

NFPA®

92

**Standard for
Smoke Control Systems**

2018



IMPORTANT NOTICES AND DISCLAIMERS CONCERNING NFPA® STANDARDS

NOTICE AND DISCLAIMER OF LIABILITY CONCERNING THE USE OF NFPA STANDARDS

NFPA® codes, standards, recommended practices, and guides (“NFPA Standards”), of which the document contained herein is one, are developed through a consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in NFPA Standards.

The NFPA disclaims liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on NFPA Standards. The NFPA also makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

In issuing and making NFPA Standards available, the NFPA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the NFPA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The NFPA has no power, nor does it undertake, to police or enforce compliance with the contents of NFPA Standards. Nor does the NFPA list, certify, test, or inspect products, designs, or installations for compliance with this document. Any certification or other statement of compliance with the requirements of this document shall not be attributable to the NFPA and is solely the responsibility of the certifier or maker of the statement.

REVISION SYMBOLS IDENTIFYING CHANGES FROM THE PREVIOUS EDITION

Text revisions are shaded. A **Δ** before a section number indicates that words within that section were deleted and a **Δ** to the left of a table or figure number indicates a revision to an existing table or figure. When a chapter was heavily revised, the entire chapter is marked throughout with the **Δ** symbol. Where one or more sections were deleted, a **•** is placed between the remaining sections. Chapters, annexes, sections, figures, and tables that are new are indicated with an **N**.

Note that these indicators are a guide. Rearrangement of sections may not be captured in the markup, but users can view complete revision details in the First and Second Draft Reports located in the archived revision information section of each code at www.nfpa.org/docinfo. Any subsequent changes from the NFPA Technical Meeting, Tentative Interim Amendments, and Errata are also located there.

REMINDER: UPDATING OF NFPA STANDARDS

Users of NFPA codes, standards, recommended practices, and guides (“NFPA Standards”) should be aware that NFPA Standards may be amended from time to time through the issuance of a Tentative Interim Amendment (TIA) or corrected by Errata. An official NFPA Standard at any point in time consists of the current edition of the document together with any TIAs and Errata then in effect.

To determine whether an NFPA Standard has been amended through the issuance of Tentative Interim Amendments or corrected by Errata, go to www.nfpa.org/docinfo to choose from the list of NFPA Standards or use the search feature to select the NFPA Standard number (e.g., NFPA 13). The document information page provides up-to-date document-specific information as well as postings of all existing TIAs and Errata. It also includes the option to register for an “Alert” feature to receive an automatic email notification when new updates and other information are posted regarding the document.

IMPORTANT NOTICES AND DISCLAIMERS CONCERNING NFPA® STANDARDS

ADDITIONAL NOTICES AND DISCLAIMERS

Updating of NFPA Standards

Users of NFPA codes, standards, recommended practices, and guides (“NFPA Standards”) should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of Tentative Interim Amendments or corrected by Errata. An official NFPA Standard at any point in time consists of the current edition of the document together with any Tentative Interim Amendments and any Errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of Tentative Interim Amendments or corrected through the issuance of Errata, consult appropriate NFPA publications such as the National Fire Codes® Subscription Service, visit the NFPA website at www.nfpa.org, or contact the NFPA at the address listed below.

Interpretations of NFPA Standards

A statement, written or oral, that is not processed in accordance with Section 6 of the Regulations Governing the Development of NFPA Standards shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Patents

The NFPA does not take any position with respect to the validity of any patent rights referenced in, related to, or asserted in connection with an NFPA Standard. The users of NFPA Standards bear the sole responsibility for determining the validity of any such patent rights, as well as the risk of infringement of such rights, and the NFPA disclaims liability for the infringement of any patent resulting from the use of or reliance on NFPA Standards.

NFPA adheres to the policy of the American National Standards Institute (ANSI) regarding the inclusion of patents in American National Standards (“the ANSI Patent Policy”), and hereby gives the following notice pursuant to that policy:

NOTICE: The user’s attention is called to the possibility that compliance with an NFPA Standard may require use of an invention covered by patent rights. NFPA takes no position as to the validity of any such patent rights or as to whether such patent rights constitute or include essential patent claims under the ANSI Patent Policy. If, in connection with the ANSI Patent Policy, a patent holder has filed a statement of willingness to grant licenses under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, copies of such filed statements can be obtained, on request, from NFPA. For further information, contact the NFPA at the address listed below.

Law and Regulations

Users of NFPA Standards should consult applicable federal, state, and local laws and regulations. NFPA does not, by the publication of its codes, standards, recommended practices, and guides, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

NFPA Standards are copyrighted. They are made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of safe practices and methods. By making these documents available for use and adoption by public authorities and private users, the NFPA does not waive any rights in copyright to these documents.

Use of NFPA Standards for regulatory purposes should be accomplished through adoption by reference. The term “adoption by reference” means the citing of title, edition, and publishing information only. Any deletions, additions, and changes desired by the adopting authority should be noted separately in the adopting instrument. In order to assist NFPA in following the uses made of its documents, adopting authorities are requested to notify the NFPA (Attention: Secretary, Standards Council) in writing of such use. For technical assistance and questions concerning adoption of NFPA Standards, contact NFPA at the address below.

For Further Information

All questions or other communications relating to NFPA Standards and all requests for information on NFPA procedures governing its codes and standards development process, including information on the procedures for requesting Formal Interpretations, for proposing Tentative Interim Amendments, and for proposing revisions to NFPA standards during regular revision cycles, should be sent to NFPA headquarters, addressed to the attention of the Secretary, Standards Council, NFPA, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101; email: stds_admin@nfpa.org.

For more information about NFPA, visit the NFPA website at www.nfpa.org. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/docinfo.

Copyright © 2017 National Fire Protection Association®. All Rights Reserved.

NFPA® 92

Standard for

Smoke Control Systems

2018 Edition

This edition of NFPA 92, *Standard for Smoke Control Systems*, was prepared by the Technical Committee on Smoke Management Systems. It was issued by the Standards Council on November 10, 2017, with an effective date of November 30, 2017, and supersedes all previous editions.

This edition of NFPA 92 was approved as an American National Standard on November 30, 2017.

Origin and Development of NFPA 92

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 smoke management in buildings. 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 another document, NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, first published in 1991.

Between 1991 and 2009, NFPA 92A and NFPA 92B were separately maintained. In 2006, NFPA 92A was rewritten as a standard with mandatory provisions regarding design, installation, and testing of smoke-control systems and was renamed *Smoke-Control Systems Utilizing Barriers and Pressure Differences*. In 2005 and 2006, both documents were reorganized to comply with the *Manual of Style for NFPA Technical Committee Documents*. Both documents eventually contained many of the same requirements for design objectives, activation, and installation.

In the Annual 2011 revision cycle, NFPA 92A and NFPA 92B were withdrawn and replaced with a new document, NFPA 92, *Standard for Smoke Control Systems*. NFPA 92 was created using requirements from both of the original documents, removing duplicate provisions and making numerous editorial changes. The new document used the term *smoke control systems* to address both containment and management systems. With the consolidation effort, the new standard covered the following topics: design of smoke management systems and calculations, design of smoke containment systems, design of stairwell pressurization systems, and testing requirements.

The 2015 edition includes editorial revisions and new requirements addressing draft curtain materials.

New to the 2018 edition of NFPA 92 is the addition of requirements regarding the verification of dedicated smoke control equipment through use of the weekly self-test function. A new annex on tenability was added to provide guidelines for designers to assess tenable conditions in spaces protected by smoke control systems, in connected spaces, and of means of egress elements during the operation of a smoke control system.

Technical Committee on Smoke Management Systems

Allyn J. Vaughn, *Chair*

NV5/JBA Consulting Engineers, NV [SE]

Elyahu Avidor, Tel Aviv, Israel [RT]

Rep. Standards Institution of Israel

Carl F. Baldassarra, Wiss Janney Elstner Associates, Inc., IL [SE]

Flora F. Chen, Hayward Fire Department, California, CA [E]

Richard J. Davis, FM Global, MA [I]

Kevin L. Derr, U.S. Architect of the Capitol, DC [E]

Kelly Eisenstein, City Of San Diego, CA [E]

Michael J. Ferreira, JENSEN HUGHES, MD [SE]

Donald Fess, Harvard University, MA [U]

Maxwell French, Cosentini Associates, MA [SE]

Brian Green, Viking Corporation, MI [M]

Rep. National Fire Sprinkler Association

Geoffrey Harris, Smoke and Fire Engineering Technology Ltd., United Kingdom [SE]

Rep. ISO TC on Smoke and Heat Control Systems and Components

David A. Killian, Walt Disney Parks & Resorts, CA [U]

William E. Koffel, Koffel Associates, Inc., MD [M]

Rep. AAMA Smoke Vent Task Group

Jeffrey A. Maddox, The Fire Consultants, Inc., CA [SE]

Cameron J. McCartney, National Research Council of Canada, Canada [RT]

James A. Milke, University of Maryland, MD [SE]

Timothy J. Orris, AMCA International, Inc., IL [M]

Rep. Air Movement & Control Association

Thomas J. Parrish, Telgian Corporation, MI [M]

Rep. Automatic Fire Alarm Association, Inc.

Joseph Plati, Code Consultants, Inc., NY [SE]

James R. Richardson, Lisle Woodridge Fire District, IL [E]

Lawrence J. Shudak, UL LLC, IL [RT]

Deo Suriya Supanavongs, Honeywell International Inc., IL [M]

Rep. National Electrical Manufacturers Association

Jeffrey S. Tubbs, Arup, MA [SE]

Paul G. Turnbull, Siemens Building Technologies, Inc., IL [M]

Michael J. Ventola, Space Age Electronics, FL [M]

Stacy N. Welch, Marriott International, Inc., MD [U]

Peter J. Willse, Global Asset Protection Services, LLC, CT [I]

Alternates

Sanjay Aggarwal, JENSEN HUGHES, CA [SE]

(Alt. to Michael J. Ferreira)

Mark Allen Belke, Greenheck Fan Corporation, WI [M]

(Alt. to Timothy J. Orris)

Diane B. Copeland, Dillon Consulting Engineers, Inc., CA [SE]

(Voting Alternate)

Jason Daniels, Code Consultants, Inc., MO [SE]

(Alt. to Joseph Plati)

Donald G. Goosman, Wiss Janney Elstner Associates, Inc., IL [SE]

(Alt. to Carl F. Baldassarra)

Gary D. Loughheed, National Research Council of Canada, Canada [RT]

(Alt. to Cameron J. McCartney)

Zachary L. Magnone, Tyco Fire Protection Products, RI [M]

(Alt. to Brian Green)

Wesley Marcks, Xtralis, Inc., MA [M]

(Alt. to Deo Suriya Supanavongs)

Andrew Neviackas, Arup, MA [SE]

(Alt. to Jeffrey S. Tubbs)

Gregory K. Shino, NV5/JBA Consulting Engineers, NV [SE]

(Alt. to Allyn J. Vaughn)

Luke C. Woods, UL LLC, MA [RT]

(Alt. to Lawrence J. Shudak)

Brittany Dawn Wright, Walt Disney Parks & Resorts, FL [U]

(Alt. to David A. Killian)

Yibing Xin, FM Global, MA [I]

(Alt. to Richard J. Davis)

Nonvoting

Christian Norgaard Madsen, Norconsult, Norway [SE]

Bent A. Borresen, Norconsult, Norway [SE]

(Alt. to Christian Norgaard Madsen)

Brian J. O'Connor, NFPA Staff Liaison

John H. Klote, Leesburg, VA [SE]

(Member Emeritus)

This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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.

Contents

Chapter 1 Administration	92- 4	6.4 Smoke Control Systems.	92- 18
1.1 Scope.	92- 4	6.5 Energy Management.	92- 21
1.2 Purpose.	92- 4	6.6 Materials.	92- 21
1.3 Retroactivity.	92- 4	6.7 Electric Services Installation.	92- 21
1.4 Equivalency.	92- 4		
1.5 Units and Formulas. (Reserved)	92- 4	Chapter 7 Smoke Control System Documentation	92- 21
Chapter 2 Referenced Publications	92- 4	7.1 Documentation Required.	92- 21
2.1 General.	92- 4	7.2 Detailed Design Report.	92- 21
2.2 NFPA Publications.	92- 4	7.3 Operations and Maintenance Manual.	92- 21
2.3 Other Publications.	92- 5		
2.4 References for Extracts in Mandatory Sections. ...	92- 5	Chapter 8 Testing	92- 21
Chapter 3 Definitions	92- 5	8.1 General.	92- 21
3.1 General.	92- 5	8.2 Preliminary Building Inspections.	92- 21
3.2 NFPA Official Definitions.	92- 5	8.3 Component System Testing.	92- 22
3.3 General Definitions.	92- 5	8.4 Acceptance Testing.	92- 22
Chapter 4 Design Fundamentals	92- 7	8.5 Testing Documentation.	92- 24
4.1 Design Objectives.	92- 7	8.6 Periodic Testing.	92- 24
4.2 Design Basis.	92- 7	8.7 Modifications.	92- 24
4.3 Design Approaches.	92- 7	Annex A Explanatory Material	92- 24
4.4 Design Criteria.	92- 7	Annex B Predicting the Rate of Heat Release of Fires	92- 45
4.5 System Operation.	92- 8	Annex C Computer-Based Models for Atria and Malls	92- 56
4.6 Stairwell Pressurization Systems.	92- 9	Annex D Additional Design Objectives	92- 61
4.7 Elevator Pressurization Systems.	92- 9	Annex E Stratification of Smoke	92- 64
4.8 Zoned Smoke Control.	92- 9	Annex F Types of Stairwell Pressurization Systems	92- 65
4.9 Combination of Systems.	92- 10	Annex G HVAC Air-Handling System Types	92- 66
4.10 Vestibules.	92- 10	Annex H Fire Fighters' Smoke Control Station (FSCS) Considerations	92- 68
4.11 Doors.	92- 10	Annex I Information on Testing for Leakage Between Smoke Zones	92- 69
Chapter 5 Smoke Management Calculation Procedures	92- 10	Annex J Advisory Information on Acceptance Testing	92- 70
5.1 Introduction.	92- 10	Annex K Example Problems Illustrating the Use of Equations	92- 71
5.2 Design Fire.	92- 10	Annex L Comparison of Equations	92- 73
5.3 Mass Consumption.	92- 11	Annex M Tenability	92- 76
5.4 Smoke Layer Calculations.	92- 12	Annex N Informational References	92- 79
5.5 Rate of Smoke Mass Production.	92- 12	Index	92- 84
5.6 Number of Exhaust Inlets.	92- 15		
5.7 Volumetric Flow Rate.	92- 15		
5.8 Density of Smoke.	92- 16		
5.9 Varying Cross-Sectional Geometries and Complex Geometries.	92- 16		
5.10 Opposed Airflow.	92- 16		
5.11 Scaling Laws.	92- 18		
Chapter 6 Building Equipment and Controls	92- 18		
6.1 General.	92- 18		
6.2 Heating, Ventilating, and Air-Conditioning (HVAC) Equipment.	92- 18		
6.3 Smoke Dampers.	92- 18		

NFPA 92

Standard for

Smoke Control Systems

2018 Edition

IMPORTANT NOTE: This NFPA document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notices and Disclaimers Concerning NFPA Standards." They can also be viewed at www.nfpa.org/disclaimers or obtained on request from NFPA.

UPDATES, ALERTS, AND FUTURE EDITIONS: New editions of NFPA codes, standards, recommended practices, and guides (i.e., NFPA Standards) are released on scheduled revision cycles. This edition may be superseded by a later one, or it may be amended outside of its scheduled revision cycle through the issuance of Tentative Interim Amendments (TIAs). An official NFPA Standard at any point in time consists of the current edition of the document, together with all TIAs and Errata in effect. To verify that this document is the current edition or to determine if it has been amended by TIAs or Errata, please consult the National Fire Codes® Subscription Service or the "List of NFPA Codes & Standards" at www.nfpa.org/docinfo. In addition to TIAs and Errata, the document information pages also include the option to sign up for alerts for individual documents and to be involved in the development of the next edition.

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

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 N. 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 N.

Chapter 1 Administration

1.1* Scope. This standard shall apply to the design, installation, acceptance testing, operation, and ongoing periodic testing of smoke control systems.

1.2 Purpose.

1.2.1 The purpose of this standard shall be to establish requirements for smoke control systems to accomplish one or more of the following:

- (1) Inhibit smoke from entering stairwells, means of egress, smoke refuge areas, elevator shafts, or similar areas
- (2) Maintain a tenable environment in smoke refuge areas and means of egress during the time required for evacuation
- (3) Inhibit the migration of smoke from the smoke zone

- (4) Provide conditions outside the smoke zone that enable emergency response personnel to conduct search and rescue operations and to locate and control the fire
- (5) Contribute to the protection of life and to the reduction of property loss

1.2.2 The requirements specifying the conditions under which a smoke control system shall be provided are addressed by other codes and standards.

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

1.3 Retroactivity.

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

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 document shall be permitted.

1.3.3 Where a smoke control 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 control systems.

1.4 Equivalency. 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.

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

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

1.5 Units and Formulas. (Reserved)

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*®, 2017 edition.

NFPA 72®, *National Fire Alarm and Signaling Code*, 2016 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2018 edition.

NFPA 101®, *Life Safety Code*®, 2018 edition.

NFPA 110, *Standard for Emergency and Standby Power Systems*, 2016 edition.

NFPA 221, *Standard for High Challenge Fire Walls, Fire Walls, and Fire Barrier Walls*, 2018 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, revised 2014.

ANSI/UL 555S, *Standard for Smoke Dampers*, 2014.

ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems*, 2014.

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 1, *Fire Code*, 2018 edition.

NFPA 3, *Standard for Commissioning of Fire Protection and Life Safety Systems*, 2018 edition.

NFPA 101®, *Life Safety Code*®, 2018 edition.

NFPA 556, *Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles*, 2016 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. An NFPA Standard, the main text of which contains only mandatory provisions using the word “shall” to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA Manuals of Style. When used in a generic sense, such as in the phrase “standards development process” or “standards development activities,” the term “standards” includes all NFPA Standards, including Codes, Standards, Recommended Practices, and Guides.

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 by 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, 2018]

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* Design Pressure Difference. The desired pressure difference between the protected space and an adjacent space measured at the boundary of the protected space under a specified set of conditions with the smoke control system operating.

3.3.4* Draft Curtain. A fixed or automatically deployable barrier that protrudes downward from the ceiling to channel, contain, or prevent the migration of smoke.

3.3.5 Fire.

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

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

3.3.5.3 *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 B for further information on *t*-squared (*t*²) profile fires.]

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

3.3.5.5 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.

3.3.6* Fire Fighters' Smoke Control Station (FSCS). A system that provides graphical monitoring and manual overriding capability over smoke control systems and equipment at designated location(s) within the building for use by the fire department.

3.3.7 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).

3.3.8 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.

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

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

3.3.9.2* 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.

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

3.3.10 Pressurized Stairwells. A type of containment smoke control system in which stair shafts are mechanically pressurized, with respect to the fire area, with outdoor air to keep smoke from contaminating them during a fire incident.

3.3.11 Registered Design Professional (RDP). An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the jurisdiction in which the project is to be constructed, or other professional with qualifications or credentials acceptable to the jurisdiction in which the project is to be constructed. [3, 2018]

3.3.12 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. [556, 2016]

3.3.12.1* First Indication of Smoke. The boundary between the transition zone and the smoke free air.

3.3.13* 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 system.

3.3.14* Smoke Containment. A smoke control method that uses mechanical equipment to produce pressure differences across smoke barriers.

3.3.15 Smoke Control Mode. A predefined operational configuration of a system or device for the purpose of smoke control.

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 smoke-free air.

3.3.19 Smoke Management. A smoke control method that utilizes natural or mechanical systems to maintain a tenable environment in the means of egress from a large-volume space or to control and reduce the migration of smoke between the fire area and communicating spaces.

3.3.20 Smoke Refuge Area. An area of the building separated from other spaces by fire resistance-rated smoke barriers in

which a tenable environment is maintained for the period of time that such areas might need to be occupied at the time of fire.

3.3.21 Space.

3.3.21.1* 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.

3.3.21.2 Large-Volume Space. An uncompartmented 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.

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

3.3.22 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.

3.3.23 System.

3.3.23.1 Compensated System. A system that adjusts for changing conditions either by modulating supply airflows or by relieving excess pressure.

3.3.23.2* Dedicated Smoke Control System. Smoke control systems and components that are installed for the sole purpose of providing smoke control and that upon activation of the systems operate specifically to perform the smoke control function.

3.3.23.3* Nondedicated Smoke Control Systems. A smoke-control system that shares components with some other system(s), such as the building HVAC system, which changes its mode of operation to achieve the smoke-control objective. [1, 2018]

3.3.23.4 Pressurization System.

3.3.23.4.1 Multiple-Injection Pressurization System. A type of smoke control system that has pressurization air supplied from multiple locations.

3.3.23.4.2 Single-Injection Pressurization System. A type of containment smoke control system that has pressurization air supplied from only one location.

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

3.3.23.6* Smoke Exhaust System. A mechanical or gravity system intended to move smoke from the smoke zone to the exterior of the building, including smoke removal, purging, and venting systems, as well as the function of exhaust fans utilized to reduce the pressure in a smoke zone.

3.3.23.7 Zoned Smoke Control System. A smoke control system that includes a combination of smoke containment and smoke management methods for smoke exhaust for the smoke zone and pressurization for all contiguous smoke control zones.

3.3.24* Tenable Environment. An environment in which smoke and heat are limited or otherwise restricted to maintain the impact on occupants to a level that is not life threatening.

3.3.25 Zone.

3.3.25.1 Smoke Control Zone. A space within a building enclosed by smoke barriers, including the top and bottom, that is part of a zoned smoke control system.

3.3.25.2 Smoke Zone. The smoke control zone in which the fire is located.

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

Chapter 4 Design Fundamentals

4.1 Design Objectives.

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

- (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

4.1.2* 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

4.2 Design Basis.

4.2.1* Smoke Containment Systems. A smoke control system in a given building shall be designed to contain smoke to a given zone or keep smoke from entering another zone.

4.2.1.1 The design pressure difference shall be based on the following:

- (1) Whether the smoke zone is sprinklered
- (2) The height of the ceiling in the smoke zone
- (3) Maximum and minimum pressure differentials

4.2.2 Smoke Management Systems. The design basis for smoke management within a given large-volume space and any unseparated spaces shall include the determination of the following parameters:

- (1) The design basis fires used to calculate smoke production (i.e., 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 space to be protected

- (3) Height, cross-sectional area, and plan area of each unseparated space that communicates with the large-volume space
- (4) Type and location of occupancies within and communicating with the large-volume space
- (5) Barriers, if any, that separate the communicating space from the large-volume space
- (6) Egress routes from the large-volume space and any communicating space
- (7) Any areas of refuge

4.2.3 Temperature Ratings.

4.2.3.1 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.

4.2.3.2 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

4.3 Design Approaches.

4.3.1 Smoke Containment Systems. The design approach for smoke containment systems shall be one of or a combination of the following:

- (1) Stairwell pressurization
- (2) Zoned smoke control
- (3) Elevator pressurization
- (4) Vestibule pressurization
- (5) Smoke refuge area pressurization

4.3.2* Smoke Management Systems. The design approach for smoke management within large-volume spaces and communicating spaces shall be one of or a combination of the following:

- (1) Natural smoke filling of an unoccupied volume or smoke reservoir and calculating or modeling of smoke layer descent to determine whether the smoke layer interface will reach a height at which occupants will be exposed to smoke prior to their ability 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 the design interval 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) Gravity smoke venting to maintain the smoke layer interface at a predefined height in the space for the design interval time
- (5) Gravity smoke venting to slow the rate of smoke layer descent for a period that allows occupants to egress from the space
- (6)* Opposed airflow to prevent smoke movement between a large-volume space and a communicating space

4.4 Design Criteria.

4.4.1* Weather Data. Designs shall incorporate the effect of outdoor temperature and wind on the performance of systems.

4.4.2 Pressure Differences. The maximum and minimum allowable pressure differences across the boundaries of smoke control zones shall be established for containment systems.

4.4.2.1 Pressure Differences Across Spaces.

4.4.2.1.1* Except as specified by 4.4.2.1.2, the pressure differences in Table 4.4.2.1.1 shall be used for designs that are based on maintaining minimum pressure differences between specified spaces.

4.4.2.1.2 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.

4.4.2.1.3 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.

4.4.2.1.4 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.

4.4.2.1.5 The calculations shall take into account the design number of doors to be opened simultaneously.

4.4.2.2* Pressure Differences Across Doors. The pressure differences across doors shall not cause the maximum force permitted to begin opening the door to exceed the value stipulated in NFPA 101 or state or local codes and regulations.

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

4.4.4 Smoke Movement and Airflow.

4.4.4.1* Makeup Air. Makeup air for smoke management systems shall be provided by fans or by openings to the outside.

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

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

Table 4.4.2.1.1 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 (927°C) next to the smoke barrier.

(2) For design purposes, a smoke control system must maintain these minimum pressure differences under specified design conditions of stack effect or wind.

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

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

4.4.4.1.4* 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.

4.4.4.2 Communicating Spaces.

4.4.4.2.1 Managing Smoke Spread to Communicating Spaces.

4.4.4.2.1.1 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 smoke barrier to limit smoke spread into the communicating space
- (3) Providing an opposed airflow through the opening to prohibit smoke spread into the communicating space

4.4.4.2.1.2 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.

4.4.4.2.1.3 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.

4.4.4.2.2* Managing Smoke from Communicating Spaces.

4.4.4.2.2.1 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 to maintain the design smoke layer interface height.

4.4.4.2.2.2 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 the communicating space and the large-volume space. (See 5.10.1.)

4.4.4.3* Openings and Leakage Areas. Designs shall incorporate the effect of openings and leakage areas in smoke barriers on the performance of smoke control systems.

4.4.4.4 Special Considerations Related to Natural Venting. Smoke management system 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.

4.4.5* Gaseous Fire Suppression Systems. The operation of the smoke control system shall not compromise the performance of gaseous agent fire protection systems.

4.5* System Operation.

4.5.1 Limitations.

4.5.1.1* Tenability. 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.

4.5.1.2* Egress Analysis. 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.

4.5.1.3* Minimum Design Smoke Layer Depth. The minimum design depth of the smoke layer for a smoke management system shall be either of the following:

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

4.5.2 Activation. Activation of smoke control systems shall be accomplished by an approved automatic means.

4.5.3 System Startup.

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

4.5.3.2 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 shutdown and startup of air-handling equipment, opening and closing of dampers, and opening and closing of natural ventilation devices

4.5.4 Duration.

4.5.4.1 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 following shall be met:

- (1) A timed egress analysis shall be conducted.
- (2) The system shall remain operational for the duration required.

4.5.4.2 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.

4.6 Stairwell Pressurization Systems.

4.6.1* General. When stairwell pressurization systems are provided, the pressure difference between the smoke zone and the stairwell, with zero and the design number of doors open, shall be as follows:

- (1) Not less than the minimum pressure difference specified in 4.4.2
- (2) Not greater than the maximum pressure difference specified in 4.4.2.2

4.6.2 Location of Supply Air Source. To limit smoke from entering the stairwell through the supply air intake, the supply air intake shall be separated from all building exhausts, outlets from smoke shafts and roof smoke and heat vents, open vents from elevator shafts, and other building openings that might expel smoke from the building in a fire.

4.6.3 Supply Air Fans.

4.6.3.1* Propeller Fans. Roof or exterior wall-mounted propeller fans shall be permitted to be used in single-injection systems, provided that wind shields are provided for the fan.

4.6.3.2 Other Types of Fans. Centrifugal or in-line axial fans shall be permitted to be used in single- or multiple-injection systems.

4.6.4* Single- and Multiple-Injection Systems.

4.6.4.1 Single-Injection Systems.

4.6.4.1.1* The air injection point for a single-injection system shall be permitted to be located at any location within the stairwell.

4.6.4.1.2* Design analysis shall be performed for all single-bottom-injection systems and for all other single-injection systems for stairwells in excess of 100 ft (30.5 m) in height.

4.6.4.2* Multiple-Injection Systems. For system designs with injection points more than three stories apart, a design analysis shall be performed to ensure that loss of pressurization air through open doors does not lead to stairwell pressurization below the minimum design pressure.

4.7* Elevator Pressurization Systems. Where elevator pressurization is provided, elevator hoistways shall be pressurized to maintain a minimum positive pressure in accordance with 4.4.2. The minimum pressure shall be maintained with the elevator car at the recall floor and elevator doors and the hoistway vents open.

4.8* Zoned Smoke Control.

4.8.1 Smoke Control Zones.

4.8.1.1 When zoned smoke control is to be used to provide containment, the building shall be divided into smoke control zones, with each zone separated from the others by smoke barriers.

4.8.1.1.1* A smoke control zone shall be permitted to consist of one or more floors.

4.8.1.1.2 A floor shall be permitted to consist of one or more smoke control zones.

4.8.1.2 The zoned smoke control system shall be designed such that when zoned smoke control is active, the pressure differences between the adjacent non-smoke zones and the smoke zone meet or exceed the minimum design pressure differences given in 4.4.2, and at locations with doors, the pressure difference shall not exceed the values given in 4.4.2.2.

4.8.2 Smoke Zone Exhaust.

4.8.2.1 The smoke zone exhaust shall discharge to the outside of the building.

4.8.2.2 The smoke zone exhaust shall be permitted to be either mechanical or natural ventilation.

4.8.3* Smoke Refuge Areas.

4.8.3.1 A non-smoke zone of a zoned smoke control system shall be permitted to be used as an area intended to protect occupants for the period of time needed for evacuation or to provide a smoke refuge area.

4.8.3.2 For areas of refuge adjacent to stairwells or elevators, provisions shall be made to prevent the loss of pressure or excessive pressures due to the interaction between the smoke refuge area smoke control and the shaft smoke control.

4.9* Combination of Systems. Smoke control systems shall be designed such that where multiple smoke control systems operate simultaneously, each system will meet its individual design objectives.

4.10 Vestibules.

4.10.1* Vestibules shall not be required but shall be permitted as part of the building smoke control system.

4.10.2* Where vestibules are provided, either pressurized or nonpressurized vestibules shall be permitted.

4.11* Doors. Doors located in smoke barriers shall be self-closing or shall be arranged to close automatically upon activation of the smoke control system.

Chapter 5 Smoke Management Calculation Procedures

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

5.1.1* Algebraic Equations. The algebraic equations in Chapter 5 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.

5.1.2* Scale Modeling.

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

5.1.2.2 The size of the fire and the interpretation of the results shall be governed by the scaling laws, as given in Section 5.11.

5.1.3* Compartment Fire Models. Compartment fire models shall be zone fire models or computational fluid dynamics (CFD) models. *(For information about zone fire models and CFD models, see Annex C.)*

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 5.2.3.2 as follows:

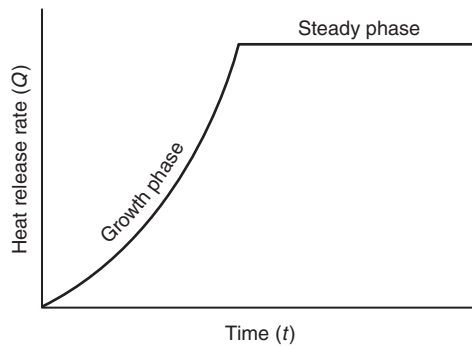


FIGURE 5.2.4(a) Unsteady Design Fire with Steady Phase.

[5.2.3.2]

$$\Delta t = \frac{mH_c}{Q}$$

where:

Δt = duration of fire (sec)

m = total fuel mass consumed (lb or kg)

H_c = heat of combustion of fuel (Btu/lb or kJ/kg)

Q = heat release rate (Btu/sec or 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:

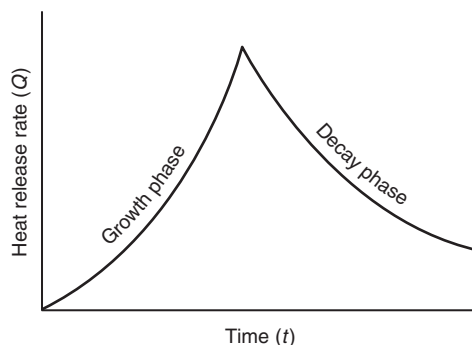


FIGURE 5.2.4(b) Unsteady Design Fire with Decay Phase.

[5.2.4.2.1a]

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

where:

 Q = heat release rate of design fire (Btu/sec) t = time after effective ignition (sec) t_g = growth time (sec)

[5.2.4.2.1b]

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

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 5.2.4.2.2 as follows:

[5.2.4.2.2]

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

where:

 Δt = duration of fire (sec) m = total fuel mass consumed (lb or kg) H_c = heat of combustion of fuel (Btu or 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 5.2.5.3 as follows:

[5.2.5.3]

$$R = \left(\frac{Q}{4\pi q_r} \right)^{1/2}$$

where:

 R = separation distance from target to center of fuel package (ft or m) Q = radiative portion of the heat release rate of the fire (Btu/ft or kW) q_r = incident radiant flux required for piloted ignition (Btu/ft² · s or kW/m²)

5.2.5.4 The radiative portion of the heat release rate of the fire shall be determined from Equation 5.2.5.4 as follows:

[5.2.5.4]

$$Q_r = \xi Q$$

where:

 Q_r = radiative portion of the heat release rate of the fire (Btu/sec or kW) ξ = radiative fraction (dimensionless) Q = heat release rate of the fire (Btu/sec or 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 5.3.1 as follows:

[5.3.1]

$$m = \frac{Q \Delta t}{H_c}$$

where:

 m = total fuel mass consumed (lb or kg) Q = heat release rate (Btu/sec or kW) Δt = duration of fire (sec) H_c = heat of combustion of fuel (Btu/lb or kJ/kg)

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

[5.3.2]

$$m = \frac{333\Delta t^3}{H_c t_g^2}$$

where:

m = total fuel mass consumed (lb or kg)
 Δt = duration of fire (sec)
 H_c = heat of combustion of fuel (Btu/lb or kJ/kg)
 t_g = growth time (sec)

5.4 Smoke Layer Calculations.

5.4.1* 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 5.4.2 and Section 5.5.

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

5.4.2.1* Steady Fires. Where all the following conditions occur, the height of the first indication of smoke above the fire surface, z , shall be calculated using either Equation 5.4.2.1a or 5.4.2.1b:

- (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

[5.4.2.1a]

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

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)

[5.4.2.1b]

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

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)

5.4.2.2* Unsteady Fires. Where all the following conditions occur, the descent of the height of the initial indication of

smoke shall be calculated for t -squared fires using Equation 5.4.2.2a or 5.4.2.2b:

- (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

[5.4.2.2a]

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

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)

[5.4.2.2b]

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

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)

5.5 Rate of Smoke Mass Production.

5.5.1 Axisymmetric Plumes.

5.5.1.1* Where the plume is axisymmetric, the mass rate of smoke production shall be calculated using Equation 5.5.1.1a, 5.5.1.1b, or 5.5.1.1c or Equation 5.5.1.1d, 5.5.1.1e, or 5.5.1.1f as follows:

[5.5.1.1a]

$$z_l = 0.533Q_c^{2/5}$$

[5.5.1.1b]

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

[5.5.1.1c]

$$\text{when } z \leq z_l, m = 0.0208Q_c^{3/5} z$$

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)

[5.5.1.1d]

$$z_l = 0.166Q_c^{2/5}$$

[5.5.1.1e]

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

[5.5.1.1f]

$$\text{when } z \leq z_l, m = 0.032Q_c^{3/5}z$$

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)

5.5.1.2 Equations 5.5.1.1b, 5.5.1.1c, 5.5.1.1e, and 5.5.1.1f shall not be used when the temperature rise above ambient ($T_p - T_o$) is less than 4°F (2.2°C). (See 5.5.5.)

5.5.1.3 The convective portion of the heat release rate of the fire shall be determined from Equation 5.5.1.3 as follows:

[5.5.1.3]

$$Q_c = \chi Q$$

where:

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

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

5.5.2* Balcony Spill Plumes.

5.5.2.1* 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 5.5.2.1a or 5.5.2.1b as follows:

[5.5.2.1a]

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

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)

[5.5.2.1b]

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

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)

5.5.2.2 Equations 5.5.2.1a and 5.5.2.1b shall not be used when the temperature rise above ambient ($T_p - T_o$) is less than 4°F (2.2°C). (See 5.5.5.)

5.5.2.3 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.

5.5.2.4* Where draft curtains are used, they shall be perpendicular to the opening, in order 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.

5.5.2.5 Where draft curtains are used, they shall remain in place and shall confine smoke when exposed to the maximum predicted temperature for the design interval time, assuming a design fire in close proximity to the draft curtain.

5.5.2.6 In addition to the requirements in 5.5.2.5, deployable draft curtains shall be activated automatically and shall remain in place until manually reset.

5.5.2.7* In the absence of any barriers, the equivalent width shall be calculated using Equation 5.5.2.7 as follows:

[5.5.2.7]

$$W = w + b$$

where:

W = width of the plume (ft or m)
 w = width of the opening from the area of origin (ft or m)
 b = distance from the opening to the balcony edge (ft or m)

5.5.2.8* 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 Equation 5.5.2.7 is < 32.8 ft (10 m), the mass flow rate of smoke production shall be calculated using either Equation 5.5.2.8a or 5.5.2.8b.

Δ

[5.5.2.8a]

$$\dot{m}_b = 0.32\dot{Q}_c^{1/3}W^{1/5}(z_b + 0.098W^{7/15}H + 19.5W^{7/15} - 49.2)$$

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)



[5.5.2.8b]

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

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)

5.5.2.9* 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 Equation 5.5.2.7 is ≥ 32.8 ft (10 m) and ≤ 45.9 ft (14 m), the mass flow rate of smoke production shall be calculated using Equation 5.5.2.9a or 5.5.2.9b.



[5.5.2.9a]

$$\dot{m}_b = 0.062(\dot{Q}_c W^2)^{1/3}(z_b + 0.51H + 52)$$

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)

[5.5.2.9b]

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

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)

5.5.2.10* 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 Equation 5.5.1.1b or 5.5.1.1e) with appropriate design fire sizes shall be evaluated and the higher mass flow rate used for the design of the atrium smoke management system.

5.5.3* Window Plumes.

5.5.3.1* Where the smoke plume is a window plume, the total heat release rate of a ventilation-limited fire shall be calculated using Equation 5.5.3.1a or 5.5.3.1b as follows:

[5.5.3.1a]

$$Q = 61.2A_w H_w^{1/2}$$

where:

Q = heat release rate (Btu/sec)

A_w = area of ventilation opening (ft²)

H_w = height of ventilation opening (ft)

[5.5.3.1b]

$$Q = 1260A_w H_w^{1/2}$$

where:

Q = heat release rate (kW)

A_w = area of ventilation opening (m²)

H_w = height of ventilation opening (m)

5.5.3.2* Where the smoke plume is a window plume, the mass entrainment for window plumes shall be determined using Equation 5.5.3.2a or 5.5.3.2b as follows:

[5.5.3.2a]

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

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)

[5.5.3.2b]

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

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)

5.5.3.3 Equations 5.5.1.1b, 5.5.1.1c, 5.5.2.1, and 5.5.3.2 shall not be used when the temperature rise above ambient ($T_p - T_a$) is less than 4°F (2.2°C). (See 5.5.5.)

5.5.4* Axisymmetric Plume Diameter.

5.5.4.1 Calculation. The diameter of an axisymmetric plume shall be calculated using Equation 5.5.4.1. The diameter constant can range from 0.25 to 0.5, and the following values shall be used: $K_d = 0.5$ for plume contact with walls and $K_d = 0.25$ for beam detection of the smoke plume

[5.5.4.1]

$$d_p = K_d \cdot z$$

where:

d_p = axisymmetric plume diameter (ft or m)

K_d = diameter constant

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

5.5.4.2 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.

5.5.5* Smoke Layer Temperature. The temperature of the smoke layer shall be determined in accordance with Equation 5.5.5 as follows:

$$T_s = T_o + \frac{K_s Q_c}{m C_p} \quad [5.5.5]$$

where:

T_s = smoke layer temperature (°F or °C)

T_o = ambient temperature (°F or °C)

K_s = fraction of convective heat release contained in smoke layer

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

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

C_p = specific heat of plume gases (0.24 Btu/lb-°F or 1.0 kJ/kg-°C)

5.5.5.1 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.

5.5.5.2 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.

5.6* Number of Exhaust Inlets.

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

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

5.6.3* The maximum volumetric flow rate that can be exhausted by a single exhaust inlet without plugholing shall be calculated using Equation 5.6.3a or 5.6.3b.

[5.6.3a]

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

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)

[5.6.3b]

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

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)

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

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

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

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

5.6.8 For rectangular exhaust inlets, D_i shall be calculated using Equation 5.6.8

[5.6.8]

$$D_i = \frac{2ab}{a+b}$$

where:

D_i = diameter of the inlet

a = length of the inlet

b = width of the inlet

5.6.9 Where multiple exhaust inlets are required to prevent plugholing (*see* 5.6.1), the minimum separation distance shall be calculated using Equation 5.6.9a or 5.6.9b as follows:

[5.6.9a]

$$S_{\min} = 0.065 V_e^{1/2}$$

where:

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

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

[5.6.9b]

$$S_{\min} = 0.9 V_e^{1/2}$$

where:

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

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

5.7* Volumetric Flow Rate. The volumetric flow rate of smoke exhaust shall be determined using Equation 5.7a or 5.7b as follows:

$$V = 60 \frac{m}{\rho}$$

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)

$$V = \frac{m}{\rho}$$

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)

5.8* Density of Smoke. The density of smoke shall be determined using Equation 5.8a or 5.8b as follows:

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

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)

$$\rho = \frac{P_{atm}}{RT}$$

where:

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

P_{atm} = atmospheric pressure (Pa)

R = gas constant (287)

T = absolute temperature of smoke (K)

5.9* 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.

5.10 Opposed Airflow.

5.10.1 Where opposed airflow is used to prevent smoke originating in a communicating space from propagating into the large-volume space, as shown in Figure 5.10.1, 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 5.10.1a or 5.10.1b as follows:

[5.7a]

[5.7b]

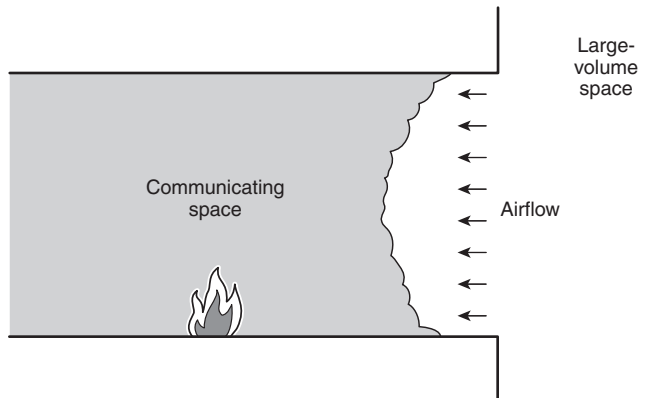


FIGURE 5.10.1 Use of Airflow to Prevent Smoke Propagation from a Communicating Space to a Large-Volume Space.

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

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)

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

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)

5.10.2 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 5.10.2, air shall be supplied from the communicating space at the limiting average velocity, v_e , as calculated in accordance with Equation 5.10.2a or 5.10.2b as follows:

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

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)

[5.10.2b]

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

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)

5.10.2.1 Where the limiting average air velocity, v_e , calculated from Equation 5.10.2a or 5.10.2b exceeds 200 ft/min (1.02 m/sec), the opposed airflow method shall not be used for the purpose of this subsection.

5.10.2.2 Equations 5.10.2a and 5.10.2b shall not be used when z is less than 10 ft (3 m).

5.10.3 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 5.10.3, air shall be supplied from the communicating space at the limiting average velocity, v_e , as determined in accordance with Equation 5.10.3a or 5.10.3b as follows:

[5.10.3a]

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

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)

[5.10.3b]

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

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)

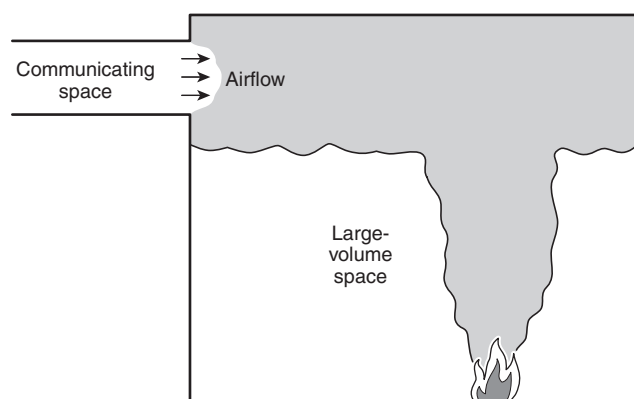


FIGURE 5.10.3 Use of Airflow to Prevent Smoke Propagation from a Large-Volume Space to a Communicating Space Located Above the Smoke Layer Interface.

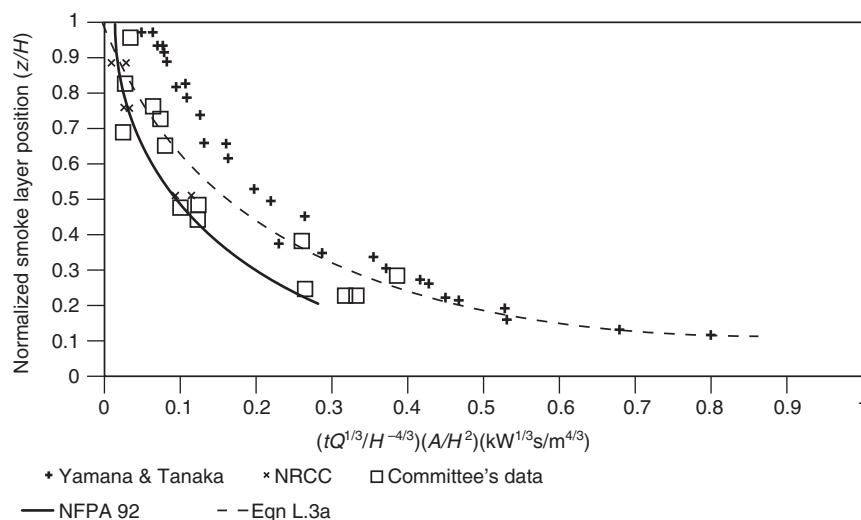


FIGURE 5.10.2 Use of Airflow to Prevent Smoke Propagation from the Plume Within the Large-Volume Space to a Communicating Space Located Below the Smoke Layer Interface.

5.10.3.1 Where the limiting average air velocity, v_o , calculated from Equation 5.10.3a or 5.10.3b exceeds 200 ft/min (1.02 m/sec), the opposed airflow method shall not be used for the purpose of this subsection.

5.10.3.2 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.

5.11* Scaling Laws.

5.11.1 The scale model shall be based on the relationships in Table 5.11.1.

Table 5.11.1 Scaling Expressions

Characteristic Relationship	Expression
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

5.11.2 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 not less than 1 ft (0.3 m).

Chapter 6 Building Equipment and Controls

6.1 General. Equipment and controls used for smoke control purposes shall be in accordance with this chapter.

6.2* Heating, Ventilating, and Air-Conditioning (HVAC) Equipment.

6.2.1 General. HVAC equipment used for smoke control purposes shall be permitted to be located within the conditioned space, within adjacent spaces, or within remote mechanical equipment rooms.

6.2.2 Outside Air. HVAC systems used for smoke control purposes shall be provided with outside air for pressurization.

6.2.3 Where supply and return air systems are interconnected as part of normal HVAC operation, smoke dampers shall be provided to separate the supply and exhaust during smoke control operation.

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

6.3 Smoke Dampers.

6.3.1 Smoke dampers used to protect openings in smoke barriers or used as safety-related dampers in engineered smoke control systems shall be listed and labeled in accordance with ANSI/UL 555S, *Standard for Smoke Dampers*.

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

6.4* Smoke Control Systems.

6.4.1 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.

6.4.2 Coordination. A single control system shall coordinate the functions provided by the fire alarm system, fire fighters' smoke control station (FSCS), and any other related systems with the operation of the building HVAC systems and dedicated smoke control equipment.

6.4.3* HVAC System Controls. Operating controls of the HVAC system shall be designed or modified to provide the smoke control mode with the highest priority over all other control modes.

6.4.4 Activation and Deactivation.

6.4.4.1 Automatic Activation.

6.4.4.1.1* Smoke control systems shall be automatically activated in response to signals received from a specific fire detection device or a combination of fire detection devices.

6.4.4.1.2* In the event that signals are received from more than one smoke zone, the system shall continue automatic operation in the mode determined by the first signal received except as provided for in 6.4.4.1.3.

6.4.4.1.3* For systems designed for operation of multiple zones using only heat-activated detection devices, it shall be permitted to expand the control strategy to accommodate additional zones, up to the limits of the mechanical system design.

6.4.4.1.4* Schedule. The equipment to be operated for each automatically activated smoke control configuration shall be fully defined in the project documents.

6.4.4.1.5* Stratification of Smoke. For large spaces where smoke stratification can occur, one of the following detection schemes shall be used:

- (1)* An upward beam to detect the smoke layer
- (2)* Detection of the smoke layer at various levels
- (3)* Horizontal beams to detect the smoke plume

6.4.4.2 Manual Activation.

6.4.4.2.1* Where approved by the authority having jurisdiction, manual activation by an authorized user shall be permitted.

6.4.4.2.2* Manual fire alarm pull stations shall not be used to activate smoke control systems that require information on the location of the fire.

6.4.4.2.3* Stairwell pressurization systems or other smoke management systems where the response of the system is identical for all zone alarms shall be permitted to be activated from a manual fire alarm pull station.

6.4.4.2.4 Fire alarm pull stations shall be permitted to cause doors in smoke barrier walls to close.

6.4.4.2.5* Manual activation and deactivation shall be permitted to be at a controlled device, at a local control panel, at the building's main control center, or at the fire command station.

6.4.4.2.6 Key-operated manual switches that are clearly marked to identify their function shall be permitted to manually activate the smoke control system.

6.4.5 FSCS Activation.

6.4.5.1 Smoke control systems shall be capable of being activated from the FSCS by switches clearly marked to identify the location and function.

6.4.5.2 Sequence of Control Priorities. Smoke control systems shall be subject to the sequences of control priorities given in 6.4.5.2.1, 6.4.5.2.2, and 6.4.5.2.2.2.

6.4.5.2.1 Automatic Activation.

6.4.5.2.1.1 Automatic activation of systems and equipment for smoke control shall have the highest priority over all other sources of automatic control within the building.

6.4.5.2.1.2* Except as provided for in 6.4.5.2.1.3, where equipment used for smoke control is also used for normal building operation, control of this equipment shall be preempted or overridden as required for smoke control.

6.4.5.2.1.3 The following controls shall not be automatically overridden:

- (1) Static pressure high limits
- (2) Duct smoke detectors on supply air systems

6.4.5.2.2 Manual Activation and Deactivation.

6.4.5.2.2.1 Manual activation or deactivation of smoke control systems and equipment shall have priority over automatic activation of smoke control systems and equipment and all other sources of automatic control within the building and over prior manual smoke control activation or deactivation commands.

6.4.5.2.2.2 If equipment used for smoke control is subject to automatic activation in response to an alarm from an automatic fire detector of a fire alarm system, or if such equipment is subject to automatic control according to building occupancy schedules, energy management strategies, or other nonemergency purposes, such automatic control shall be preempted or overridden by manual activation or deactivation of the smoke control equipment.

6.4.5.2.2.3 Manual controls provided specifically for manual activation or deactivation for smoke control purposes shall be clearly marked to indicate the location and function served.

6.4.5.2.2.4 Operation of manual controls that are shared both for smoke control functions and for other building control purposes, as in a building's main control center, shall fully cover the smoke control functionality in operational documentation for the control center.

6.4.5.2.3 FSCS Activation. The FSCS shall have the highest priority control over all smoke control systems and equipment.

6.4.5.3 Response Time.

6.4.5.3.1 The smoke control mode shall be initiated within 10 seconds after an automatic, manual, or FSCS activation command is received at the smoke control system.

6.4.5.3.2* Smoke control systems shall activate individual components (e.g., dampers, fans) in the sequence necessary to prevent physical damage to the fans, dampers, ducts, and other equipment.

6.4.5.3.3* Smoke Containment Systems. The time necessary for individual smoke containment components to achieve their desired state or operational mode from when the component receives the signal shall not exceed the following time periods:

- (1) Fan operation at the desired state: 60 seconds
- (2) Completion of damper travel: 75 seconds

6.4.5.3.4* Smoke Management Systems. The total response time, including that necessary for detection, shutdown of smoke management operating equipment, and smoke control system startup, shall allow for full operational mode to be achieved before the conditions in the space exceed the design smoke conditions.

6.4.5.4* Fire Fighters' Smoke Control Station (FSCS).

6.4.5.4.1 An FSCS shall be provided for all smoke control systems.

6.4.5.4.2 The FSCS shall be installed at a location acceptable to the authority having jurisdiction.

6.4.5.4.3* The FSCS shall provide status indication, fault condition indication, and manual control of all smoke control system components.

6.4.5.4.4 Status indicators and controls shall be arranged and labeled to convey the intended system objectives.

6.4.5.4.5 Operator controls, status indication, and fault indication shall be provided for each smoke control zone, each piece of equipment capable of activation for smoke control, or a combination of these approaches.

6.4.5.4.6 Positive status indication (ON and OFF) shall be provided individually or by zone in accordance with 6.4.5.4.5 for the following:

- (1) Dedicated smoke control system fans
- (2) Nondedicated fans used for smoke control having a capacity in excess of 2000 ft³/min (57 m³/min)

6.4.5.4.7* ON status shall be sensed by a pressure difference, an airflow switch, or some other positive proof of airflow.

6.4.5.4.8 Positive status indication (fully open and fully closed) of damper position shall be provided if individual controls for the damper are provided on the FSCS.

6.4.5.4.9 Provision shall be included for testing the pilot lamps on the FSCS control panel(s) by means of one or more "LAMP TEST" momentary push buttons or other self-restoring means.

6.4.5.4.10 Diagrams and graphic representations of the system shall be used.

6.4.5.4.11 The FSCS shall have the highest priority control over all smoke control systems and equipment.

6.4.5.4.12 Where manual controls for control of smoke control systems are also provided at other building locations, the control mode selected from the FSCS shall prevail.

6.4.5.4.13 FSCS control shall override or bypass other building controls such as hand-off-auto and start/stop switches located on fan motor controllers, freeze detection devices, and duct smoke detectors except as provided by 6.4.5.4.13.1.

6.4.5.4.13.1 The FSCS fan control capability shall not be required to bypass hand-off-auto or start/stop switches located on motor controllers of nondedicated smoke control system fans where both of the following conditions exist:

- (1) Such fan motor controllers are located in mechanical or electrical equipment rooms or in other areas accessible only to authorized personnel.
- (2) The use of such a motor controller switch to turn a fan on or off will cause an off-normal indication at the building's main control center during normal HVAC or building control operations of the nondedicated fan.

6.4.5.4.14 FSCS control shall not take precedence over fire suppression, electrical protection, or personnel protection devices.

6.4.6 Controls for Stairwell Pressurization Systems. When stairwell pressurization systems are provided, they shall be activated as described in 6.4.6.1 through 6.4.6.4.2.

6.4.6.1 Automatic Activation.

6.4.6.1.1* Operation of any zone of the building fire alarm system shall cause all stairwell pressurization fans to start except as indicated in 6.4.6.1.2.

6.4.6.1.2 Where an engineering analysis determines that operation of all stairwell pressurization fans is not required to achieve the design objective, only the stairwell pressurization fans identified during the analysis shall be required to be activated.

6.4.6.2 Smoke Detection.

6.4.6.2.1 A smoke detector shall be provided in the air supply to the pressurized stairwell.

6.4.6.2.2 On detection of smoke in the air supply, the supply fan(s) shall be stopped.

6.4.6.3 Manual Pull Stations. Stairwell pressurization systems where the response of the system is identical for all zone alarms shall be permitted to be activated from a manual fire alarm pull station.

6.4.6.4 FSCS Activation.

6.4.6.4.1 Manual activation and deactivation control of the stairwell pressurization systems shall be provided at the FSCS.

6.4.6.4.2 An override switch shall be permitted to be provided at the FSCS to restart the stairwell pressurization fan(s) after shutdown from the smoke detector.

6.4.7 Controls for Zoned Smoke Control Systems.

6.4.7.1 General. When zoned smoke control systems are provided, they shall be activated as described in 6.4.7.2.1 and 6.4.7.2.2.

6.4.7.2 Automatic Activation.

6.4.7.2.1* When signals from fire alarm systems are used to activate the zoned smoke control system(s), the fire alarm zones shall be arranged to coincide with the smoke containment zones.

6.4.7.2.2 Where an automatic smoke detection system is used to automatically activate a zoned smoke control system, the smoke detection system shall be permitted to be of limited coverage having spacing greater than 900 ft² (84 m²) per detector.

6.4.7.2.3 Where an automatic smoke detection system is used to automatically activate a zoned smoke control system, the location of smoke detectors and the zoning of the detectors shall be arranged to detect smoke before it leaves the smoke zone.

6.4.7.2.4 Where a waterflow switch or heat detector is used to activate a zoned smoke control system, zoning of such systems shall coincide with the smoke containment zone.

6.4.7.3* Zoned smoke control systems shall not be activated from manual fire alarm pull stations.

6.4.8* Control System Verification.

6.4.8.1 Every dedicated smoke control system and each dedicated smoke control subsystem in a nondedicated smoke control system shall have a means of verifying correct operation when activated.

6.4.8.2 Verification shall include positive confirmation of activation, testing, manual override, and the presence of operating power downstream of all circuit disconnects.

6.4.8.3 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.

6.4.8.4 Fire alarm signaling paths to the smoke control system shall be monitored for integrity in accordance with 10.17.1 of *NFPA 72* with trouble annunciation provided at the FSCS, unless both of the following conditions are met:

- (1) The interconnecting wiring between the fire alarm system and the smoke control system is located within 20 ft (6.1 m) of each other.
- (2) The conductors are installed in conduit or equivalently protected against mechanical injury.

6.4.8.5 Ground-fault annunciation shall not be required where receipt of the activation signal by the smoke control system is not affected by a single ground fault.

6.4.8.6 Operational capability of individual components of dedicated smoke control systems shall be verified using the weekly self-test function provided by the UUKL-listed smoke control panel mandated by 6.4.1, except as specified in 6.4.8.7.

N 6.4.8.7 Where verification of individual components tested through the preprogrammed weekly testing sequence will interfere with normal building operation and produce unwanted effects to normal building operation, such individual components shall be permitted to be bypassed from the weekly self-testing where approved by the code official and where in accordance with 6.4.8.7.1 and 6.4.8.7.2.

N 6.4.8.7.1 Where the operation of components is bypassed from the preprogrammed weekly test, presence of power downstream of all disconnects shall be verified weekly by the listed control unit.

N 6.4.8.7.2 All components that are bypassed from the preprogrammed weekly test shall be tested semiannually. The system shall also be tested under standby power conditions.

6.5 Energy Management. Energy management systems, particularly those that cycle supply, return, and exhaust fans for energy conservation, shall be overridden when their control or operation is in conflict with a smoke control mode.

6.6 Materials.

6.6.1 Materials used for systems providing smoke control shall conform to NFPA 90A and other applicable NFPA documents.

6.6.2 Duct materials shall be selected and ducts shall be designed to convey smoke, to withstand additional pressure (both positive and negative) by the supply and exhaust fans when operating in a smoke control mode, and to maintain their structural integrity during the period for which the system is designed to operate.

6.6.3* 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 is likely to be exposed.

6.7 Electric Services Installation.

6.7.1 All electrical installations shall meet the requirements of NFPA 70.

6.7.2 The smoke control system shall be designed so that loss of normal power for a period of up to 15 minutes will result in the components automatically performing their function upon restoration of power.

6.7.3 Where standby power is provided in accordance with NFPA 110 the standby power source and related transfer switches shall be separated from transformers and switch gear for the primary power supply and enclosed in a room with a 1-hour fire resistance-rated fire barrier wall installed in accordance with NFPA 221.

Chapter 7 Smoke Control System Documentation

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

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

7.2 Detailed Design Report.

7.2.1 The detailed design report shall provide documentation of the smoke control system as it is designed and intended to be installed.

7.2.2 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
- (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

7.3* 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.

7.3.1 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 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

7.3.2 Copies of the operations and maintenance manual shall be provided to the owner and the authorities having jurisdiction.

7.3.3 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.

7.3.4 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.

Chapter 8 Testing

8.1* General.

8.1.1 Each smoke control system shall be tested against its specific design criteria.

8.1.2 Testing shall confirm that the design objectives **described** in Section 4.1 are achieved.

8.1.3 Design documents shall include all acceptance testing procedures and pass/fail criteria.

8.1.4* Responsibility for each phase of the testing shall be defined clearly prior to commencing inspection and testing.

8.2 Preliminary Building Inspections.

8.2.1 Prior to testing, the party responsible for testing shall verify completeness of building construction.

8.2.2 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

8.3* Component System Testing.

8.3.1 An operational test of each smoke control system component and subsystem shall be performed prior to the acceptance test.

8.3.2 Operational tests shall be performed prior to interconnection of individual components and subsystems to the smoke control system.

8.3.3* Smoke control system operational testing shall include all subsystems to the extent that they affect the operation of the smoke control system.

8.3.4 Requirements and responsibilities for each component test shall be identified in the design documentation.

8.3.5 All documentation from component system testing relative to the smoke control system shall be included in the final testing documentation.

8.4 Acceptance Testing.

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

8.4.2* Test Parameters. Where appropriate to the design, all parameters shall be measured during acceptance testing

8.4.3* Measurement Locations. The locations for measurement of the parameters identified in 8.4.2 shall be in accordance with nationally recognized methods.

8.4.4 Testing Procedures. The acceptance testing shall include the procedures described in 8.4.4.1 through 8.4.4.4.

8.4.4.1* 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 control.

8.4.4.2* 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.

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

8.4.4.4 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

8.4.4.5 The force necessary to open each egress door shall be measured using a spring-type scale and recorded.

8.4.4.6 Door-opening forces shall not exceed those allowed by the building code.

8.4.4.7 Activation of each smoke control system response to all means of activation, both automatic and manual, as specified in

the design report and operations and maintenance manual in Chapter 7, shall be verified and recorded.

8.4.4.8 The proper operation of all fans, dampers, and related equipment, as outlined by the project documents referenced in 6.4.4.1.4, shall be verified and recorded.

8.4.5* Testing of Smoke Management Systems in Large-Volume Spaces. Acceptance testing to verify systems performance shall include the following:

- (1) Prior to performance testing:
 - (a) 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.
 - (b) For larger openings, measure the velocity by making appropriate traverses of the opening.
- (2) Activate the smoke management system, then do the following:
 - (a) Verify and record the operation of all fans, dampers, doors, and related equipment.
 - (b) Measure fan exhaust capacities and air velocities through inlet doors and grilles or at supply grilles if there is a mechanical makeup air system.
 - (c) 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.

8.4.6 Testing of Smoke Containment Systems.

8.4.6.1 Pressure Testing.

8.4.6.1.1 With the containment system activated, the pressure difference across each smoke barrier shall be measured and recorded with all interior doors closed.

8.4.6.1.2 If an exterior door would normally be open during evacuation, it shall be open during testing.

8.4.6.1.3 The HVAC system shall be off unless the normal mode is to leave the HVAC system on during smoke control operations.

8.4.6.1.4* With the containment system activated and the number of egress doors used in the system design open, the pressure difference across the barrier shall be measured and recorded.

8.4.6.1.5 No pressure difference shall be less than the minimum design pressure differences in Table 4.4.2.1.1 or the pressures specified in the design documents.

8.4.6.2* Force Testing.

8.4.6.2.1 With the containment system activated and the number of doors used in the system design open, the force necessary to open each egress door shall be measured and recorded.

8.4.6.2.2 All other doors shall be closed when the measurements specified in 8.4.6.2.1 are made.

8.4.6.3 Stairwell Pressurization Systems.

8.4.6.3.1 The requirements in 8.4.6.3 shall apply where stairwell pressurization is the only smoke control system in the building.

8.4.6.3.2 Where stairwell pressurization is used in combination with zoned smoke control, the requirements of 8.4.6.7.1 shall apply.

8.4.6.3.3 Pressurized stairwell vestibules shall be treated as a zone in a zoned smoke control system. (See 8.4.6.4.)

8.4.6.4* Zoned Smoke Control System.

8.4.6.4.1 The requirements in 8.4.6.4 shall apply where zoned smoke control is the only smoke control system in the building.

8.4.6.4.2 Normal HVAC Mode.

8.4.6.4.2.1 The pressure difference across all smoke control zones that divide a building floor shall be measured and recorded while the HVAC systems serving the floor's smoke zones are operating in their normal (non-smoke control) mode and while all smoke barrier doors that separate the floor zones are closed.

8.4.6.4.3 Smoke Control Mode for Each Smoke Control Zone.

8.4.6.4.3.1 Each separate smoke control zone shall be activated by a simulated fire alarm input.

8.4.6.4.3.2 The pressure difference across all smoke barriers that separate the smoke zone from adjacent zones shall be measured and recorded.

8.4.6.4.3.3 The measurements shall be made while all smoke barrier doors that separate the smoke zone from the other zones are fully closed.

8.4.6.4.3.4 One measurement shall be made across each smoke barrier or set of doors, and the data shall clearly indicate the higher and lower pressure sides of the doors or barriers.

8.4.6.4.3.5 Doors that have a tendency to open slightly due to the pressure difference shall have one pressure measurement made while held closed and another made while not held closed.

8.4.6.4.3.6* Testing, as described in 8.4.6.4.3.1, shall continue until all fire alarm inputs have been activated.

8.4.6.5* Elevator Smoke Control Systems.

8.4.6.5.1 Elevator Hoistway Pressurization Systems.

8.4.6.5.1.1 General.

(A) The requirements in 8.4.6.5.1 shall apply where elevator hoistway pressurization is the only smoke control system in the building.

(B) Where elevator hoistway pressurization is used in combination with zoned smoke control, the requirements of 8.4.6.7.3 shall apply.

8.4.6.5.1.2 Pressure Testing.

(A) With the elevator pressurization system activated, the pressure difference across each elevator door with all elevator doors closed shall be measured and recorded.

(B) If the elevator door on the recall floor would normally be open during system pressurization, it shall be open during testing.

(C) The HVAC system shall be off unless the normal mode is to leave the HVAC system on during smoke control operations.

Δ (D) If the elevator pressurization system has been designed to operate during elevator movement, the tests in 8.4.6.5.1.2(A) through 8.4.6.5.1.2(C) shall be repeated under these conditions.

8.4.6.5.2 Lobby Pressurization Systems.

8.4.6.5.2.1 General.

(A) The requirements in 8.4.6.5.2 shall apply where enclosed elevator lobby pressurization is the only smoke control system in the building.

(B) Where elevator lobby pressurization is used in combination with zoned smoke control, the requirements of 8.4.6.7.3 shall apply.

(C)* Where enclosed elevator lobbies are pressurized by an elevator lobby pressurization system, or where enclosed elevator lobbies receive secondary pressurization from the elevator hoistway, the requirements of 8.4.6.7.3 shall apply.

8.4.6.6 Smoke Refuge Area.

8.4.6.6.1 A smoke refuge area shall be treated as a zone in a zoned smoke control system.

8.4.6.6.2 The tests outlined in 8.4.6.4 shall be conducted.

8.4.6.7 Combination of Smoke Control Systems.

8.4.6.7.1* Stairwell and Zoned Smoke Control System.

8.4.6.7.1.1 The stairwell pressurization system shall be considered as one zone in a zoned smoke control system.

8.4.6.7.1.2 The tests outlined in 8.4.6.1, 8.4.6.2, and 8.4.6.4 shall be conducted.

8.4.6.7.1.3 All tests shall be conducted with both systems operating in response to a simulated fire alarm input.

8.4.6.7.2 Smoke Refuge Area and Zoned Smoke Control System.

8.4.6.7.2.1 A smoke refuge area shall be treated as a separate zone in a zoned smoke control system.

8.4.6.7.2.2 The tests outlined 8.4.6.4 shall be conducted.

8.4.6.7.3 Elevator Pressurization and Zoned Smoke Control System.

8.4.6.7.3.1 The elevator pressurization system shall be considered as one zone in a zoned smoke control system.

8.4.6.7.3.2 Each elevator lobby in an enclosed elevator lobby pressurization system shall be considered as one zone in a zoned smoke control system.

8.4.6.7.3.3 The tests outlined in 8.4.6.4 shall be conducted.

8.4.6.7.3.4 The tests outlined in 8.4.6.5.1 shall be conducted if a hoistway pressurization system is present.

8.4.6.7.3.5 The tests outlined in 8.4.6.5.2 shall be conducted if a lobby pressurization system is present.

8.4.6.7.3.6 The tests outlined in both 8.4.6.5.1 and 8.4.6.5.2 shall be conducted if both systems are present.

8.4.7 Tests of Fire Fighter's Smoke Control Station.

8.4.7.1 All inputs to and outputs from the FSCS shall be tested.

8.4.7.2 Tests shall include manual override of normal and automatic smoke control modes.

8.5 Testing Documentation.

8.5.1* Upon completion of acceptance testing, a copy of all operational testing documentation shall be provided to the owner and to the authority having jurisdiction.

8.5.2 Owner's manuals containing complete data on the smoke control system and instructions for operating and maintaining the system shall be provided to the owner.

8.6 Periodic Testing.

8.6.1* Periodic testing of smoke control equipment shall be performed in accordance with this section.

8.6.1.1 Dedicated systems shall be tested at least semiannually.

8.6.1.2 Non-dedicated systems shall be tested at least annually.

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

8.6.3 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

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

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

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

8.6.5.2 The smoke control system shall be operated for each sequence in the current design criteria.

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

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

8.6.6 Special arrangements shall be considered for the introduction of large quantities of outside air into occupied areas or sensitive equipment spaces when outside temperature and humidity conditions are extreme and when such unconditioned air could damage contents.

8.7 Modifications.

8.7.1* All operational and acceptance testing shall be performed on the applicable part of the system whenever the system is changed or modified.

8.7.2 If the smoke control system or the zone boundaries have been modified since the last test, acceptance testing shall be conducted on the portion modified.

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

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 control system designs. The designs are based on select design objectives presented in Section 4.1.

This standard addresses the following topics:

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

This standard does not address the interaction of sprinklers and smoke control systems. The cooling effect of sprinklers can result in some of the smoke losing buoyancy and migrating downward below the design smoke layer interface. This standard also does not provide methodologies to assess the effects of smoke exposure on people, property, or mission continuity.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.3.4 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.

A.3.3.2 Ceiling Jet. Normally, the temperature of the ceiling jet is greater than the adjacent smoke layer.

A.3.3.3 Design Pressure Difference. Protected spaces include the nonsmoke zones in a zoned smoke control system, the stairwells in a stairwell pressurization system, a smoke refuge area, and the elevator shaft in an elevator hoistway system.

A.3.3.4 Draft Curtain. A draft curtain can be a solid fixed obstruction such as a beam, girder, soffit, or similar material. Alternately, a deployable barrier can be used that descends to a fixed depth during its operation.

A.3.3.6 Fire Fighters' Smoke Control Station (FSCS). Other fire fighters' systems (such as voice alarm, public address, fire department communication, and elevator status and controls) are not covered in this document.

A.3.3.9 Plume. A plume entrains air as it rises so that the mass flow of the plume increases with height and the temperature and other smoke properties of the plume decrease with height.

A.3.3.9.1 Axisymmetric Plume. Strictly speaking, an axisymmetric plume applies only to round fires, but it is a useful idealization for fires of many other shapes. When the largest dimension of a fire is much less than the height of the plume, the plume mass flow and temperature can be approximated by those characteristics of an axisymmetric plume.

An axisymmetric plume (*see Figure A.3.3.9.1*) is expected for a fire originating on the atrium floor, removed from any walls. In that case, air is entrained from all sides along the entire height of the plume until the plume becomes submerged in the smoke layer.

A.3.3.9.2 Balcony Spill Plume. A balcony spill plume is one that flows under and around a balcony before rising, giving the impression of spilling from the balcony, from an inverted perspective, as illustrated in Figure A.3.3.9.2.

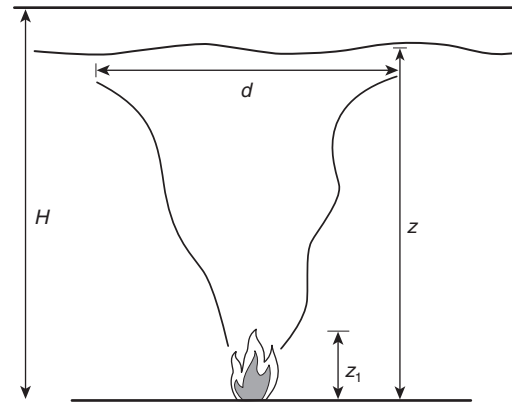


FIGURE A.3.3.9.1 Approximation of an Axisymmetric Plume.

A.3.3.9.3 Window Plume. Plumes issuing from wall openings, such as doors and windows of an adjacent compartment, into a large-volume open space are referred to as window plumes (*see Figure A.3.3.9.3*). Window plumes usually occur when the adjacent compartment is fully involved in a fire typically after the compartment has reached flashover.

A.3.3.12.1 First Indication of Smoke. See Figure A.3.3.12.1. For design evaluations using the algebraic approach outlined in Chapter 5, the first indication of smoke can be determined using Equations 5.4.2.1a and b and Equations 5.4.2.2a and b.

For design evaluations using physical or computational fluid dynamics (CFD) modeling, a method to define the smoke interface height and the first indication of smoke using a limited number of point measurements over the height of the atrium is required. One approach (Cooper et al. [4]; Madrzykowski and Vettori [29]) uses linear interpolation of the point measurements. Using temperature data, the interfaces are at the heights at which the temperature is as follows:

[A.3.3.13.1]

$$T_n = C_n (T_{\max} - T_b) + T_b$$

where:

T_n = temperature at the interface height

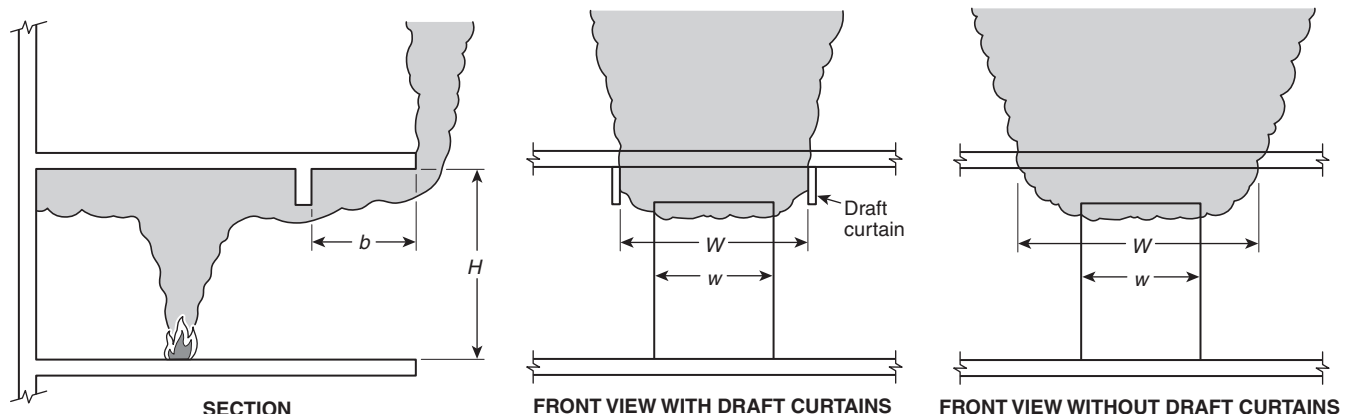


FIGURE A.3.3.9.2 Approximation of a Balcony Spill Plume.

C_n = interpolation constant with values of 0.1–0.2 for the first indication of smoke and 0.8–0.9 for the smoke layer interface, respectively

$T_{\max}$ = temperature in the smoke layer

T_b = temperature in the cold lower layer

A.3.3.13 Smoke Barrier. A smoke barrier might or might not have a fire resistance rating. Such barriers might have protected openings. Smoke barriers as used with smoke control or smoke management systems described in this standard could have openings protected either by physical opening protectives or by pressure differences created by the smoke control or smoke management system. Smoke barriers described in some other codes and standards might require that the openings be protected by physical opening protectives.

A.3.3.14 Smoke Containment. Smoke containment can be achieved by using smoke barriers alone. This standard deals with active mechanical systems. Passive smoke containment achieved by construction features are outside the scope of this document. For further information on the use of smoke barriers, see the requirements in NFPA 101 and NFPA 5000.

A.3.3.17 Smoke Layer. The smoke layer includes a transition zone that is nonhomogeneous and separates the hot upper layer from the smoke-free air. The smoke layer is not a homogeneous mixture, nor does it have a uniform temperature. The calculation methods presented in this standard can assume homogeneous conditions.

A.3.3.18 Smoke Layer Interface. In practice, the smoke layer interface (see Figure A.3.3.12.1) is an effective boundary within a transition buffer zone, which can be several feet (meters) thick. Below this effective boundary, the smoke density in the transition zone decreases to zero. This height is used in the application of the equations in 5.5.3.1, 5.5.3.2, 5.5.4.1, and Section 5.7.

A.3.3.21.1 Communicating Space. Communicating spaces can open directly into the large-volume space or connect through open passageways.

A.3.3.23.2 Dedicated Smoke Control System. Dedicated smoke-control systems are separate systems of air-moving and

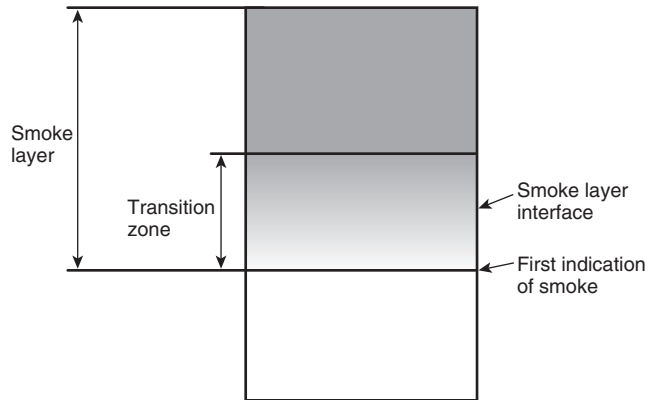


FIGURE A.3.3.12.1 First Indication of Smoke.

distribution equipment that do not function under normal building operating conditions.

Advantages of dedicated systems include the following:

- (1) Modification of system controls after installation is less likely.
- (2) Operation and control of the system is generally simpler.
- (3) Reliance on or impact by other building systems is limited.

Disadvantages of dedicated systems include the following:

- (1) System impairments might go undiscovered between periodic tests or maintenance activities.
- (2) Systems can require more physical space.

A.3.3.23.3 Nondedicated Smoke Control Systems. Advantages of nondedicated systems include the following:

- (1) Impairments to shared equipment required for normal building operation are likely to be corrected promptly.
- (2) Limited additional space for smoke-control equipment is necessary.

Disadvantages of nondedicated systems include the following:

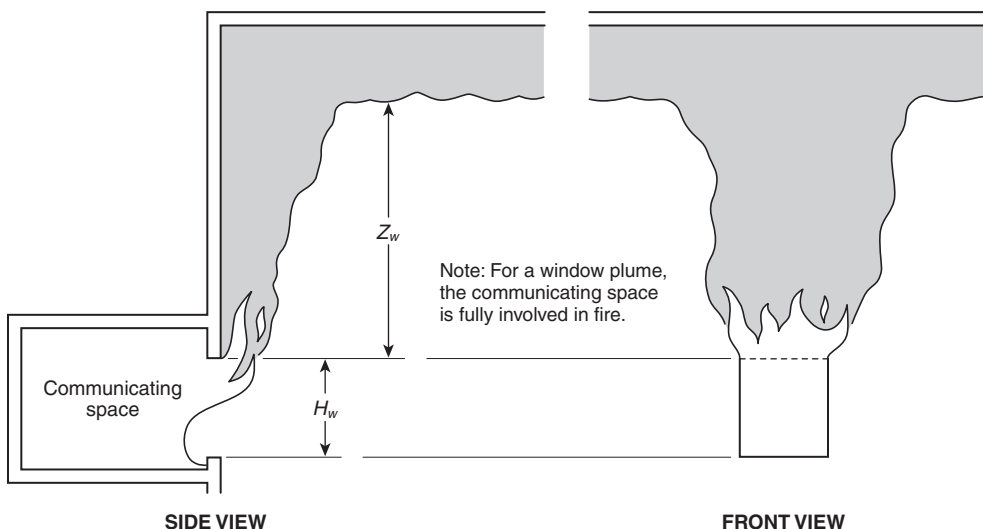


FIGURE A.3.3.9.3 Approximation of a Window Plume.