; an elevator hoistway; an escalator opening; or as a utility shaft used for

plumbing, electrical, air-conditioning, or communications facilities. [101, 2009]

3.3.2* Ceiling Jet. A flow of smoke under the ceiling, extending radially from the point of fire plume impingement on the ceiling.

3.3.3* Communicating Space. A space within a building that has an open pathway to a large-volume space such that smoke from a fire either in the communicating space or in a large-volume space can move from one to another without restriction.

3.3.4 Covered Mall. A single building enclosing a number of tenants and occupancies wherein two or more tenants have a main entrance into one or more malls.

3.3.5 Draft Curtain. A solid material, beam, girder, or similar material or construction used to channel or contain smoke that is attached to the underside of the ceiling and protrudes a limited distance downward.

3.3.6 End-to-End Verification. A self-testing method that provides positive confirmation that the desired result (i.e., airflow or damper position) has been achieved when a controlled device has been activated, such as during smoke control, testing, or manual override operations.

3.3.7 Fire.

3.3.7.1 Fuel Limited Fire. A fire that has a heat release rate that is controlled by the material burning.

3.3.7.2 Sprinkler Controlled Fire. A fire that has a constant or decaying heat release rate due to the action of sprinkler spray.

3.3.7.3 Steady Fire. A fire that has a constant heat release rate.

3.3.7.4 t -Squared (t^2) Fire. A fire that has a heat release rate that grows proportionally to the square of time from ignition. [See Annex C for further information on t -squared (t^2) profile fires.]

3.3.7.5 Unsteady Fire. A fire that has a heat release rate that varies with respect to time.

3.3.7.6 Ventilation Limited Fire. A fire where every object in the fire compartment is fully involved in fire and the heat release rate depends on the airflow through the openings to the fire compartment.

3.3.8* First Indication of Smoke. The boundary between the transition zone and the smokefree air.

3.3.9 Growth Time (t_g). The time interval from the time of effective ignition until the heat release rate of the fire is 1000 Btu/sec (1055 kW).

3.3.10 Large-Volume Space. An uncomparted space, generally two or more stories in height, within which smoke from a fire either in the space or in a communicating space can move and accumulate without restriction.

3.3.11 Plugholing. The condition where air from below the smoke layer is pulled through the smoke layer into the smoke exhaust due to a high exhaust rate.

3.3.12* Plume. A column of smoke that rises above a fire.

3.3.12.1* Axisymmetric Plume. A plume that rises above a fire, does not come into contact with wall or other obstacles, and is not disrupted or deflected by airflow.

3.3.12.2* Balcony Spill Plume. A smoke plume that originates from a compartment fire, flows out the doorway, flows under a balcony, and flows upward after passing the balcony edge.

3.3.12.3* Window Plume. A plume that flows out of an opening to a room or other compartment that is involved in a ventilation limited fire.

3.3.13 Separated Spaces. Spaces within a building that are isolated from large-volume spaces by smoke barriers.

3.3.14 Smoke. The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass. [318, 2009]

3.3.15* Smoke Barrier. For the purposes of this standard, a continuous membrane, either vertical or horizontal, such as a wall, floor, or ceiling assembly, that is designed and constructed to restrict the movement of smoke in conjunction with a smoke control or management system.

3.3.16 Smoke Damper. A device within the air distribution system to control the movement of smoke.

3.3.17* Smoke Layer. The accumulated thickness of smoke below a physical or thermal barrier.

3.3.18* Smoke Layer Interface. The theoretical boundary between a smoke layer and the smokefree air.

3.3.19 Smoke Management System. An engineered system that includes all methods that can be used singly or in combination to modify smoke movement.

3.3.20 Stack Effect. The vertical airflow within buildings caused by the temperature-created density differences between the building interior and exterior or between two interior spaces.

3.3.21 Tenable Environment. An environment in which the products of combustion, including toxic gases, particulates, and heat, are limited or otherwise restricted to maintain the impact on occupants to a level that is not life threatening.

3.3.22* Transition Zone. The layer between the smoke layer interface and the first indication of smoke in which the smoke layer temperature decreases to ambient.

- (1) The design basis fires used to calculate smoke production (type, location, and quantity of fuel for each design basis fire, extent of coverage and reliability of automatic suppression, and extent and type of ventilation)
- (2) Height, cross-sectional area, and plan area of the large volume to be protected
- (3) Height, cross-sectional area, and plan area of each unseparated space that communicates with the large-volume area
- (4) Type and location of occupancies within and communicating with the large-volume space
- (5) Barriers separating adjacent spaces from the large-volume space
- (6) Egress routes from the large-volume space and any communicating space
- (7) Areas of refuge, if any

4.2.2 The source of the smoke from the design basis fires shall consider fire locations within the large-volume space and within unseparated communicating spaces.

4.3 Design Approaches.

4.3.1* The design approach for smoke management in large-volume spaces shall be one or a combination of the following:

- (1) Natural smoke filling of an unoccupied volume or smoke reservoir and modeling smoke layer descent to determine whether the smoke layer interface will reach a height at which occupants will be exposed to smoke before they are able to egress from the space
- (2)*Mechanical smoke exhaust capacity to remove smoke from a space to maintain the smoke layer interface at a predefined height in the space for an indefinite period of time
- (3) Mechanical smoke exhaust capacity to remove smoke from a space to slow the rate of smoke layer descent for a period that allows occupants to safely egress from the space
- (4) Natural smoke venting to maintain the smoke layer interface at a predefined height in the space for an indefinite period of time
- (5) Natural smoke venting to slow the rate of smoke layer descent for a period that allows occupants to egress from the space
- (6) Approaches that maintain a tenable environment for a period of time that allows occupants to safely egress from the space

4.3.2 The smoke development analysis in each of the design approaches listed in 4.3.1 shall be justified using algebraic calculations, computational fluid dynamics (CFD) models, compartment fire models, scale modeling, or zone models (*see Chapter 5*).

4.4 Design Considerations.

4.4.1 Design Limitations.

4.4.1.1* Minimum Design Smoke Layer Depth. The minimum design depth of the smoke layer shall be either of the following:

- (1) Twenty percent of the floor-to-ceiling height
- (2) Based on an engineering analysis

4.4.1.2 Special Considerations Related to Natural Venting. Designs that use a mix of natural and mechanical ventilation shall have supporting engineering analysis or physical (scale) modeling to verify the design functions as intended.

Chapter 4 Design Fundamentals

4.1 Design Objectives.

4.1.1 The design objectives shall include management of smoke within the large-volume space and any unseparated spaces that communicate with the large-volume space.

4.1.2* The design objectives to be achieved over the design interval time by a smoke management system shall include one or both of the following:

- (1) Maintaining a tenable environment within all exit access and area of refuge access paths for the time necessary to allow occupants to reach an exit or area of refuge
- (2) Maintaining the smoke layer interface to a predetermined elevation

4.2 Design Basis.

4.2.1 The design basis for a given large-volume building shall include the determination of the following parameters:



4.4.2 Communicating Spaces.

4.4.2.1 Managing Smoke Spread to Communicating Spaces. Managing smoke spread to communicating spaces shall be accomplished by one of the following methods:

- (1) Maintaining the smoke layer interface at a level higher than that of the highest opening to the communicating space
- (2)*Providing a barrier to transform a communicating space into a separated space
- (3) Providing an opposed airflow through the opening to prohibit smoke spread into the communicating space

4.4.2.1.1 When smoke barriers are used to limit smoke spread into the communicating space, engineering calculations shall be provided to verify whether a pressure difference applied across the smoke barrier will be needed to prevent smoke migration.

4.4.2.1.2 When the airflow method is used to prevent smoke movement from the large-volume space into communicating spaces for large openings, the flow shall be nearly perpendicular to the plane of the opening.

4.4.2.2* Managing Smoke from Communicating Spaces.

4.4.2.2.1 When communicating spaces are designed to allow the smoke to spill into the large-volume space, the smoke spilling into the large-volume space shall be handled by the smoke management system either to maintain the design smoke layer interface height or to maintain a tenable environment.

4.4.2.2.2 When the smoke control systems are designed to use airflow to prevent the movement of smoke into the large-volume space, sufficient exhaust from the communicating space shall be provided to establish a minimum flow between it and the large-volume space. (See 5.5.1.)

4.5 Smoke Management System Operation.

4.5.1 Activation.

4.5.1.1 Activation of smoke management systems shall be accomplished by an approved automatic means.

4.5.1.2 For large spaces where smoke stratification can occur, one of the following detection means shall be used:

- (1) Beam-type smoke detector(s) aimed at an upward angle to intersect the smoke layer regardless of the level of stratification
- (2) Horizontally mounted beam-type smoke detector(s) located at the ceiling with additional beam-type smoke detector(s) located at other levels in the volume to cover any identified unconditioned (dead air) spaces
- (3) Horizontally mounted beam-type smoke detector(s) located below the lowest expected level of stratification

4.5.2* System Startup.

4.5.2.1 The smoke management system shall achieve full operation prior to conditions in the space reaching the design smoke conditions.

4.5.2.2 The determination of the time it takes for the system to become operational shall consider the following events (as appropriate to the specific design objectives):

- (1) Time for detection of the fire incident
- (2) HVAC system activation time including shut-down and start-up of air handling equipment, opening and closing of dampers, and opening and closing of natural ventilation devices

4.5.3 Duration.

4.5.3.1 When the design of the smoke management system is based on occupants exiting a space before being exposed to smoke or before tenability thresholds are reached, the system shall remain operational for the duration required.

4.5.3.2 Smoke management systems designed to maintain tenable conditions shall not be required to prevent the descent of a smoke layer in spaces where tenable conditions are demonstrated.

4.5.3.3 When the design of the smoke management system is based on occupants' exiting a space before being exposed to smoke or before tenability thresholds are reached, a timed egress analysis shall be conducted.

4.5.4 Manual Override.

4.5.4.1 A means of manually starting and stopping the smoke management system shall be provided at an approved location accessible to the fire department.

4.5.4.2 Manual controls shall be able to override automatic system operation.

4.6 Makeup Air. Makeup air shall be provided by fans, openings to the outside leakage paths, or the combination thereof.

4.6.1 The supply points for the makeup air shall be located beneath the smoke layer interface.

4.6.2* Mechanical makeup air shall be less than the mass flow rate of the mechanical smoke exhaust.

4.6.3 The makeup air shall not cause door-opening force to exceed allowable limits.

4.6.4* The makeup air velocity shall not exceed 200 ft/min (1.02 m/sec) where the makeup air could come into contact with the plume unless a higher makeup air velocity is supported by engineering analysis.

4.7 Operating Conditions. The smoke management system components shall be capable of continuous use at the maximum temperatures expected over the design interval time.

4.8* Weather Data. Designs shall incorporate the effect of outdoor temperature and wind on the performance of the smoke management system.

4.9* Stratification of Smoke. For large-volume spaces where smoke stratification can occur, one of the detection schemes of 4.5.1.2 shall be used.

Chapter 5 Calculation Procedures

5.1* Introduction. The method of analysis used for the smoke management system shall be one of the methods given in 5.1.1 through 5.1.3.

5.1.1* Scale Modeling.

5.1.1.1 In a scale model, the model shall be proportional in all dimensions to the actual building.

5.1.1.2 The size of the fire and the interpretation of the results shall be governed by the scaling laws, as given in Section 5.6.

5.1.2* Algebraic Equations. The algebraic equations of Chapter 6 shall be permitted to be used to provide a means of calculating individual factors that collectively can be used to establish the design requirements of a smoke management system.

5.1.3* Compartment Fire Models. Compartment fire models shall be zone fire models or CFD models. (For information about zone fire models, see Annex E. For information about CFD models, see Annex F.)

5.2 Design Fire.

5.2.1* General. This section presents the equations that shall be used to calculate the heat release rates for design fires. (For information about the heat release rates of fires, see Annex B.)

5.2.2 Design Fire Types. Design fires shall be one of the following:

- (1) Steady fire with a constant heat release rate
- (2) Unsteady fire with a heat release rate that varies with time

5.2.3 Steady Design Fires.

5.2.3.1 The heat release rate of steady design fires shall be based on available or developed test data.

5.2.3.2 Where the available fuel mass is used to limit the duration of a steady design fire, the duration of the fire shall be calculated using Equation 5.2.3.2a or 5.2.3.2b as follows:

$$\Delta t = \frac{mH_c}{Q} \quad (5.2.3.2a)$$

where:

Δt = duration of fire (sec)

m = total fuel mass consumed (lb)

H_c = heat of combustion of fuel (Btu/lb)

Q = heat release rate (Btu/sec)

$$\Delta t = \frac{mH_c}{Q} \quad (5.2.3.2b)$$

where:

Δt = duration of fire (sec)

m = total fuel mass consumed (kg)

H_c = heat of combustion of fuel (kJ/kg)

Q = heat release rate (kW)

5.2.4 Unsteady Design Fires. Unsteady design fires shall include a growth phase and shall include a steady phase or a decay phase, as depicted in Figure 5.2.4(a) and Figure 5.2.4(b), where steady or decay phases are justified based on test data, fuel configuration, or proposed protection systems.

5.2.4.1 Growth Phase. The growth phase of the fire shall be described using one of the following:

- (1) Fire test data
- (2) t -squared fire growth model
- (3) Other fire growth models acceptable to the authority having jurisdiction

5.2.4.2 t -squared Fire Growth Model.

5.2.4.2.1 Where used, the heat release rate of a t -squared design fire shall be calculated according to Equation 5.2.4.2.1a or 5.2.4.2.1b as follows:

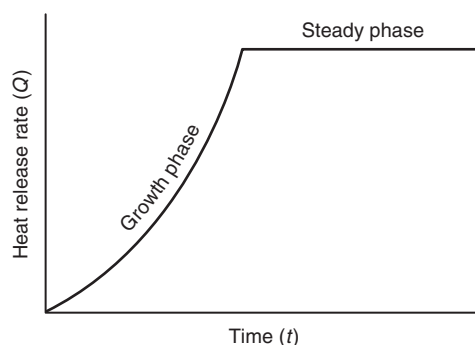


FIGURE 5.2.4(a) Unsteady Design Fire with Steady Phase.

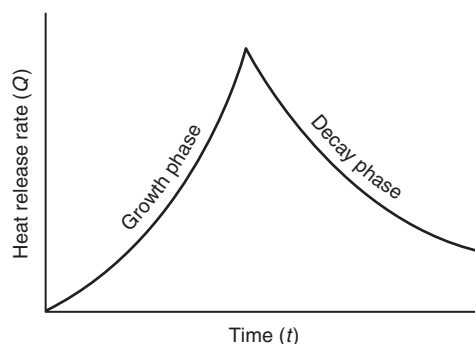


FIGURE 5.2.4(b) Unsteady Design Fire with Decay Phase.

$$Q = 1000 \left(\frac{t}{t_g} \right)^2 \quad (5.2.4.2.1a)$$

where:

Q = heat release rate of design fire (Btu/sec)

t = time after effective ignition (sec)

t_g = growth time (sec)

$$Q = 1055 \left(\frac{t}{t_g} \right)^2 \quad (5.2.4.2.1b)$$

where:

Q = heat release rate of design fire (kW)

t = time after effective ignition (sec)

t_g = growth time (sec)

5.2.4.2.2 Where the available fuel mass is used to limit the duration of a t -squared fire, the duration of the fire shall be calculated using Equation 5.2.4.2.2a or 5.2.4.2.2b as follows:

$$\Delta t = \left(\frac{mH_c t_g^2}{333} \right)^{1/3} \quad (5.2.4.2.2a)$$

where:

Δt = duration of fire (sec)

m = total fuel mass consumed (lb)

H_c = heat of combustion of fuel (Btu/lb)

t_g = growth time (sec)



$$\Delta t = \left(\frac{m H_c t_g^2}{333} \right)^{1/3} \quad (5.2.4.2.2b)$$

where:

Δt = duration of fire (sec)

m = total fuel mass consumed (kg)

H_c = heat of combustion of fuel (kJ/kg)

t_g = growth time (sec)

5.2.4.3 Steady Phase. The growth of an unsteady design fire shall be permitted to reach a steady heat release rate based on one of the following:

- (1) Fire test data
- (2) Engineering analysis of fire growth and sprinkler response

5.2.4.4* Decay Phase. The heat release rate of a design fire shall be permitted to decay based on one of the following:

- (1) Fire test data
- (2) Analysis of the effect of sprinkler protection on the fuel at the prevailing ceiling height

5.2.5* Separation Distance.

5.2.5.1 The design fire shall be determined by considering the type of fuel, fuel spacing, and configuration.

5.2.5.2 The selection of the design fire shall start with a determination of the base fuel package, which is the maximum probable size fuel package likely to be involved in fire.

5.2.5.3 The design fire shall be increased if other combustibles are within the separation distance, R , as determined from Equation 5.2.5.3a or 5.2.5.3b.

$$R = \left(\frac{Q_r}{4\pi q_r''} \right)^{1/2} \quad (5.2.5.3a)$$

where:

R = separation distance from target to center of fuel package (ft)

Q_r = radiative portion of the heat release rate of the fire (Btu/ft)

q_r'' = incident radiant flux required for piloted ignition (Btu/ft²·s)

$$R = \left(\frac{Q_r}{4\pi q_r''} \right)^{1/2} \quad (5.2.5.3b)$$

where:

R = separation distance from target to center of fuel package (m)

Q_r = radiative portion of the heat release rate of the fire (kW)

q_r'' = incident radiant flux required for piloted ignition (kW/m²)

5.2.5.4 The radiative portion of the heat release rate of the fire shall be determined from Equation 5.2.5.4a or 5.2.5.4b.

$$Q_r = \xi Q \quad (5.2.5.4a)$$

where:

Q_r = radiative portion of the heat release rate of the fire (Btu/sec)

ξ = radiative fraction (dimensionless)

Q = heat release rate of the fire (Btu/sec)

$$Q_r = \xi Q \quad (5.2.5.4b)$$

where:

Q_r = radiative portion of the heat release rate of the fire (kW)

ξ = radiative fraction (dimensionless)

Q = heat release rate of the fire (kW)

5.2.5.5 A value of 0.3 shall be used for the radiative fraction unless another value is substantiated in accordance with test data.

5.2.5.6 If the base fuel package is not circular, an equivalent radius shall be calculated by equating the floor area covered by the fuel package with that subtended by a circle of the equivalent radius.

5.2.5.7 A value of 0.9 Btu/ft²·sec (10 kW/m²) shall be used for the incident radiant heat flux required for piloted ignition unless another value is substantiated in accordance with approved test data.

5.3 Mass Consumption.

5.3.1 For a steady fire, the total mass consumption required to sustain the steady heat release rate shall be determined in accordance with Equation 5.3.1a or 5.3.1b as follows:

$$m = \frac{Q \Delta t}{H_c} \quad (5.3.1a)$$

where:

m = total fuel mass consumed (lb)

Q = heat release rate (Btu/sec)

Δt = duration of fire (sec)

H_c = heat of combustion of fuel (Btu/lb)

$$m = \frac{Q \Delta t}{H_c} \quad (5.3.1b)$$

where:

m = total fuel mass consumed (kg)

Q = heat release rate (kW)

Δt = duration of fire (sec)

H_c = heat of combustion of fuel (kJ/kg)

5.3.2 For a t -squared fire, the total mass consumed shall be determined in accordance with Equation 5.3.2a or 5.3.2b as follows:

$$m = \frac{333 \Delta t^3}{H_c t_g^2} \quad (5.3.2a)$$

where:

m = total fuel mass consumed (lb)

Δt = duration of fire (sec)

H_c = heat of combustion of fuel (Btu/lb)

t_g = growth time (sec)

$$m = \frac{333 \Delta t^3}{H_c t_g^2} \quad (5.3.2b)$$

where:

m = total fuel mass consumed (kg)

Δt = duration of fire (sec)

H_c = heat of combustion of fuel (kJ/kg)

t_g = growth time (sec)

5.4* Varying Cross-Sectional Geometries and Complex Geometries. When the large space has a nonuniform cross-sectional area, the design analysis shall take into account the variation of cross-sectional area with height.

5.5 Opposed Airflow.

5.5.1 Where opposed airflow is used to prevent smoke originating in a communicating space from propagating into the large-volume space as shown in Figure 5.5.1, the communicating space shall be exhausted at a sufficient rate to cause the average air velocity in the opening from the large-volume space to exceed the limiting average air velocity, v_e , calculated using Equation 5.5.1a or 5.5.1b as follows:

$$v_e = 38 \left(gH \frac{T_f - T_o}{T_f} \right)^{1/2} \quad (5.5.1a)$$

where:

v_e = limiting average air velocity (ft/min)

g = acceleration of gravity (32.2 ft/sec²)

H = height of the opening as measured from the bottom of the opening (ft)

T_f = temperature of heated smoke (R)

T_o = temperature of ambient air (R)

$$v_e = 0.64 \left(gH \frac{T_f - T_o}{T_f} \right)^{1/2} \quad (5.5.1b)$$

where:

v_e = limiting average air velocity (m/sec)

g = acceleration of gravity (9.81 m/sec²)

H = height of the opening as measured from the bottom of the opening (m)

T_f = temperature of heated smoke (K)

T_o = temperature of ambient air (K)

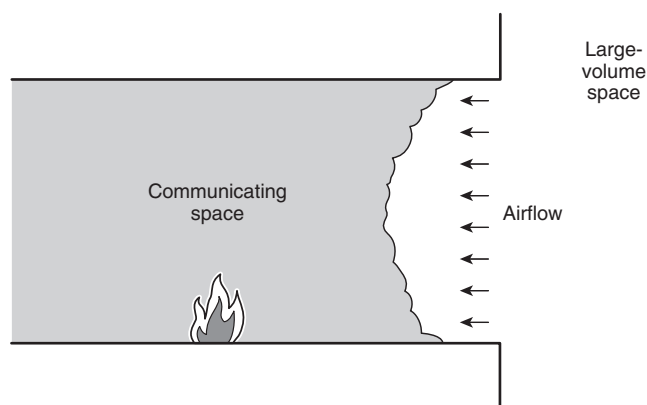
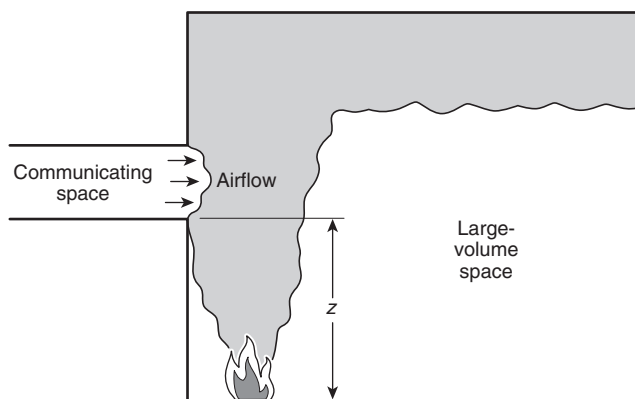


FIGURE 5.5.1 Use of Airflow to Prevent Smoke Propagation from a Communicating Space to a Large-Volume Space.

5.5.2 Where opposed airflow is used to prevent smoke originating from the plume within the large-volume space from propagating into a communicating space below the smoke layer interface as illustrated in Figure 5.5.2, air shall be supplied from the communicating space at the limiting average velocity, v_e , as calculated in accordance with Equation 5.5.2a or 5.5.2b as follows:



Note: The term z is the distance from the base of the fire to the bottom of the opening.

FIGURE 5.5.2 Use of Airflow to Prevent Smoke Propagation from the Plume Within the Large-Volume Space to a Communicating Space Located Below the Smoke Layer Interface.

$$v_e = 17 \left(\frac{Q}{z} \right)^{1/3} \quad (5.5.2a)$$

where:

v_e = limiting average air velocity (ft/min)

Q = heat release rate of the fire (Btu/sec)

z = distance above the base of the fire to the bottom of the opening (ft)

$$v_e = 0.057 \left(\frac{Q}{z} \right)^{1/3} \quad (5.5.2b)$$

where:

v_e = limiting average air velocity (m/sec)

Q = heat release rate of the fire (kW)

z = distance above the base of the fire to the bottom of the opening (m)

5.5.2.1 Where the limiting average air velocity, v_e , calculated from Equation 5.5.2a or 5.5.2b exceeds 200 ft/min (1.02 m/sec), the opposed airflow method shall not be used for the purpose of this section.

5.5.2.2 Equations 5.5.2a and 5.5.2b shall not be used when z is less than 10 ft (3 m).

5.5.3 Where opposed airflow is used to prevent smoke originating in the large-volume space from propagating into a communicating space above the smoke layer interface as shown in Figure 5.5.3, air shall be supplied from the communicating space at the limiting average velocity, v_e , as determined in accordance with Equation 5.5.3a or 5.5.3b as follows:

$$v_e = 38 \left(gH \frac{T_f - T_o}{T_f} \right)^{1/2} \quad (5.5.3a)$$

where:

v_e = limiting average air velocity (ft/min)

g = acceleration of gravity (32.2 ft/sec²)

H = height of the opening as measured from the bottom of the opening (ft)

T_f = temperature of heated smoke (R)

T_o = temperature of ambient air (R)

$$v_e = 0.64 \left(gH \frac{T_f - T_o}{T_f} \right)^{1/2} \quad (5.5.3b)$$

where:

v_e = limiting average air velocity (m/sec)

g = acceleration of gravity (9.81 m/sec²)

H = height of the opening as measured from the bottom of the opening (m)

T_f = temperature of heated smoke (K)

T_o = temperature of ambient air (K)

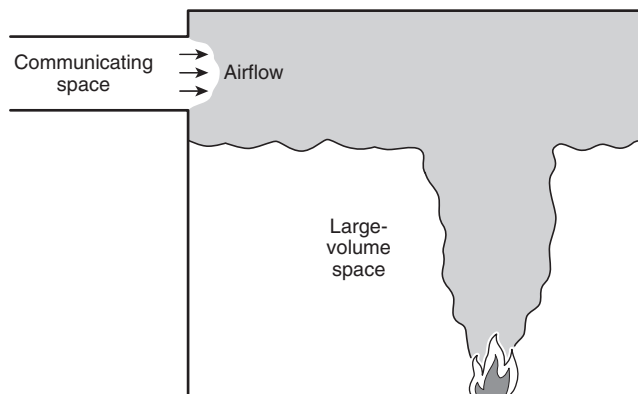


FIGURE 5.5.3 Use of Airflow to Prevent Smoke Propagation from a Large-Volume Space to a Communicating Space Located Above the Smoke Layer Interface.

5.5.3.1 Where the limiting average air velocity, v_e , calculated from Equation 5.5.3a or 5.5.3b exceeds 200 ft/min (1.02 m/sec), the opposed airflow method shall not be used for the purpose of this section.

5.5.3.2 The mass flow rate of air supply from the communicating space shall be included in the design of the smoke exhaust for the large-volume space.

5.6* Scaling Laws.

5.6.1 The scale model shall be based on the relationships in Table 5.6.1.

5.6.2 The model shall be made large enough that the height of one story in the scale model, or the design height of the smoke interface, is no less than 1 ft (0.3 m).

Chapter 6 Algebraic Equations

6.1 Smoke Layer Calculations.

6.1.1* General. The position of the first indication of smoke at any time or the smoke layer interface height shall be determined from the relations in 6.1.2 and Section 6.2.

6.1.2 Height of First Indication of Smoke with No Smoke Exhaust Operating.

6.1.2.1* Steady Fires. Where all of the following conditions occur, the height of the first indication of smoke above the fire surface, z , shall be calculated using Equation 6.1.2.1a or 6.1.2.1b:

Table 5.6.1 Scaling Expressions

Characteristic Relationship

Geometric position	$x_m = x_F (l_m/l_F)$
Temperature	$T_m = T_F$
Pressure difference	$\Delta p_m = \Delta p_F (l_m/l_F)$
Velocity	$v_m = v_F (l_m/l_F)^{1/2}$
Total heat release rate	$Q_m = Q_F (l_m/l_F)^{5/2}$
Convective heat release rate	$Q_{c,m} = Q_{c,F} (l_m/l_F)^{5/2}$
Volumetric exhaust rate	$V_{fan,m} = V_{fan,F} (l_m/l_F)^{5/2}$
Time	$t_m = t_F (l_m/l_F)^{1/2}$

where:

l = length

Δp = pressure difference

Q = heat release rate

t = time

T = temperature (ambient and smoke)

v = velocity

V = volumetric exhaust rate

x = position

Subscripts:

c = convective

F = full-scale

m = small-scale model

- (1) Uniform cross-sectional areas with respect to height
- (2) A/H^2 ratios in the range from 0.9 to 14
- (3) $z/H > 0.2$
- (4) Steady fires
- (5) No smoke exhaust operating

$$\frac{z}{H} = 0.67 - 0.28 \ln \left(\frac{tQ^{1/3}}{H^{4/3}} \frac{A}{H^2} \right) \quad (6.1.2.1a)$$

where:

z = distance above the base of the fire to the first indication of smoke (ft)

H = ceiling height above the fire surface (ft)

t = time (sec)

Q = heat release rate from steady fire (Btu/sec)

A = cross-sectional area of the space being filled with smoke (ft²)

$$\frac{z}{H} = 1.11 - 0.28 \ln \left(\frac{tQ^{1/3}}{H^{4/3}} \frac{A}{H^2} \right) \quad (6.1.2.1b)$$

where:

z = distance above the base of the fire to the first indication of smoke (m)

H = ceiling height above the fire surface (m)

t = time (sec)

Q = heat release rate from steady fire (kW)

A = cross-sectional area of the space being filled with smoke (m²)

6.1.2.2* Unsteady Fires. Where all of the following conditions occur, the descent of the height of the initial indication of smoke shall be calculated for t -squared fires using Equation 6.1.2.2a or 6.1.2.2b:

- (1) Uniform cross-sectional areas with respect to height
 (2) A/H^2 ratios in the range from 0.9 to 23
 (3) $z/H > 0.2$
 (4) Unsteady fires
 (5) No smoke exhaust operating

$$\frac{z}{H} = 0.23 \left(\frac{t}{t_g^{2/5} H^{4/5} \left(\frac{A}{H^2} \right)^{3/5}} \right)^{-1.45} \quad (6.1.2.2a)$$

where:

z = distance above the base of the fire to the first indication of smoke (ft)
 H = ceiling height above the fire surface (ft)
 t = time (sec)
 t_g = growth time (sec)
 A = cross-sectional area of the space being filled with smoke (ft²)

$$\frac{z}{H} = 0.91 \left(\frac{t}{t_g^{2/5} H^{4/5} \left(\frac{A}{H^2} \right)^{3/5}} \right)^{-1.45} \quad (6.1.2.2b)$$

where:

z = distance above the base of the fire to the first indication of smoke (m)
 H = ceiling height above the fire surface (m)
 t = time (sec)
 t_g = growth time (sec)
 A = cross-sectional area of the space being filled with smoke (m²)

6.2 Rate of Smoke Mass Production.

6.2.1 Axisymmetric Plumes.

6.2.1.1* Where the plume is axisymmetric, the mass rate of smoke production shall be calculated using Equations 6.2.1.1a, 6.2.1.1b, or 6.2.1.1c, or Equations 6.2.1.1a(1), 6.2.1.1b(1), or 6.2.1.1c(1) as follows:

$$z_l = 0.533Q_c^{2/5} \quad (6.2.1.1a)$$

$$\text{when } z > z_l, m = (0.022Q_c^{1/3} z^{5/3}) + 0.0042Q_c \quad (6.2.1.1b)$$

$$\text{when } z \leq z_l, m = 0.0208Q_c^{3/5} z \quad (6.2.1.1c)$$

where:

z_l = limiting elevation (ft)
 Q_c = convective portion of heat release rate (Btu/sec)
 z = distance above the base of the fire to the smoke layer interface (ft)
 m = mass flow rate in plume at height z (lb/sec)

$$z_l = 0.166Q_c^{2/5} \quad [6.2.1.1a(1)]$$

$$\text{when } z > z_l, m = (0.071Q_c^{1/3} z^{5/3}) + 0.0018Q_c [6.2.1.1b(1)]$$

$$\text{when } z \leq z_l, m = 0.032Q_c^{3/5} z \quad [6.2.1.1c(1)]$$

where:

z_l = limiting elevation (m)
 Q_c = convective portion of heat release rate (kW)
 z = distance above the base of the fire to the smoke layer interface (m)
 m = mass flow rate in plume at height z (kg/sec)

6.2.1.2 Equations 6.2.1.1b, 6.2.1.1b(1), 6.2.1.1c, and 6.2.1.1c(1) shall not be used when the temperature rise above ambient ($T_p - T_o$) is less than 4°F (2.2°C). (See 6.2.5.)

6.2.1.3 The convective portion of the heat release rate of the fire shall be determined from Equation 6.2.1.3a or 6.2.1.3b.

$$Q_c = \chi Q \quad (6.2.1.3a)$$

where:

Q_c = convective portion of the heat release rate of the fire (Btu/s)
 χ = convective fraction (dimensionless)
 Q = heat release rate of the fire (Btu/ft)

$$Q_c = \chi Q \quad (6.2.1.3b)$$

where:

Q_c = convective portion of the heat release rate of the fire (kW)
 χ = convective fraction (dimensionless)
 Q = heat release rate of the fire (kW)

6.2.1.4 A value of 0.7 shall be used for the convective fraction unless another value is substantiated in accordance with test data.

6.2.2 Balcony Spill Plumes.

6.2.2.1* Where the smoke plume is a balcony spill plume and the height, z_b , of the smoke layer is <50 ft (15 m), the mass rate of smoke production shall be calculated using either Equation 6.2.2.1a or 6.2.2.1b as follows:

$$m = 0.12(QW^2)^{1/3} (z_b + 0.25H) \quad (6.2.2.1a)$$

where:

m = mass flow rate in plume (lb/sec)
 Q = heat release rate of the fire (Btu/sec)
 W = width of the plume as it spills under the balcony (ft)
 z_b = height above the underside of the balcony to the smoke layer interface (ft)
 H = height of balcony above base of fire (ft)

$$m = 0.36(QW^2)^{1/3} (z_b + 0.25H) \quad (6.2.2.1b)$$

where:

m = mass flow rate in plume (kg/sec)
 Q = heat release rate of the fire (kW)
 W = width of the plume as it spills under the balcony (m)
 z_b = height above the underside of the balcony to the smoke layer interface (m)
 H = height of balcony above base of fire (m)

6.2.2.2 Equations 6.2.2.1a and 6.2.2.1b shall not be used when the temperature rise above ambient ($T_p - T_o$) is less than 4°F (2.2°C). (See 6.2.5.)



6.2.2.3 The width of the plume, W , shall be permitted to be determined by considering the presence of any physical barriers such as draft curtains protruding below the balcony to restrict horizontal smoke migration under the balcony.

6.2.2.4 When draft curtains are used, they shall be perpendicular to the opening to channel smoke and extend below the balcony ceiling a distance of at least 10 percent of the floor-to-ceiling height of the balcony.

6.2.2.5* In the absence of any barriers, the equivalent width shall be calculated using Equation 6.2.2.5a or 6.2.2.5b as follows:

$$W = w + b \quad (6.2.2.5a)$$

where:

W = width of the plume (ft)

w = width of the opening from the area of origin (ft)

b = distance from the opening to the balcony edge (ft)

$$W = w + b \quad (6.2.2.5b)$$

where:

W = width of the plume (m)

w = width of the opening from the area of origin (m)

b = distance from the opening to the balcony edge (m)

6.2.2.6* Where the smoke plume is a balcony spill plume and the height, z_b , of the smoke layer is <50 ft (15 m) and the width of the plume determined using Equations 6.2.2.5a or 6.2.2.5b is < 32.8 ft (10 m), the mass flow rate of smoke production shall be calculated using either Equation 6.2.2.6a or 6.2.2.6b.

(6.2.2.6a)

$$\dot{m}_b = 0.31\dot{Q}_c^{1/3}W^{1/5}(z_b + 0.098W^{7/15}H + 19.5W^{7/15} - 15)$$

where:

$\dot{m}_b$ = mass flow entering the smoke layer at height z_b (lb/sec)

$\dot{Q}_c$ = convective heat output (Btu/sec)

W = length of the spill (ft)

z_b = height of plume above the balcony edge (ft)

H = height of balcony above the base of the fire (ft)

(6.2.2.6b)

$$\dot{m}_b = 0.59\dot{Q}_c^{1/3}W^{1/5}(z_b + 0.17W^{7/15}H + 10.35W^{7/15} - 15)$$

where:

$\dot{m}_b$ = mass flow entering the smoke layer at height z_b (kg/s)

$\dot{Q}_c$ = convective heat output (kW)

W = length of the spill (m)

z_b = height of plume above the balcony edge (m)

H = height of balcony above the base of the fire (m)

6.2.2.7* Where the smoke plume is a balcony spill plume and the height, z_b , of the smoke layer is ≥ 50 ft (15 m) and the width of the plume determined using Equations 6.2.2.5a or 6.2.2.5b is ≥ 32.8 ft (10 m) and ≤ 45.9 ft (14 m), the mass flow rate of smoke production shall be calculated using either Equation 6.2.2.7a or 6.2.2.7b.

$$\dot{m}_b = 0.067(\dot{Q}_c W^2)^{1/3}(z_b + 0.51H + 15.75) \quad (6.2.2.7a)$$

where:

$\dot{m}_b$ = mass flow entering the smoke layer at height z_b (lb/sec)

$\dot{Q}_c$ = convective heat output (Btu/sec)

W = length of the spill (ft)

z_b = height of plume above the balcony edge (ft)

H = height of balcony above the base of the fire (ft)

$$\dot{m}_b = 0.2(\dot{Q}_c W^2)^{1/3}(z_b + 0.51H + 15.75) \quad (6.2.2.7b)$$

where:

$\dot{m}_b$ = mass flow entering the smoke layer at height z_b (kg/sec)

$\dot{Q}_c$ = convective heat output (kW)

W = length of the spill (m)

z_b = height of plume above the balcony edge (m)

H = height of balcony above the base of the fire (m)

6.2.2.8* For high smoke layer interface heights ($z_b \geq 50$ ft [15 m]), both a balcony spill plume fire scenario and an atrium fire scenario [axisymmetric plume using Equations 6.2.1.1b or 6.2.1.1b(1)] with appropriate design fire sizes shall be evaluated and the higher mass flow rate used for the design of the atrium smoke management system.

6.2.3* Window Plumes.

6.2.3.1* Where the smoke plume is a window plume, the total heat release rate of a ventilation-limited fire shall be calculated using Equation 6.2.3.1a or 6.2.3.1b as follows:

$$Q = 61.2A_w H_w^{1/2} \quad (6.2.3.1a)$$

where:

Q = heat release rate (Btu/sec)

A_w = area of ventilation opening (ft²)

H_w = height of ventilation opening (ft)

$$Q = 1260A_w H_w^{1/2} \quad (6.2.3.1b)$$

where:

Q = heat release rate (kW)

A_w = area of ventilation opening (m²)

H_w = height of ventilation opening (m)

6.2.3.2* Where the smoke plume is a window plume, the mass entrainment for window plumes shall be determined using Equation 6.2.3.2a or 6.2.3.2b as follows:

$$m = \left[0.077(A_w H_w^{1/2})^{1/3}(z_w + a)^{5/3} \right] + 0.18A_w H_w^{1/2} \quad (6.2.3.2a)$$

where:

m = mass flow rate plume at height z_w (lb/sec)

A_w = area of ventilation opening (ft²)

H_w = height of ventilation opening (ft)

z_w = height above the top of the window (ft)

$a = [2.40A_w^{2/5} H_w^{1/5}] - 2.1H_w$ (ft)

$$m = \left[0.68(A_w H_w^{1/2})^{1/3}(z_w + a)^{5/3} \right] + 1.59A_w H_w^{1/2} \quad (6.2.3.2b)$$

where:

m = mass flow rate plume at height z_w (kg/sec)

A_w = area of ventilation opening (m²)

H_w = height of ventilation opening (m)

z_w = height above the top of the window (m)

$a = [2.40A_w^{2/5} H_w^{1/5}] - 2.1H_w$ (m)

6.2.3.3 Equations 6.2.1.1b, 6.2.1.1c, 6.2.2.1, and 6.2.3.2 shall not be used when the temperature rise above ambient ($T_p - T_o$) is less than 4°F (2.2°C). (See 6.2.5.)

6.2.4* Axisymmetric Plume Diameter. The diameter of an axisymmetric plume shall be calculated using Equation 6.2.4a or 6.2.4b as follows:

$$d_p = K_d \cdot z \quad (6.2.4a)$$

where:

d_p = axisymmetric plume diameter (ft)

K_d = diameter constant

z = distance above the base of the fire (ft)

The diameter constant can range from 0.25 to 0.5, and the following values shall be used:

(1) $K_d = 0.5$ for plume contact with walls

(2) $K_d = 0.25$ for beam detection of the smoke plume

$$d_p = K_d \cdot z \quad (6.2.4b)$$

where:

d_p = axisymmetric plume diameter (m)

K_d = diameter constant

z = distance above the base of the fire (m)

6.2.4.1 Plume Contact with Walls. When the calculated plume diameter indicates that the plume will come into contact with all the walls of the large-volume space or with two parallel walls of the large-volume space, the point of contact shall be the smoke layer interface.

6.2.5* Smoke Layer Temperature. The temperature of the smoke layer shall be determined in accordance with Equation 6.2.5a or 6.2.5b as follows:

$$T_s = T_o + \frac{K_s Q_c}{m C_p} \quad (6.2.5a)$$

where:

T_s = smoke layer temperature (°F)

T_o = ambient temperature (°F)

K_s = fraction of convective heat release contained in smoke layer

Q_c = convective portion of heat release (Btu/sec)

m = mass flow rate of the plume at elevation z (lb/sec)

C_p = specific heat of plume gases (0.24 Btu/lb·°F)

$$T_s = T_o + \frac{K_s Q_c}{m C_p} \quad (6.2.5b)$$

where:

T_s = average plume smoke layer temperature (°C)

T_o = ambient temperature (°C)

K_s = fraction of convective heat release contained in smoke layer

Q_c = convective portion of heat release (kW)

m = mass flow rate of the plume at elevation z (kg/sec)

C_p = specific heat of plume gases (1.0 kJ/kg·°C)

6.2.5.1 For calculating the volumetric flow rate of smoke exhaust, a value of 1.0 shall be used for the fraction of convective heat release contained in the smoke layer, K_s , unless another value is substantiated in accordance with test data.

6.2.5.2 For calculating the maximum volumetric flow rate, $V_{\max}$, that can be exhausted without plugholing, a value of 0.5 shall be used for the fraction of convective heat release contained in the smoke layer, K_s , unless another value is substantiated in accordance with approved test data.

6.3* Number of Exhaust Inlets.

6.3.1 The minimum number of exhaust inlets shall be determined so that the maximum flow rates for exhaust without plugholing are not exceeded.

6.3.2 More than the minimum number of exhaust inlets required shall be permitted.

6.3.3* The maximum volumetric flow rate that can be exhausted by a single exhaust inlet without plugholing shall be calculated using Equation 6.3.3a or 6.3.3b.

$$V_{\max} = 452 \gamma d^{5/2} \left(\frac{T_s - T_o}{T_o} \right)^{1/2} \quad (6.3.3a)$$

where:

$V_{\max}$ = maximum volumetric flow rate without plugholing at T_s (ft³/min)

γ = exhaust location factor (dimensionless)

d = depth of smoke layer below the lowest point of the exhaust inlet (ft)

T_s = absolute temperature of the smoke layer (R)

T_o = absolute ambient temperature (R)

$$V_{\max} = 4.16 \gamma d^{5/2} \left(\frac{T_s - T_o}{T_o} \right)^{1/2} \quad (6.3.3b)$$

where:

$V_{\max}$ = maximum volumetric flow rate without plugholing at T_s (m³/sec)

γ = exhaust location factor (dimensionless)

d = depth of smoke layer below the lowest point of the exhaust inlet (m)

T_s = absolute temperature of the smoke layer (K)

T_o = absolute ambient temperature (K)

6.3.4* For exhaust inlets centered no closer than twice the diameter from the nearest wall, a value of 1.0 shall be used for γ .

6.3.5* For exhaust inlets centered less than twice the diameter from the nearest wall, a value of 0.5 shall be used for γ .

6.3.6* For exhaust inlets on a wall, a value of 0.5 shall be used for the value of γ .

6.3.7* The ratio d/D_i shall be greater than 2, where D_i is the diameter of the inlet.

6.3.8 For rectangular exhaust inlets, D_i shall be calculated using Equation 6.3.8.

$$D_i = \frac{2ab}{a+b} \quad (6.3.8)$$

where:

a = length of the inlet

b = width of the inlet

6.3.9 Where multiple exhaust inlets are required to prevent plugholing (see 6.3.1), the minimum separation distance shall be calculated using Equation 6.3.9a or 6.3.9b as follows:



$$S_{\min} = 0.065V_e^{1/2} \quad (6.3.9a)$$

where:

$S_{\min}$ = minimum edge-to-edge separation between inlets (ft)

V_e = volumetric flow rate of one exhaust inlet (ft³/min)

$$S_{\min} = 0.9V_e^{1/2} \quad (6.3.9b)$$

where:

$S_{\min}$ = minimum edge-to-edge separation between inlets (m)

V_e = volumetric flow rate of one exhaust inlet (m³/sec)

6.4* Volumetric Flow Rate. The volumetric flow rate of smoke exhaust shall be determined using Equation 6.4a or 6.4b as follows:

$$V = 60 \frac{m}{\rho} \quad (6.4a)$$

where:

V = volumetric flow rate of smoke exhaust (ft³/min)

m = mass flow rate of smoke exhaust (lb/sec)

ρ = density of smoke (lb/ft³)

$$V = \frac{m}{\rho} \quad (6.4b)$$

where:

V = volumetric flow rate of smoke exhaust (m³/sec)

m = mass flow rate of smoke exhaust (kg/sec)

ρ = density of smoke (kg/m³)

6.5* Density of Smoke. The density of smoke shall be determined using Equation 6.5a or 6.5b as follows:

$$\rho = \frac{144P_{atm}}{R(T + 460)} \quad (6.5a)$$

where:

ρ = density of smoke at temperature (lb/ft³)

P_{atm} = atmospheric pressure (lb/in.²)

R = gas constant (53.34)

T = temperature of smoke (°F)

$$\rho = \frac{P_{atm}}{RT} \quad (6.5b)$$

where:

ρ = density of smoke at temperature (kg/m³)

P_{atm} = atmospheric pressure (Pa)

R = gas constant (287)

T = absolute temperature of smoke (K)

7.2* Makeup Air System. For systems with makeup air supplied by fans, supply fan activation shall be sequenced with exhaust fan activation.

7.3* Control Systems.

7.3.1 General. Control systems shall be listed in accordance with ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems*, category UUKL for their intended purpose.

7.3.2 Coordination. The control system shall fully coordinate the smoke management system interlocks and interface with other related systems.

7.3.3 HVAC System Controls. Operating controls for the HVAC system shall accommodate the smoke management mode, which shall have the highest priority over all other control modes.

7.3.4 Response Time. The total response time, including that necessary for detection, shutdown of operating equipment, and smoke management system start-up, shall allow for full operational mode to be achieved before the conditions in the space exceed the design smoke conditions.

7.3.5 Sequencing. The smoke management system shall activate individual components, such as dampers and fans, in sequence as necessary to avoid physical damage to the equipment.

7.3.6* Control System Verification and Instrumentation.

7.3.6.1 A means shall be provided to indicate a trouble condition if the system does not operate as intended when activated.

7.3.6.2 Failure to receive positive confirmation after activation or cessation of such positive confirmation while the system or subsystem remains activated shall result in an off-normal indication at the smoke control system within 200 seconds.

7.3.7* Manual Control. Manual control of smoke management and fire alarm systems shall be provided at an approved location accessible to the fire department.

7.3.8 Operational Capability. Operational capability of smoke management equipment shall be verified using the weekly self-test function provided by the UUKL-listed smoke control panel mandated by 7.3.1.

7.4* Electrical Services. Electrical installations shall meet the requirements of NFPA 70, *National Electrical Code*.

7.5 Materials.

7.5.1 Ducts intended to convey smoke and the duct materials shall conform to NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, and other applicable NFPA documents.

7.5.2 Ducts that are part of a smoke management system shall be designed, selected, and constructed to withstand the positive and negative pressures to which they are subjected when operating in a smoke management mode.

7.5.3 Equipment, including, but not limited to, fans, ducts, and balance dampers, shall be suitable for its intended use and the probable temperatures to which it might be exposed.

Chapter 7 Equipment and Controls

7.1 Smoke Dampers.

7.1.1 Smoke dampers shall be listed in accordance with ANSI/UL 555S, *Standard for Smoke Dampers*.

7.1.2 Combination fire and smoke dampers shall be listed in accordance with ANSI/UL 555, *Standard for Fire Dampers*, and ANSI/UL 555S, *Standard for Smoke Dampers*.

Chapter 8 Testing

8.1 General.

8.1.1* Each system shall be tested against its specific design criteria using component system testing, acceptance testing, and periodic testing and maintenance.

8.1.2 Construction documents shall include all acceptance testing procedures and pass/fail criteria.

8.2 Component System Testing.

8.2.1* Responsibility for testing shall be defined clearly prior to component system testing.

8.2.2 Prior to testing, the party responsible for testing shall verify completeness of building construction, including the following architectural features:

- (1) Smoke barriers including joints therein
- (2) Firestopping
- (3) Doors and closers related to smoke control
- (4) Glazing that encloses a large-volume space

8.2.3* Operational testing of each individual system component shall be performed.

8.2.4* Testing shall include all subsystems to the extent that they affect or are affected by the operation of the smoke management system.

8.2.5 All documentation from component system testing shall be available for inspection.

8.3 Acceptance Testing.

8.3.1* General. Acceptance testing shall demonstrate that the final integrated system installation complies with the specific design and is functioning properly.

8.3.2 Test Parameters. Where appropriate to the design, the following parameters shall be measured during acceptance testing:

- (1) Total volumetric flow rate
- (2) Airflow velocities
- (3) Airflow direction
- (4) Door-opening forces
- (5) Pressure differences
- (6) Ambient indoor and outdoor temperatures
- (7) Wind speed and direction

8.3.3 Measurement Locations. The locations for measurement of the parameters identified in 8.3.2 shall be in accordance with nationally recognized methods.

8.3.4 Testing Procedures. The acceptance testing shall include the procedures described in 8.3.4.1 through 8.3.4.5.

8.3.4.1* 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 management.

8.3.4.2* If standby power has been provided for the operation of the smoke management system, the acceptance testing shall be conducted while on both normal and standby power.

8.3.4.3 The acceptance testing shall include demonstrating that the correct outputs are produced for a given input for each control sequence specified.

8.3.4.4 The complete smoke management sequence shall be demonstrated for the following:

- (1) Normal mode
- (2) Automatic smoke management mode for first alarm
- (3) Manual override of normal and automatic smoke management modes
- (4) Return to normal

8.3.4.5* Acceptance tests for the fire protective signaling system in conjunction with the smoke management system shall be permitted.

8.3.5* System Testing.

8.3.5.1 Specific smoke management performance criteria shall be developed by the system designer and described in the construction documents.

8.3.5.2 Acceptance testing to verify system performance shall include the following:

- (1) Prior to performance testing, verify the exact location of the perimeter of each large-volume space smoke management system, identify any door openings into that space, and identify all adjacent areas that are to remain open and that are to be protected by airflow alone. For larger openings, measure the velocity by making appropriate traverses of the opening.
- (2) Activate the smoke management system. Verify and record the operation of all fans, dampers, doors, and related equipment. Measure fan exhaust capacities and air velocities through inlet doors and grilles or at supply grilles if there is a mechanical makeup air system. Measure the force to open exit doors.
- (3) Where appropriate to the design, measure and record the pressure difference across all doors that separate the smoke management system area from adjacent spaces and the velocities at interfaces with open areas.

8.3.6 Testing Documentation.

8.3.6.1 Upon completion of acceptance testing, a copy of all operational testing documentation shall be provided to the owner.

8.3.6.2 This documentation shall be available for reference for periodic testing and maintenance.

8.3.7 Owner's Manuals and Instruction. Information shall be provided to the owner that defines the operation and maintenance of the system.

8.3.8 Modifications.

8.3.8.1 All operation and acceptance tests shall be performed on the applicable part of the system wherever there are system changes and modifications.

8.3.8.2 Documentation shall be updated to reflect these changes or modifications.

8.4 Periodic Testing.

8.4.1* Proper maintenance of the system shall, as a minimum, include the periodic testing of all equipment, such as initiating devices, fans, dampers, controls, doors, and windows.

8.4.2* The equipment shall be maintained in accordance with the manufacturer's recommendations.

8.4.3 The periodic tests shall determine the airflow quantities and the pressure differences at the following locations:



- (1) Across smoke barrier openings
- (2) At the air makeup supplies
- (3) At smoke exhaust equipment

8.4.4 All data points shall coincide with the acceptance test location to facilitate comparison measurements.

8.4.5 The system shall be tested at least semiannually by persons who are thoroughly knowledgeable in the operation, testing, and maintenance of the systems.

8.4.5.1 The results of the tests shall be documented in the operations and maintenance log and made available for inspection.

8.4.5.2 The smoke management system shall be operated for each sequence in the current design criteria.

8.4.5.3 The operation of the correct outputs for each given input shall be observed.

8.4.5.4 Tests shall also be conducted under standby power if applicable.

8.4.6* Special arrangements shall be considered for the introduction of large quantities of outside air into occupied areas or computer centers when outside temperature and humidity conditions are extreme and when such unconditioned air could damage contents.

Chapter 9 Design Documentation

9.1* Documentation Required. The following documents shall be generated by the designer during the design process:

- (1) Detailed design report
- (2) Operations and maintenance manual

9.2 Detailed Design Report. The detailed design report shall provide documentation of the smoke management system as it is designed and intended to be installed, along with supporting calculations.

9.3 Operations and Maintenance Manual. The operations and maintenance manual shall provide the requirements to ensure the proper operation of the system over the life of the building.

9.3.1 The manual shall include the following:

- (1) Procedures used in the initial commissioning of the system as well as the measured performance of the system at the time of commissioning
- (2) Testing and inspection requirements for the system and system components and the required frequency of testing
- (3) Critical design assumptions used in the design, and the limitations on the building and its use that arise out of the design assumptions and limitations

9.3.2 Copies of the operations and maintenance manual shall be provided to the owner and the authority having jurisdiction.

9.3.3 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.

9.3.4 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.

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1 This standard incorporates methods for applying engineering calculations and reference models to provide a designer with the tools to develop smoke management system designs. The designs are based on select design objectives presented in Section 4.1.

Previous editions of this document were presented as a guide. Now that the document has been reformatted as a standard, much of the guidance material has been relocated to the annexes. This relocated material offers the designer better understanding of the principles of smoke management and optional approaches that can be followed by an experienced designer.

The objective of this standard is to provide owners, designers, code authorities, and fire departments with a method for managing smoke in large-volume, noncompartmented spaces. This standard addresses the following:

- (1) Basic physics of smoke movement in indoor spaces
- (2) Methods of smoke management
- (3) Supporting data and technology
- (4) Building equipment and controls applicable to smoke management systems
- (5) Approaches to test and maintenance methods

The requirements of the standard specifically apply to malls, atria, and other large spaces where the fuel loading is reasonably quantified and the mechanisms of smoke management can be reasonably calculated from formulas and empirical analysis.

This standard does not address the interaction of sprinklers and smoke management systems. The cooling effect of sprinklers results in some of the smoke losing buoyancy and migrating downward below the design smoke layer interface. This effect is more pronounced when early suppression fast response (ESFR) sprinkler technology is used.

Even with a sprinkler system and water supply adequate for the type and arrangement of storage, the heat release rates from a controlled warehouse fire can be considerably greater than that noted in this standard. Accurate heat release data are not readily available at this time for many storage configurations or a sprinkler-controlled rack storage fire. In such cases the horizontal fire spread is limited, but the fire typically spreads to the vertical limit of combustible storage (up the face and within the flues of storage). In most cases where the clearance between the roof and the top of storage is limited [≤ 10 ft (3 m)], it is expected that the flames will extend vertically into the smoke layer.

In some circumstances, it is possible to remove smoke by gravity venting. The capacity of gravity vents to move smoke through a vent is a function of both the depth and the temperature of the hot layer. Procedures for determining the capabilities of gravity venting are contained in NFPA 204, *Standard for Smoke and Heat Venting*. NFPA 204 is to be used rather than NFPA 92B to the extent that gravity venting is considered.

A.1.2.1 In addition to the purposes listed, smoke management systems can also be used for the following purposes:

- (1) Provide conditions within and outside the fire zone to assist emergency response personnel in conducting search and rescue operations and in locating and controlling the fire
- (2) Contribute to the protection of life and reduction of property loss
- (3) Aid in post-fire smoke removal