NFPA®

204

Standard for Smoke and Heat Venting

2021

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NFPA® 204

Standard for

Smoke and Heat Venting

2021 Edition

This edition of NFPA 204, *Standard for Smoke and Heat Venting*, was prepared by the Technical Committee on Smoke Management Systems. It was issued by the Standards Council on October 5, 2020, with an effective date of October 25, 2020, and supersedes all previous editions.

This edition of NFPA 204 was approved as an American National Standard on October 25, 2020.

Origin and Development of NFPA 204

This project was initiated in 1956 when the NFPA Board of Directors referred the subject to the Committee on Building Construction. A tentative guide was submitted to NFPA in 1958. Revised and tentatively adopted in 1959 and again in 1960, the guide was officially adopted in 1961. In 1968, a revised edition was adopted that included a new section, Inspection and Maintenance.

In 1975, a reconfirmation action failed as concerns over use of the guide in conjunction with automatic sprinklered buildings surfaced. Because of this controversy, work on a revision to the guide continued at a slow pace.

The Technical Committee and Subcommittee members agreed that the state of the art had progressed sufficiently to develop improved technology-based criteria for design of venting; therefore, the 1982 edition of the document represented a major advance in engineered smoke and heating venting, although reservations over vent and sprinkler applications still existed.

At the time the guide was formulated, the current venting theory was considered unwieldy for this format; consequently, the more adaptable theory as described herein was adopted.

Appreciation must be extended to Dr. Gunnar Heskestad at the Factory Mutual Research Corporation (now FM Global) for his major contribution to the theory applied in this standard, which is detailed in Annex B.

The 1985 edition again revised Chapter 6 on the subject of venting in sprinklered buildings. Test data from work done at the Illinois Institute of Technology Research, which had been submitted to the committee as part of a public proposal, did not permit consensus to be developed on whether sprinkler control was impaired or enhanced by the presence of automatic roof vents of typical spacing and area. The revised wording of Chapter 6 encouraged the designer to use the available tools and data referenced in the document while the use of automatic venting in sprinklered buildings was under review.

The 1991 edition made minor changes to Chapter 6 to acknowledge that a design basis existed for using sprinklers and automatic heat venting together but that such had not received wide recognition.

The 1998 edition represented a complete revision of the guide. The rewrite deleted the previous tables that listed vent areas and incorporated engineering equations and referenced computer models, such as LAVENT and DETACT, to provide the designer with the necessary tools to develop vent designs based on performance objectives. This rewrite was based extensively on state-of-the-art technology published in the references. In many cases, the authors of these references participated in the task group's rewrite efforts.

For the 2002 edition of NFPA 204, the document was converted from a guide to a standard, thus implementing mandatory requirements and updated language. The document was also updated to meet *Manual of Style for NFPA Technical Committee Documents* requirements.

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The 2007 edition included a number of technical changes. New provisions on air entrainment into the fire plume, the effect of wind on the location of air vents, sizing of air paths, air velocity limitations, and plugholing were provided.

In addition, information on the use of vents as air inlets and a better description of the smoke layer interface were added. Revisions with regard to how heat release rates, discharge coefficients, exhaust rates, and the number of exhaust inlets are to be determined were incorporated. Reference to international standards on vents, mechanical smoke extract, and draft curtains, as well as updated annex text on recent research efforts, were provided.

The 2012 edition was updated to include additional requirements and annex material for venting in sprinklered buildings.

The 2015 edition included revised provisions on draft curtains. These requirements created consistency with NFPA 92.

The 2018 edition was updated to include a correction to an Annex A image, the addition of a definition for the term *standard*, and updated references.

For the 2021 edition, all references in Chapters 5 and 6 that permit sprinkler waterflow to activate automatic smoke vents have been removed. In addition, SI unit conversions have been added to Annex C, and references have been updated.

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

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Standard for

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A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. 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 should be sent to the technical committee responsible for the source document.

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

Chapter 1 Administration

1.1 Scope.

1.1.1* This standard shall apply to the design of venting systems for the emergency venting of products of combustion from fires in buildings. The provisions of Chapters 4 through 10 shall apply to the design of venting systems for the emergency venting of products of combustion from fires in nonsprinklered, single-story buildings using both hand calculations and computer-based solution methods as provided in Chapter 9. Chapter 11 shall apply to venting in sprinklered buildings.

1.1.2* This standard shall not specify under which conditions venting is to be provided or required.

1.1.3 Where a conflict exists between a general requirement and a specific requirement, the specific requirement shall be applicable.

1.2 Purpose. (Reserved)

1.3 Application.

1.3.1* This standard shall not apply to ventilation within a building designed for regulation of environmental air for personnel comfort, to regulation of commercial cooking operations, to regulation of odor or humidity in toilet and bathing facilities, to regulation of cooling of production equipment, or to venting for explosion pressure relief.

1.3.2 This standard shall apply to building construction of all types.

1.3.3 This standard shall apply to venting fires in building spaces with ceiling heights that permit the design fire plume and smoke layer to develop.

1.3.4* This standard shall apply to situations in which the hot smoke layer does not enhance the burning rate of the fuel array. Vent designs developed with this standard shall not be valid for those time intervals where smoke layer temperatures exceed 600°C (1112°F).

1.3.5* This standard shall not be valid for fires having heat release rates greater than $Q_{feasible}$ as determined in accordance with the following equation:

[1.3.5]

$$Q_{feasible} = 12{,}000\left(z_s\right)^{5/2}$$

where:

$Q_{feasible}$ = feasible fire heat release rate (kW)

z_s = height of the smoke layer boundary above the fire base (m)

1.3.6* The engineering equations or computer-based models incorporated into this standard shall be used to calculate the time duration that the smoke layer boundary is maintained at or above the design elevation in a curtained area, relative to the design interval time.

1.4 Retroactivity.

1.4.1 The provisions of this standard shall not be required to be applied retroactively.

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

Δ 1.5 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.

***N* 1.5.1** Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

***N* 1.5.2** The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

Δ 1.6 Units and Formulas.

***N* 1.6.1** The units of measure in this document are presented in the International System (SI) of Units.

***N* 1.6.2** The values presented for measurements in this document are expressed with a degree of precision appropriate for practical application and enforcement. It is not intended that

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the application or enforcement of these values be more precise than the precision expressed.

N 1.6.3 The following symbols define the variables in the equations used throughout the body of this standard:

A = area (of burning surface)
A_i = inlet area for fresh air, below design level of smoke layer boundary
A_v = total vent area of all vents in a curtained area
α = thermal diffusivity, $k/\rho c$
α_g = fire growth coefficient
γ = exhaust location factor (dimensionless)
c_p = specific heat
$C_{d,v}$ = vent discharge coefficient
$C_{d,i}$ = inlet discharge coefficient
d = smoke layer depth
d_c = depth of draft curtain
D = base diameter of the fire
g = acceleration of gravity
H = ceiling height above base of fire
h_c = heat of combustion
h_g = heat of gasification
K = fraction of adiabatic temperature rise
k = thermal conductivity
$k_e\beta$ = constant used in Equation E.5.1
$k\rho c$ = thermal inertia
l = thickness
L = mean flame height above the base of the fire
L_f = flame length, measured from leading edge of burning region
L_v = length of vent opening in the longer direction
$\dot{m}$ = mass burning rate
$\dot{m}''$ = mass burning rate per unit area
$\dot{m}''_\infty$ = mass burning rate per unit area for an infinite diameter pool
$\dot{m}_v$ = mass flow rate through vent
$\dot{m}_p$ = mass flow rate in the plume
$\dot{m}_{pL}$ = mass flow rate in the plume at mean flame height (L)
$\dot{q}''_i$ = incident heat flux per unit area
Q = total heat release rate

(continues)

Q'' = total heat release rate per unit floor area
Q_c = convective heat release rate = $\chi_c Q$
$Q_{feasible}$ = feasible fire heat release rate (kW)
r = radius from fire axis
RTI = response time index $\tau u^{1/2}$
τ = time constant of heat-responsive element for convective heating
ρ = density
ρ_o = ambient air density
S = center to center spacing of vents
t = time
t_d = time to detector activation
t_g = growth time of fire
t_{ig} = time to ignition
t_r = design interval time
t_{sa} = time to sprinkler activation
t_{vo} = time to vent opening
ΔT = gas temperature rise (from ambient) at detector site
ΔT_a = adiabatic temperature rise
ΔT_e = temperature rise (from ambient) of heat-responsive element
T = smoke layer temperature (K)
T_o = ambient air temperature
T_{ig} = ignition temperature
T_s = surface temperature
u = gas velocity at detector site
W_{min} = lateral fire spread by radiation
W_s = largest horizontal dimension of fire
W_v = width of vent opening in the shorter direction
V = flame spread velocity
χ_c = convective fraction of total heat release rate (fraction carried as heat in plume above flames) where χ_c is a convective-heat fraction between 0.6 and 0.7
χ_r = radiant fraction of total heat release rate
y = elevation of smoke layer boundary
y_{ceil} = elevation of ceiling
y_{curt} = elevation of bottom of draft curtain
y_{fire} = elevation of the base of the fire above the floor
z_s = height of the smoke layer boundary above base of fire
z_{si} = height of the smoke layer interface above the base of the fire
z_o = height of virtual origin above base of fire (below base of fire, if negative)

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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 13, *Standard for the Installation of Sprinkler Systems,* 2019 edition.

NFPA 72®, National Fire Alarm and Signaling Code®, 2019 edition.

2.3 Other Publications.

Δ **2.3.1 FM Publications.** FM Global, 270 Central Avenue, P.O. Box 7500, Johnston, RI 02919.

FM 4430, *Approval Standard for Heat and Smoke Vents,* 2012.

2.3.2 NIST Publications. National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070.

DETACT-QS (DETector ACTuation — Quasi Steady) software.

DETACT-T2 (DETector ACTuation — Time Squared) software.

LAVENT (Link-Actuated VENTs) software.

Δ **2.3.3 UL Publications.** Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 793, *Standard for Automatically Operated Roof Vents for Smoke and Heat,* 2008, revised 2016.

2.3.4 Other Publications.

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

2.4 References for Extracts in Mandatory Sections.

NFPA 72®, National Fire Alarm and Signaling Code®, 2019 edition.

NFPA 92, *Standard for Smoke Control Systems,* 2021 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities,* 2021 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 Ceiling Jet. A flow of smoke under the ceiling, extending radially from the point of fire plume impingement on the ceiling.

3.3.2 Clear (Air) Layer. The zone within a building containing air that has not been contaminated by the smoke produced from a fire in the building, and that is located between the floor and the smoke layer boundary.

3.3.3* Clear Layer Interface. The boundary between a smoke layer and smoke-free air.

3.3.4 Continuously Growing Fires. Fires that, if unchecked, will continue to grow over the design interval time.

3.3.5 Curtained Area. An area of a building that has its perimeter delineated by draft curtains, full height partitions, exterior walls, or any combinations thereof.

3.3.6 Design Depth of the Smoke Layer. The difference between the height of the ceiling and the minimum height of the smoke layer boundary above the finished floor level that meets design objectives.

3.3.7 Design Fire. As used in this standard, the time-rate heat release history selected as the input for the calculations prescribed herein.

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3.3.8 Design Interval Time. The duration of time for which a design objective is to be met, measured from the time of detector activation.

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

3.3.10* Effective Ignition. The time at which a *t*-squared design fire starts.

3.3.11 Fuel Array. A collection and arrangement of materials that can support combustion.

3.3.12 Heat Detector. A fire detector that detects either abnormally high temperature or rate-of-temperature rise, or both. [**72,** 2019]

3.3.13 Limited-Growth Fires. Fires that are not expected to grow beyond a predictable maximum heat release rate.

3.3.14 Mechanical Smoke Exhaust System. A dedicated or shared-duty fan system designed and suitable for the removal of heat and smoke.

3.3.15 Plastics.

3.3.16 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. [**92,** 2021]

3.3.17 Smoke. The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass. [**318,** 2021]

3.3.18* Smoke Layer. The accumulated thickness of smoke below a physical or thermal barrier. [**92,** 2021]

3.3.19* Smoke Layer Boundary. An effective boundary centered in a transition zone between the dense portion of the smoke layer and the first indication of smoke.

3.3.20 Vent. As used in this standard, a device or construction that, when activated, is an opening directly to the exterior at or near the roof level of a building that relies on the buoyant forces created by a fire to exhaust smoke and heat.

3.3.21 Vent System. A system used for the removal of smoke and heat from a fire that utilizes manually or automatically operated heat and smoke vents at roof level and that exhausts smoke from a reservoir bounded by exterior walls, interior walls, or draft curtains to achieve the design rate of smoke mass flow through the vents, and that includes a provision for makeup air.

Chapter 4 Fundamentals

4.1* Design Objectives. The design objectives to be achieved over the design interval time by a vent system design during a design fire or design fires shall include the following:

(1) The minimum allowable smoke layer boundary height
(2) The maximum allowable smoke layer temperature

4.2* Design Basis. A design for a given building and its combustible contents and their distribution shall comprise selecting a design basis (limited-growth versus continuous-growth fire) and establishing the following parameters:

(1) Layout of curtained areas
(2) A draft curtain depth
(3) Type detector and specific characteristics
(4) Detector spacing
(5) A design interval time, t_r, following detection for maintaining a clear layer (for continuous-growth fires)
(6) Total vent area per curtained area
(7) Distribution of individual vents
(8) An air inlet area

4.3 Determination of Contents Hazard.

4.3.1 The determination of contents hazard shall take into account the fuel loading and the rate of heat release anticipated from the combustible materials or flammable liquids contained within the building.

4.3.2 The heat release rate of the design fire shall be quantified in accordance with Chapter 8.

4.4 Venting.

4.4.1 Design Objectives. In order to satisfy design objectives, a vent system shall be designed to slow, stop, or reverse the descent of a smoke layer produced by fire in a building, by exhausting smoke to the exterior.

4.4.2* Vent System Designs and Smoke Production.

4.4.2.1 Vent systems shall be designed in accordance with this standard by calculating the vent area required to achieve a mass rate of flow through the vents that equals the mass rate of smoke production.

4.4.2.2 Vent system designs shall limit the descent of the smoke layer to the design elevation of the smoke layer boundary.

4.4.2.3 Alternative vent system designs shall be permitted to be developed in accordance with this standard by calculating the vent area required to achieve a mass rate of flow through the vents that is less than the mass rate of smoke production, such that the descent of the smoke layer is slowed to meet the design objectives.

4.4.3* Vent Mass Flow. Vent system designs shall be computed on the basis that the mass flow rate through a vent is determined primarily by buoyancy pressure.

4.5 Smoke Production.

4.5.1* Base of the Fire. For the purposes of the equations in this standard, the base of the fire shall be at the bottom of the burning zone.

4.5.2* Fire Size. Burning and entrainment rates of possible fire scenarios shall be considered before establishing the conditions of the design fire.

4.5.3* Entrainment.

4.5.3.1 The entrainment formulas specified in this standard shall be applied only to a single fire origin.

4.5.3.2* Virtual Origin. Predicted plume mass flow above the top of the flame shall take into account the virtual origin, z_o, of the fire as determined in 9.2.3.2.

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4.6 Vent Flows.

4.6.1* Buoyancy and Vent Flow.

4.6.1.1 Flow through a vent shall be calculated on the basis of buoyancy pressure difference, assuming that no pressure is contributed by the expansion of gases.

4.6.1.2* Beneficial wind effects shall not be taken into account when calculating vent areas.

4.6.1.3 Air inlets and vents shall be located to avoid adverse wind effects.

4.6.2* Inlet Air.

4.6.2.1 Predicted vent flows shall take into account the area of inlet air openings.

4.6.2.2 Inlet air shall be introduced below the smoke layer boundary.

4.6.2.3 Wall and ceiling leakage above the smoke layer boundary in the curtained area shall not be included in vent flow calculations. *(See Chapter 6 for information on air inlets.)*

Chapter 5 Vents

Δ **5.1* Listed Vents.** Normally closed vents shall be listed and labeled in accordance with UL 793, *Standard for Automatically Operated Roof Vents for Smoke and Heat*; FM 4430, *Approval Standard for Heat and Smoke Vents*; or other approved, nationally recognized standards.

5.2 Vent Design Constraints.

5.2.1* The means of vent actuation shall be selected with regard to the full range of expected ambient conditions.

Δ **5.2.2*** Vents shall consist of a single unit (vent), in which the entire unit (vent) opens fully with the activation of a single detector, or multiple units (vents) in rows or arrays (ganged vents) in which the units (vents) open simultaneously with the activation of a single heat detector, a fusible link, a smoke detector, or other means of detection to satisfy the venting requirements for a specific hazard.

5.2.3* Where the hazard is localized, vents shall open directly above such hazard.

5.2.4 Vents, and their supporting structure and means of actuation, shall be designed so that they can be inspected visually after installation.

5.3 Methods of Operation.

5.3.1* Normally, closed vents shall be designed to open automatically in a fire to meet design objectives or to comply with performance objectives or requirements.

5.3.2* Vents, other than thermoplastic drop-out vents, shall be designed to fail in the open position such that failure of a vent-operating component results in an open vent.

5.3.3 Vents shall be opened using gravity or other approved opening force.

5.3.4 The opening mechanism shall not be prevented from opening the vent by snow, roof debris, or internal projections.

5.3.5* All vents shall be designed to open by manual means. Means of opening shall be either internal or external, as approved by the authority having jurisdiction.

5.3.6 Vents designed for remote operation shall utilize approved fusible links and shall also be capable of actuation by an electric power source, heat-responsive device, or other approved means.

Δ **5.3.7** Vents designed to activate by smoke detection or other activation methods external to the vent shall be approved in accordance with Section 5.1.

5.4 Dimensions and Spacing of Vents.

5.4.1 The dimensions and spacing of vents shall meet the requirements of 5.4.1.1 and 5.4.1.2 to avoid plugholing.

5.4.1.1 The area of a unit vent shall not exceed $2d^2$, where d is the design depth of the smoke layer.

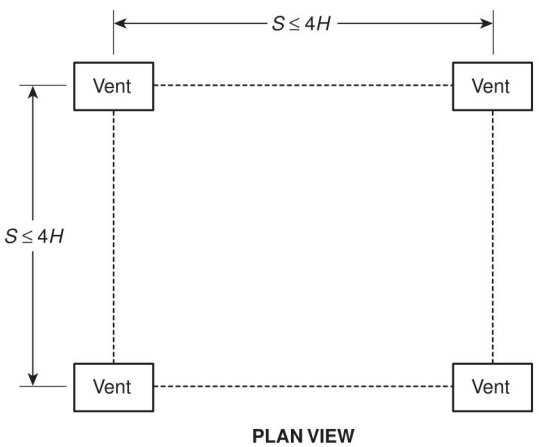
5.4.1.2* For vents with $L_v/W_v > 2$, the width, W_v, shall not exceed the design depth of the smoke layer, d.

5.4.2* In plan view, the center-to-center spacing of vents in a rectangular matrix, S, as shown in Figure 5.4.2(a), within a curtained area shall not exceed $4H$, where H is the ceiling height as shown in Figure 5.4.2(b), parts (a) through (d).

5.4.3* The spacing of vents, in plan view, shall be such that the horizontal distance from any point on a wall or draft curtain to the center of the nearest vent, within a curtained area, does not exceed $2.8H$ as indicated in Figure 5.4.3.

5.4.4 The total vent area per curtained area shall be sized to meet the design objectives and the performance objectives relative to the design fire, determined in accordance with Chapter 8.

5.5 Mechanical Smoke Exhaust Systems. Mechanical smoke exhaust systems shall be designed in accordance with Chapter 10.



Δ **FIGURE 5.4.2(a) Vent Spacing in Rectangular Matrix (plan view).**

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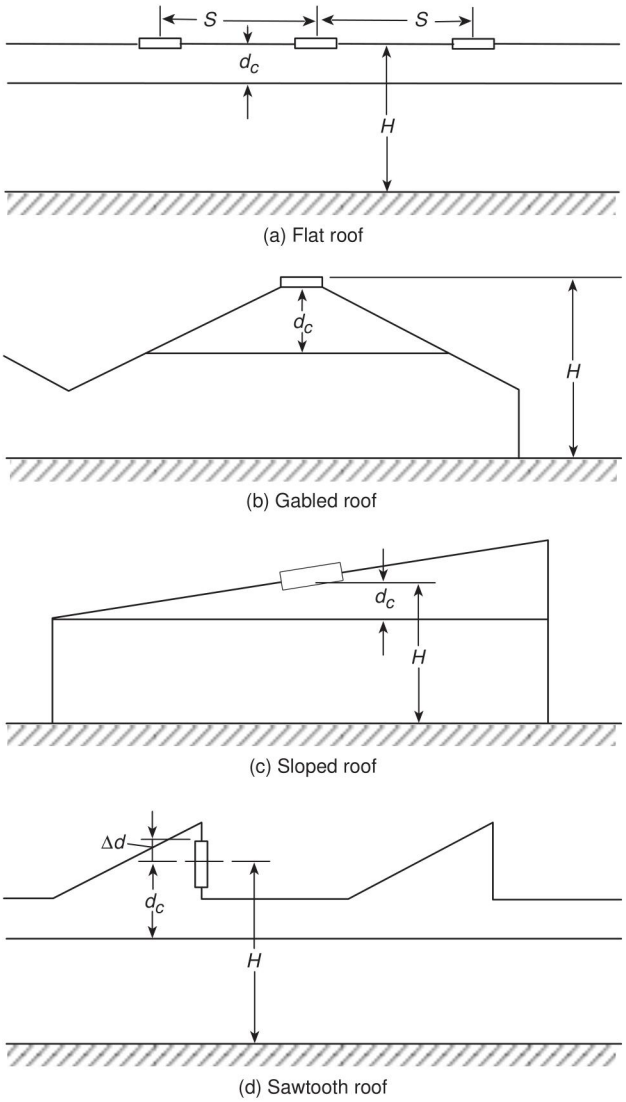


FIGURE 5.4.2(b) Measurement of Ceiling Height *(H)* and Curtain Board Depth *(d_c)*.

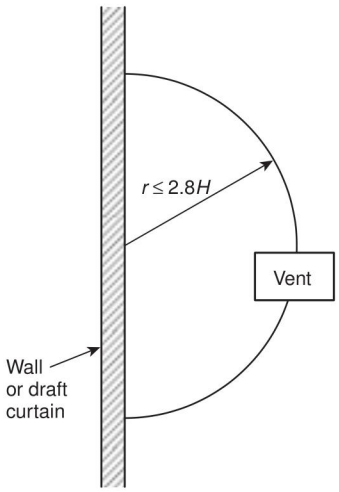
Chapter 6 Air Inlets

6.1* General. Air inlets shall be provided for supplying makeup air for vent systems.

6.2 Construction. Air inlets consisting of louvers, doors, dampers, windows, shutters, or other approved openings shall be designed and constructed to provide passage of outdoor air into the building.

6.3* Location. Air inlets shall be installed as indicated in 6.3.1 or 6.3.2.

6.3.1 Air inlets shall be installed in external walls of the building below the height of the design level of the smoke layer boundary and shall be clearly identified or marked as air inlets.



Δ FIGURE 5.4.3 Vent Location near a Wall or Draft Curtain (plan view).

6.3.2 In larger buildings where there is more than one curtained area, air inlets shall be permitted to be provided by vents in other nonadjacent curtained areas.

6.4 Installation.

6.4.1 Materials of construction and methods of installation for air inlets shall resist expected extremes of temperature, wind, building movement, rain, hail, snow, ice, sunlight, corrosive environment, internal and external dust, dirt, and debris.

6.4.2 The means of air inlet actuation shall be selected with regard to the full range of expected ambient conditions.

Δ 6.4.3 To satisfy the vent system requirements, air inlets shall consist of one of the following:

(1) A single unit (air inlet) in which the entire unit (air inlet) opens fully with the activation of a single detector
(2) Multiple units (air inlets) in rows or arrays (ganged air inlets) in which the units (air inlets) open simultaneously with the activation of a single heat detector, a fusible link, a smoke detector, or other means of detection to satisfy the vent system requirements

6.4.4 Air inlets and their supporting structures and means of actuation shall be designed such that they can be inspected visually after installation.

6.5 Methods of Operation.

6.5.1 Air inlets shall be either constantly open or automatically placed in the open position after a fire is detected.

6.5.2 Air inlets shall be designed to open in a fire to meet design objectives or to comply with performance objectives or requirements.

6.5.3 Air inlets shall be designed to fail in the open position such that failure of an air inlet–operating component results in an open air inlet.

6.5.4 Air inlets shall be opened using an approved means as the opening force.

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6.5.5 Air inlet opening mechanisms shall not be prevented from opening the air inlet by snow, debris, or internal projections.

6.5.6 Operating mechanisms for air inlets shall be jam-proof, corrosion-resistant, dust-resistant, and resistant to pressure differences arising from applicable positive or negative loading resulting from environmental conditions, process operations, overhead doors, or traffic vibrations.

6.5.7 Air inlets designed for remote operation shall be activated by approved devices and shall be capable of actuation by an electrical power source, heat-responsive device, or other approved means.

6.6 Dimensions and Spacing of Air Inlets.

6.6.1 The total inlet area per curtained area shall be sized to meet the design objectives and the performance objectives or requirements specified relative to the design fire, determined in accordance with Chapter 8.

6.6.2 One inlet area shall be permitted to serve more than one curtained area.

6.6.3* The air velocity at the plume shall not exceed 1 m/sec (3.28 ft/sec).

6.7 Air Paths. Air paths from an air inlet opening to the curtained area where smoke is being exhausted shall be at least three times the size of the air inlet opening.

Chapter 7 Draft Curtains

7.1* General. Where the spacing between walls exceeds the limits in Section 7.4, draft curtains shall be provided.

7.2* Construction.

7.2.1 Draft curtains 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.

7.3 Location and Depth.

7.3.1* Draft curtains shall extend vertically downward from the ceiling the minimum distance required so that the value of d_c, as shown in Figure 5.4.2(a), is a minimum of 20 percent of the ceiling height, H, measured as follows:

(1) For flat roofs and sawtooth roofs with flat ceiling areas, from the ceiling to the floor
(2) For sloped roofs, from the center of the vent to the floor

7.3.2 Where there are differing vent heights, H, each vent shall be calculated individually.

7.4 Spacing.

7.4.1* Neither the length nor the width of a curtained area shall exceed eight times the ceiling height.

7.4.2* Where draft curtains extend to a depth of less than 30 percent of the ceiling height, the distance between draft curtains shall be not less than one ceiling height.

Chapter 8 The Design Fire

8.1* General.

8.1.1 The design fire shall be selected from among a number of challenging candidate fires, consistent with the building and its intended use, considering all of the following factors that tend to increase the challenge:

(1) A low-level flame base (usually floor level)
(2) Increasing fire growth rate
(3) Increasing ultimate heat release rate in the design interval time

8.1.2 The candidate fire that produces a vent system design meeting the design objectives for all candidate fires shall be selected as the design fire.

8.2 Steady (Limited-Growth) Fires.

8.2.1 For steady fires, or fires that do not develop beyond a maximum size, the required vent area per curtained area shall be calculated based on the maximum calculated heat release rate (Q and Q_t), the associated distance from the fire base to the design elevation of the smoke layer boundary (z_s), and the predicted fire diameter (D).

8.2.2* Steady fires shall be permitted to include special-hazard fires and fires in occupancies with concentrations of combustibles separated by aisles of sufficient width to prevent the spread of fire by radiation beyond the initial fuel package or initial storage array.

8.2.3 The minimum aisle width required to prevent lateral fire spread by radiation, W_{min}, shall be calculated for radiant heat flux from a fire based on an ignition flux of 20 kW/m^2 (2.5 hp/ft^2) in accordance with the following equation:

[8.2.3]

$$W_{min} = 0.042 Q_{max}^{1/2}$$

where:
W_{min} = minimum aisle width required to prevent lateral fire spread by radiation (m)
Q_{max} = maximum anticipated heat release rate (kW)

8.2.4 The fire diameter, D, shall be the diameter of a circle having the same area as the floor area of the fuel concentration.

8.2.5 The heat release rate shall be the heat release rate per unit area times the floor area of the fuel concentration, using the maximum storage height above the fire base and associated heat release rate.

8.2.6* The heat release rate per unit area shall be determined by test or from published data acceptable to the AHJ.

8.3 Growing (Continuous-Growth) Fires.

8.3.1* For fuel configurations that have been tested, the fire growth shall be modeled to follow the test results acceptable to the AHJ. For other fuel configurations that have not been tested, a t-squared fire growth as shown in Figure 8.3.1 shall be used with a fire growth coefficient based on published data acceptable to the AHJ and in accordance with the following equation:

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[8.3.1]

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

where:
Q = heat release rate of fire (kW)
t = time from effective ignition following an incubation period (sec)
t_g = time at which the fire exceeds an intermediate size of 1055 kW (sec)

8.3.2* A *t*-squared fire growth shall be permitted to be expressed in terms of a fire growth coefficient, α_g, in lieu of growth time, t_g, as follows:

[8.3.2]

$$Q = \alpha_g t^2$$

where:
Q = heat release rate of fire (kW)
α_g = fire growth coefficient (kW/sec^2)
t = time (sec)

8.3.3 The instantaneous heat release rate per unit height of the storage array shall be considered to be constant, regardless of the storage height. Accordingly, for different storage heights, the growth time, t_g, shall be calculated as being inversely proportional to the square root of the storage height, and the fire growth coefficient, α_g, shall be calculated as being directly proportional to the storage height. *(See Section F.1.)*

8.3.4* The vent system shall maintain the smoke boundary layer above the design elevation from the time of effective ignition until the end of the design interval time, t_r, where t_r is measured from the time of detection, t_d.

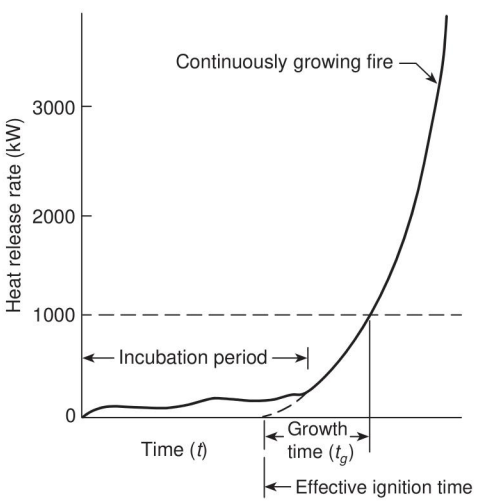


FIGURE 8.3.1 Conceptual Illustration of Continuous-Growth Fire.

8.3.5 The heat release rate at the end of the design interval time shall be calculated in accordance with the following equation:

[8.3.5]

$$Q = 1055\left(\frac{t_r + t_d}{t_g}\right)^2$$

where:
Q = heat release rate (kW)
t_r = time at end of design interval (sec)
t_d = time of detection (sec)
t_g = time at which fire exceeds 1055 kW (sec)

8.3.6 The end of the design interval time, t_r, shall be selected to correspond to the design objectives as determined for the specific project design.

8.3.7 The instantaneous diameter of the fire needed for the calculation of L and z_o shall be calculated from the instantaneous heat release rate, Q, and data on the heat release rate per unit floor area, Q'', where Q'' is proportional to storage height in accordance with the following equation:

[8.3.7]

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

where:
D = instantaneous fire diameter (m)
Q = instantaneous heat release rate (kW)
Q'' = heat release rate per unit floor area (kW/m^2)

Chapter 9 Sizing Vents

9.1* General.

9.1.1* The design vent area in a curtained area shall equal the vent area required to meet the design objectives for the most challenging fire predicted for the combustibles within the curtained area.

9.1.2 Vent areas shall be determined using hand calculations in accordance with Section 9.2 or by use of a computer-based model in accordance with Section 9.3.

9.1.3 The design fire used in the evaluation of a proposed vent design in accordance with Section 9.1 shall be determined in accordance with Chapter 8.

9.1.4* Vent systems shall be designed specifically for the hazard of each curtained area in a building.

9.2 Hand Calculations.

9.2.1 Vent System Designs. Vent systems, other than those complying with Section 9.3, shall be sized and actuated to meet design objectives in accordance with Section 9.2.

9.2.2 Design Concepts.

9.2.2.1* Equilibrium shall be assumed as illustrated in Figure 9.2.2.1, where symbols are as defined in Section 1.6.

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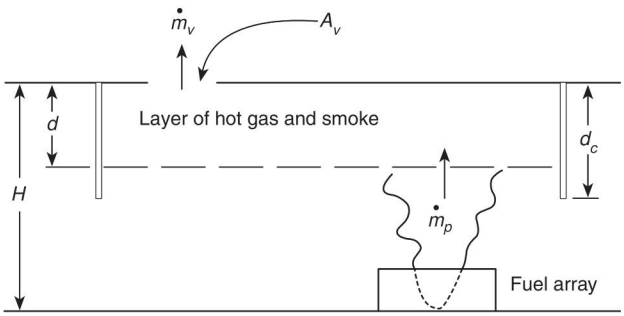


FIGURE 9.2.2.1 Schematic of Venting System.

9.2.2.2 The smoke layer boundary shall be at or above the bottom of the draft curtains.

9.2.2.3 At equilibrium, the mass flow rate into the smoke layer shall be equal to the mass flow rate out of the vent or vents ($\dot{m}_p = \dot{m}_v$).

9.2.3 Mass Flow Rate in Plume.

9.2.3.1* The mean flame height shall be calculated in accordance with the following equation:

[9.2.3.1]

$$L = -1.02D + 0.235\,Q^{2/5}$$

where:
L = mean flame height above the base of the fire (m)
D = base diameter of fire (m)
Q = total heat release rate (kW)

9.2.3.2 The virtual origin, z_o, is the effective point source of the fire plume and shall be calculated in accordance with the following equation:

[9.2.3.2]

$$z_o = 0.083Q^{2/5} - 1.02D$$

where:
z_o = virtual fire origin
Q = total heat release rate (kW)
D = base diameter of fire (m)

9.2.3.3 Smoke entrainment relationships shall be applicable to axisymmetric plumes.

9.2.3.4 For line-like fires where a long, narrow plume is created by a fuel or storage array, the smoke production calculated in accordance with this standard shall be applicable only if the height of the smoke layer boundary above the base of the fire (z_s) is greater than or equal to four times the largest horizontal dimension of the fire, W_s.

9.2.3.5 If z_s is smaller than $4W_s$, the smoke production rates calculated in accordance with this standard shall be increased by the factor $[4W_s/(z_s)]^{2/3}$.

9.2.3.6 When the mean flame height, L, is below the smoke layer boundary ($L < z_s$), the mass flow rate in the fire plume shall be calculated in accordance with the following equation:

[9.2.3.6]

$$\dot{m}_p = \left[0.071\,Q_c^{1/3}\left(z_s - z_o\right)^{5/3}\right]\left[1 + 0.027\,Q_c^{2/3}\left(z_s - z_o\right)^{-5/3}\right]$$

where:
$\dot{m}_p$ = mass flow rate in the plume (kg/s)
Q_c = convective heat release rate = $0.7Q$ (kW)
z_s = height of the smoke layer boundary above the base of the fire (m)
z_o = height of virtual origin above the base of the fire (if below the base of the fire, z_o is negative) (m)

9.2.3.7 When the mean flame height (L) is equal to or above the smoke layer boundary ($L \geq z_s$), the mass flow rate shall be calculated in accordance with the following equation:

[9.2.3.7]

$$\dot{m}_p = \left(0.0056Q_c\right)\frac{z_s}{L}$$

where:
$\dot{m}_p$ = mass flow rate in the plume (kg/sec)
Q_c = convective heat release rate = $0.7Q$ (kW)
z_s = height above the base of the fire (m)
L = mean flame height (m)

9.2.3.8 The base of the fire shall be the lowest point of the fuel array.

9.2.4* Mass Flow Rate Through Vents.

9.2.4.1* The mass flow through the vent shall be calculated in accordance with the following equation:

[9.2.4.1]

$$\dot{m}_v = \frac{C_{d,v}A_v}{\sqrt{1 + \dfrac{C_{d,v}^2A_v^2}{C_{d,i}^2A_i^2}\left(\dfrac{T_o}{T}\right)}}\sqrt{\left(2\rho_o^2gd\right)}\sqrt{\frac{T_o\left(T - T_o\right)}{T^2}}$$

where:
$\dot{m}_v$ = mass flow through vent (kg/sec)
$C_{d,v}$ = vent discharge coefficient
A_v = vent area (m^2)
ρ_o = ambient density (kg/m^3)
g = acceleration due to gravity (9.81 m/sec^2)
d = smoke layer depth (m)
T_o = ambient temperature (K)
T = smoke layer temperature (K)
$C_{d,i}$ = inlet discharge coefficient
A_i = inlet area (m^2)

9.2.4.2* The discharge coefficients for the vents and inlets used shall be those provided by the vent or inlet manufacturer. If no data are available, the discharge coefficient shall be taken from Table 9.2.4.2 unless an analysis or data acceptable to the

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Table 9.2.4.2 Default Discharge Coefficients for Vents and Inlets

Vent or Inlet Type	Discharge Coefficient [(*d*, *v*) and (*d*, *i*)]
Louvered with blades at 90 degrees to airflow	0.55
Flap type or door open at least 55 degrees Drop-out vent leaving clear opening	
Flap type or door open at least 30 degrees	0.35
Fixed weather louver with blades at 45 degrees	0.25

AHJ are provided by the designer to validate the use of an alternative value.

9.2.4.3 The smoke layer temperature, T, used in 9.2.4.1 shall be determined from the following equation:

[9.2.4.3]

$$T = T_o + \frac{KQ_c}{c_p \dot{m}_p}$$

where:
T = smoke layer temperature (K)
T_o = ambient temperature (K)
K = fraction of convected energy contained in the smoke layer gases *(see 9.2.4.4)*
Q_c = convective heat release rate (kW)
c_p = specific heat of the smoke layer gases (kJ/kg-K)
$\dot{m}_p$ = plume mass flow rate (kg/sec) *(see 9.2.3)*

9.2.4.4 The value of K used in Equation 9.2.4.3 shall be 0.5, unless an analysis acceptable to the AHJ is provided by the designer to validate the use of an alternative value.

9.2.5 Required Vent Area and Inlet Area.

9.2.5.1 Vent Area. The required vent area shall be the minimum total area of all vents within a curtained area required to be open to prevent the smoke from descending below the design level of the smoke layer boundary when used in conjunction with the required inlet area.

9.2.5.2 Inlet Area. The required inlet area shall be the minimum total area of all inlets required to be open to prevent the smoke from descending below the design level of the smoke layer boundary when used in conjunction with the required vent area(s).

9.2.5.3 Area Calculation. The required vent area and inlet areas shall be calculated by equating the plume mass flow rate determined in 9.2.3 and the vent mass flow rates determined in 9.2.4.

9.2.5.4 Detection and Activation.

9.2.5.4.1* Detection, for the purpose of automatically actuating vents, shall be by one of the following methods:

(1) By either heat or smoke at the vent location
(2) By activation of fire protection systems
(3) By heat or smoke detectors installed on a regular matrix within the curtained area in accordance with *NFPA 72*
(4) By other approved means shown to meet design objectives

9.2.5.4.2 For calculating both the detection time, t_d, of the first detector to operate and the detection time, t_{vo}, of the detector controlling the actuation of the last vent to operate in a curtained area prior to the end of the design interval time, the location of the design fire shall be assumed to be the farthest distance possible from both the first and last detectors to operate the vents within the curtained area.

9.2.5.4.2.1* Detection times for heat detectors or fusible links shall be determined in accordance with *NFPA 72*.

9.2.5.4.3 Detection times for smoke detectors shall be determined as the time to reach a certain temperature rise, ΔT, at activation. In the case of continuous-growth, *t*-squared fires, gas temperatures shall be determined in accordance with the following equation, where ΔT is assumed to be 0 when the numerator of the first bracket is zero or negative:

[9.2.5.4.3]

$$\Delta T = \frac{3575}{t_g^{4/5} H^{3/5}} \left[\frac{t / \left(t_g^{2/5} H^{4/5} \right) - 0.442 \left(1 + r/H \right)}{1 + 1.65 r/H} \right]^{4/3}$$

where:
T = temperature (C)
t_g = fire growth time (sec)
H = ceiling height above the base of the fire (m)
r = radius from fire axis (m)

9.2.5.4.3.1* The temperature rise for activation shall be based on dedicated tests, or the equivalent, for the combustibles associated with the occupancy and the detector model to be installed.

9.2.5.4.3.2 Where the data described in 9.2.5.4.3.1 are not available, a minimum temperature rise of 20°C (68°F) shall be used.

9.2.5.4.4 Detection Computer Programs.

9.2.5.4.4.1* As an alternate to the calculations specified in 9.2.5.4.2, DETACT-T2 shall be permitted to be used to calculate detection times in continuous-growth and *t*-squared fires.

9.2.5.4.4.2* As an alternative to the calculations specified in 9.2.5.4.2, DETACT-QS shall be permitted to be used to calculate detection times in fires of any fire growth history.

9.2.5.4.4.3 Other computer programs determined to calculate detection times reliably shall be permitted to be used when approved by the AHJ.

9.3 Models.

9.3.1 Vents, other than vent systems designed in accordance with Section 9.2, shall be sized and actuated to meet design objectives in accordance with Section 9.3.

9.3.2 The computer model LAVENT or other approved mathematical models shall be used to assess the effects of the design fire and to establish that a proposed vent system design meets design objectives. *(See Section F.2.)*

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9.3.3 When models other than LAVENT are used, evidence shall be submitted to demonstrate efficacy of the model to evaluate the time-varying events of a fire and to calculate the effect of vent designs reliably in terms of the design objectives.

9.3.4 The design fire used in the evaluation of a proposed vent system design in accordance with Section 9.3 shall be determined in accordance with Chapter 8.

Chapter 10 Mechanical Smoke Exhaust Systems

10.1* General.

10.1.1* Mechanical smoke exhaust systems shall be permitted in lieu of the vent systems described in Chapter 9.

10.1.2 Mechanical smoke exhaust systems and vent systems shall not serve the same curtained area.

10.1.3 Mechanical smoke exhaust systems shall be designed in accordance with Sections 10.2 through 10.4.

10.2 Exhaust Rates. Exhaust rates per curtained area shall be not less than the mass plume flow rates, $\dot{m}_p$, as determined in accordance with 9.2.3, unless it can be demonstrated that a lower exhaust rate will prevent the smoke from descending below the design level of the smoke layer boundary during the design period.

10.3 Fire Exposure.

10.3.1 Mechanical smoke exhaust systems shall be capable of functioning under the expected fire exposure.

10.3.2 The temperature of the smoke layer shall be determined in accordance with 9.2.4.3 and 9.2.4.4.

10.4* Number of Exhaust Inlets.

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

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

10.4.3* The maximum volumetric flow rate that can be exhausted by a single exhaust inlet without plugholing shall be calculated using Equation 10.4.3.

[10.4.3]

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

where:
V_{max} = maximum volumetric flow rate without plugholing at T_s (m^3/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)

10.4.4* For exhaust inlets centered no closer than twice the diameter from the nearest wall, a value of 1 shall be used for γ.

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

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

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

10.4.8 For rectangular exhaust inlets, D_i shall be calculated using Equation 10.4.8 as follows:

[10.4.8]

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

where:
D_i = diameter of exhaust inlet
a = length of the inlet
b = width of the inlet

10.4.9 Where multiple exhaust inlets are required to prevent plugholing *(see 10.4.1)*, the minimum separation distance shall be calculated using Equation 10.4.9 as follows:

[10.4.9]

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

where:
S_{min} = minimum edge-to-edge separation between inlets (m)
V_e = volumetric flow rate of one exhaust inlet (m^3/sec)

10.5 Intake Air. Intake air shall be provided to make up air required to be exhausted by the mechanical smoke exhaust systems. *(See Chapter 6 for additional information on the location of air inlets.)*

Chapter 11 Venting in Sprinklered Buildings

11.1* Design. Where provided, the design of venting for sprinklered buildings shall be based on an engineering analysis acceptable to the AHJ, demonstrating that the established objectives are met. *(See Section F.3.)*

11.2* Automatic Sprinkler Systems. The automatic sprinkler system shall be designed in accordance with NFPA 13.

11.3* Storage Occupancies Protected by Control Mode Sprinklers.

11.3.1 Where draft curtains are provided, they shall be located over the longitudinal center of an aisle.

11.3.2 The aisle width shall not be less than 1.5 times the spacing between sprinklers in the direction perpendicular to the draft curtain.

11.3.3 Sprinklers shall be located on both sides of the curtain per NFPA 13 requirements for sprinkler placement with respect to walls.

11.3.4 The aisle width required by 11.3.2 shall not be required if a full height partition is used in lieu of a draft curtain.

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Chapter 12 Inspection and Maintenance

12.1* General. Smoke and heat venting systems and mechanical smoke exhaust systems shall be inspected and maintained in accordance with Chapter 12.

12.2* Requirements.

12.2.1 Mechanically Opened Vents. Mechanically opened vents shall be provided with manual release devices that allow direct activation to facilitate inspection, maintenance, and replacement of actuation components.

12.2.2 Thermoplastic Drop-Out Vents. Thermoplastic drop-out vents do not allow nondestructive operation; however, inspection of installed units shall be conducted to ensure that the units are installed in accordance with the manufacturer's instructions and that all components are in place, undamaged, and free of soiling, debris, and extraneous items that might interfere with the operation and function of the unit.

12.2.3 Inspection and Maintenance. The inspection and maintenance of multiple-function vents shall ensure that other functions do not impair the intended fire protection operation.

12.3 Inspection, Maintenance, and Acceptance Testing.

12.3.1 Inspection Schedules.

12.3.1.1 A written inspection schedule and procedures for inspection and maintenance shall be developed.

12.3.1.2 Inspection programs shall provide written notations of the date and time of inspections and of discrepancies found.

12.3.1.3 All deficiencies shall be corrected immediately.

12.3.1.4* Vents shall be inspected and maintained in an operating condition in accordance with Chapter 12.

12.3.2 Mechanically Opened Vents.

12.3.2.1 An acceptance performance test and inspection of all mechanically opened vents shall be conducted immediately following installation to establish that all operating mechanisms function properly and that installation is in accordance with this standard and the manufacturer's specifications.

12.3.2.2* Mechanically opened vents shall be inspected and subjected to an operational test annually, following the manufacturer's recommendations.

12.3.2.3* All pertinent characteristics of performance shall be recorded.

12.3.2.4 Special mechanisms, such as gas cylinders, thermal sensors, or detectors, shall be checked annually or as specified by the manufacturer.

12.3.3 Thermoplastic Drop-Out Vents.

12.3.3.1* An acceptance inspection of all thermoplastic drop-out vents shall be conducted immediately after installation and shall include verification of compliance with the manufacturer's drawings and recommendations by visual examination.

12.3.3.2* Thermoplastic drop-out vents shall be inspected annually in accordance with 12.4.2 and the manufacturer's recommendations.

12.3.3.3 Changes in appearance, damage to any components, fastening security, weather tightness, and the adjacent roof and flashing condition shall be noted at the time of inspection, and any deficiency shall be corrected.

12.3.3.4 Any soiling, debris, or encumbrances that could impair the operation of the vent shall be promptly removed without causing damage to the vent.

12.3.4 Inlet Air Sources. Where required for the operation of vent systems, intake air sources shall be inspected at the same frequency as vents.

12.4 Conduct and Observation of Operational Tests.

12.4.1 Mechanically Opened Vents and Air Inlets.

12.4.1.1 Mechanically opened vents and air inlets shall be operated during tests by simulating actual fire conditions.

12.4.1.2 The restraining cable at the heat-responsive device (or other releasing device) shall be disconnected, releasing the restraint and allowing the trigger or latching mechanism to operate.

12.4.1.3* When the heat-responsive device restraining cable for mechanically opened vents or air inlets is under tension, observation shall be made of its whip and travel path to determine any possibility that the vent, building construction feature, or service piping could obstruct complete release. Any interference shall be corrected by removal of the obstruction, enclosure of cable in a suitable conduit, or other appropriate arrangement.

12.4.1.4 Following any modification, the unit shall be retested for evaluation of adequacy of corrective measures.

12.4.1.5 Latches shall release smoothly and the vent or air inlet shall open immediately and move through its design travel to the fully opened position without any assistance and without any problems such as undue delay indicative of a sticking weather seal, corroded or unaligned bearings, or distortion binding.

12.4.1.6 Manual releases shall be tested to verify that the vents and air inlets operate as designed.

12.4.1.7 All operating levers, latches, hinges, and weather-sealed surfaces shall be examined to determine conditions, such as deterioration and accumulation of foreign material. An operational test shall be conducted after corrections are completed, when conditions are found to warrant corrective action.

12.4.1.8 Following painting of the interior or exterior of vents and air inlets or the addition of sealants or caulking, the units shall be opened and inspected to check for paint, sealants, or caulking that causes the parting surfaces to adhere to each other.

12.4.1.9 Heat-responsive devices coated with paint or other substances that could affect their response shall be replaced with devices having an equivalent temperature and load rating.

12.4.2 Thermoplastic Drop-Out Vents.

12.4.2.1 All weather-sealed surfaces on thermoplastic drop-out vents shall be examined to determine any adverse conditions, such as any indication of deterioration and accumulation of foreign material. Any adverse condition that interferes with normal vent operation, such as caulking or sealant bonding the drop-out vent to the frame, shall be corrected.

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12.4.2.2 Following painting of the interior or exterior of the frame or flashing of the vents, the units shall be inspected for paint adhering surfaces together; any paint that interferes with normal operation shall be removed or the vent shall be replaced with a new, listed and labeled unit having comparable operating characteristics.

12.4.2.3 Manual releases shall be tested annually.

12.4.3 Inspection, Maintenance, and Testing of Mechanical Smoke-Exhaust Systems.

12.4.3.1 Component Testing.

12.4.3.1.1 The operational testing of each individual system component of the mechanical smoke-exhaust system shall be performed as each component is completed during construction.

12.4.3.1.2 It shall be documented in writing that each individual system component's installation is complete and that the component has been tested and found to be functional.

12.4.3.2 Acceptance Testing.

12.4.3.2.1 Acceptance tests shall be conducted to demonstrate that the mechanical smoke-exhaust system installation complies with and meets the design objectives and is functioning as designed.

12.4.3.2.2 Documentation from component system testing shall be available for review during final acceptance testing.

12.4.3.2.3 If standby power has been provided for the operation of the mechanical smoke-exhaust system, the acceptance testing shall be conducted while on both normal and standby power.

12.4.3.2.4 Acceptance testing shall be performed on the mechanical smoke-exhaust system by completing the following steps:

(1) Activate the mechanical smoke-exhaust system.
(2) Verify and record the operation of all fans, dampers, doors, and related equipment.
(3) Measure fan exhaust capacities, air velocities through inlet doors and grilles, or at supply grilles if there is a mechanical makeup air system.

12.4.3.2.5 Operational tests shall be performed on the applicable part of the smoke-exhaust system wherever there are system changes and modifications.

12.4.3.2.6 Upon completion of acceptance testing, a copy of all operational testing documentation shall be provided to the owner and shall be maintained and made available for review by the AHJ.

12.4.3.3 Periodic Testing.

12.4.3.3.1 Mechanical smoke-exhaust systems shall be tested semiannually by persons who are knowledgeable in the operation, testing, and maintenance of the systems.

12.4.3.3.2 The results of the tests shall be documented and made available for inspection.

12.4.3.3.3 Tests shall be conducted under standby power where applicable.

12.4.3.4 Exhaust System Maintenance.

12.4.3.4.1 During the life of the building, maintenance shall be performed to ensure that mechanical smoke-exhaust systems will perform their intended function under fire conditions.

12.4.3.4.2 Maintenance of the systems shall include the testing of all equipment, including initiating devices, fans, dampers, and controls.

12.4.3.4.3 Equipment shall be maintained in accordance with the manufacturer's recommendations.

12.4.3.5 Inspection Schedule.

12.4.3.5.1 A written inspection schedule and procedures for inspection and maintenance for mechanical smoke-exhaust systems shall be developed.

12.4.3.5.2 Inspection programs shall provide written notations of date and time of inspections and for discrepancies found.

12.4.3.5.3 All system components shall be inspected semiannually in conjunction with operational tests.

12.4.3.5.4 Any deficiencies noted in the system components or smoke-exhaust system performance shall be corrected immediately.

12.5 Air Inlets.

12.5.1 Air inlets necessary for operation of smoke and heat vents or mechanical smoke-exhaust systems shall be maintained clear and free of obstructions.

12.5.2 Operating air inlet louvers, doors, dampers, and shutters shall be examined and operated to assure movement to fully open positions.

12.5.3 Operating equipment shall be maintained and lubricated as necessary.

12.6 Ice and Snow Removal. Ice and snow shall be removed from vents promptly, following any accumulation.

Chapter 13 Design Documentation

13.1* Documentation Required. All of the following documents shall be generated by the designer during the design process:

(1) Design brief
(2) Conceptual design report
(3) Detailed design report
(4) Operations and maintenance manual

13.1.1 Design Brief. The design brief shall contain a statement of the goals and objectives of the vent system and shall provide the design assumptions to be used in the conceptual design.

13.1.1.1 The design brief shall include, as a minimum, all of the following:

(1) System performance goals and design objectives *(see Section 4.1 and 4.4.1)*
(2) Performance criteria (including design tenability criteria, where applicable)
(3) Building characteristics (height, area, layout, use, ambient conditions, other fire protection systems)

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(4) Design basis fire(s) *(see 4.5.2 and Chapter 8)*
(5) Design fire location(s)
(6) Identified design constraints
(7) Proposed design approach

13.1.1.2 The design brief shall be developed in the first stage of the design process to assure that all stakeholders understand and agree to the goals, objectives, design fire, and design approach, so that the conceptual design can be developed on an agreed-upon basis. Stakeholders shall include, as a minimum, the building owner and the AHJ.

13.1.2 Conceptual Design Report. The conceptual design report shall provide the details of the conceptual design, based upon the design brief, and shall document the design calculations.

13.1.2.1 The conceptual design shall include, as a minimum, all of the following design elements and the technical basis for the design elements:

(1) Areas of curtained spaces
(2) Design depth of the smoke layer and draft curtain depth
(3) Detection method, detector characteristics, and spacing
(4) Design interval time (if applicable)
(5) Vent size and number per curtained area, method of vent operation, and vent spacing
(6) Inlet vent area(s), location(s), and operation method

13.1.2.2 The conceptual design report shall include all design calculations performed to establish the design elements, all design assumptions, and all building use limitations that arise out of the system design.

13.1.3 Detailed Design Report.

13.1.3.1 The detailed design report shall provide documentation of the vent system as it is to be installed.

13.1.3.2 The detailed design report shall include, as a minimum, all of the following:

(1) Vent and draft curtain specifications
(2) Inlet and vent operation system specifications
(3) Detection system specifications
(4) Detailed inlet, vent, and draft curtain siting information
(5) Detection and vent operation logic
(6) Systems commissioning procedures

13.1.4 Operations and Maintenance Manual. The operations and maintenance manual shall provide to the building owner the requirements to ensure the intended operation of the vent system over the life of the building.

13.1.4.1 The procedures used in the initial commissioning of the vent system shall be described in the manual, as well as the measured performance of the system at the time of commissioning.

13.1.4.2 The manual shall describe the testing and inspection requirements for the system and system components and the required frequency of testing. *(See Chapter 12 for testing frequency.)*

Δ **13.1.4.3** The manual shall describe the assumptions used in the design and shall provide limitations on the building and its use that arise out of the design assumptions and limitations.

13.1.4.4 Copies of the operations and maintenance manual shall be provided to the owner and to the AHJ.

13.1.4.5 The building owner shall be responsible for all system testing and shall maintain records of all periodic testing and maintenance using the operations and maintenance manual.

13.1.4.6 The building owner shall be responsible for providing a copy of the operations and maintenance manual, including testing results, to all tenants of the space protected by the vent system.

13.1.4.7 The building owner and tenants shall be responsible for limiting the use of the space in a manner consistent with the limitations provided in the operations and maintenance manual.

Annex A Explanatory Material

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

A.1.1.1 This standard incorporates engineering equations (hand calculations) and references models to provide a designer with the tools to develop vent system designs. The designs are based on selected design objectives, stated in 4.4.1, related to specific building and occupancy conditions. Engineering equations are included for calculating vent flows, smoke layer depths, and smoke layer temperatures, based on a prescribed burning rate. Examples using the hand calculations and the LAVENT (Link-Actuated VENTs) computer model are presented in Annex D.

Previous editions of this document have included tables listing vent areas based on preselected design objectives. These tables were based on the hot upper layer at 20 percent of the ceiling height. Different layer depths were accommodated by using a multiplication factor. Draft curtain and vent spacing rules were set. Minimum clear visibility times were related to fire growth rate, ceiling height, compartment size, curtain depth, and detector activation times, using engineering equations.

The following list provides a general description of the significant phenomena that occur during a fire when a fire-venting strategy is implemented:

(1) Due to buoyancy, hot gases rise vertically from the combustion zone and flow horizontally below the roof until blocked by a vertical barrier (a wall or draft curtain), thus forming a layer of hot gases below the roof.
(2) The volume and temperature of gases to be vented are a function of the fire's rate of heat release and the amount of air entrained into the buoyant plume produced.
(3) As the depth of the layer of hot gases increases, the layer temperature continues to rise and the vents open.
(4) The operation of vents within a curtained area enables some of the upper layer of hot gases to escape and thus slows the thickening rate of the layer of hot gases. With sufficient venting area, the thickening rate of the layer can be arrested and even reversed. The rate of discharge through a vent of a given area is primarily determined by the depth of the layer of hot gases and the layer temperature. Adequate quantities of replacement inlet air from air inlets located below the hot upper layer are needed if the products of combustion-laden upper gases are to be exhausted according to design. See Figure A.1.1.1(a) for an illustration of the behavior of fire under a vented and

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curtained roof, and Figure A.1.1.1(b) for an example of a roof with vents.

The majority of the information provided in this standard applies to nonsprinklered buildings. A limited amount of guidance is provided in Chapter 11 for sprinklered buildings.

The provisions of this standard can be applied to the top story of multiple-story buildings. Many features of these provisions would be difficult or impracticable to incorporate into the lower stories of such buildings.

A.1.1.2 The decision whether to provide venting in a building depends on design objectives set by a building owner or occupant or on local building code and fire code requirements.

A.1.3.1 See NFPA 90A for ventilation to regulate environmental air for personnel comfort. See NFPA 96 for regulation of commercial cooking operations. See NFPA 68 for venting for explosion pressure relief.

A.1.3.4 The distance from the fire base to the smoke layer boundary, z_s, is a dominant variable and should be considered carefully. Additionally, some design situations can result in smoke layer temperatures, as expressed in Equation 9.2.4.3, that exceed 600°C (1112°F). In such cases, the radiation from the smoke layer can be sufficient to ignite all of the combustibles under the curtained area at this temperature, and perhaps in the adjacent area, which is unacceptable.

A.1.3.5 The feasibility of roof venting should be questioned when the heat release rate approaches values associated with ventilation control of the burning process (i.e., where the fire becomes controlled by the inlet air replacing the vented hot gas and smoke). Ventilation-controlled fires might be unable to support a clear layer.

To maintain a clear layer, venting at heat release rates greater than $Q_{feasible}$ necessitates vent areas larger than those indicated by the calculation scheme provided in this standard.

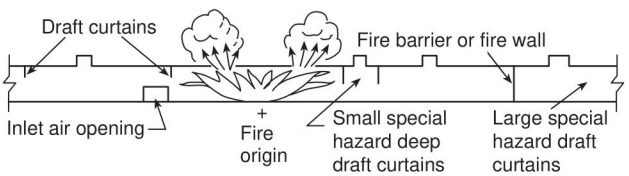


FIGURE A.1.1.1(a) Behavior of Combustion Products Under Vented and Curtained Roof.



FIGURE A.1.1.1(b) View of Roof Vents on Building.

A.1.3.6 Large, undivided floor areas present extremely difficult firefighting problems because the fire department might need to enter these areas in order to combat fires in central portions of the building. If the fire department is unable to enter because of the accumulation of heat and smoke, firefighting efforts might be reduced to an application of hose streams to perimeter areas while fire continues in the interior. Windowless buildings also present similar firefighting problems. One fire protection tool that can be a valuable asset for firefighting operations in such buildings is smoke and heat venting.

An appropriate design time facilitates such activities as locating the fire, appraising the fire severity and its extent, evacuating the building, and making an informed decision on the deployment of personnel and equipment to be used for firefighting.

A.2.1 Some of these documents might also be referenced in this standard for specific informational purposes and are therefore also listed in Annex G.

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.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.3 Clear Layer Interface. See Figure A.3.3.3 for a description of the smoke layer interface, smoke layer, and first indication of smoke.

A.3.3.9 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.

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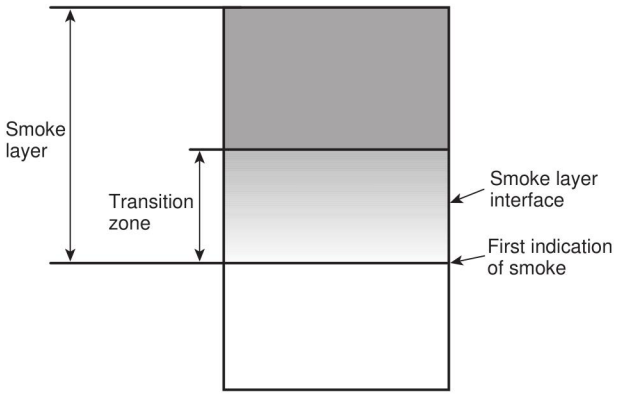


FIGURE A.3.3.3 First Indication of Smoke.

A.3.3.10 Effective Ignition. See Figure 8.3.1 for a conceptual illustration of continuous fire growth and effective ignition time.

A.3.3.18 Smoke Layer. See Figure A.3.3.3 for a description of the clear layer interface, smoke layer, and smoke layer boundary.

A.3.3.19 Smoke Layer Boundary. See Figure A.3.3.3 for a description of the clear layer interface, smoke layer, and smoke layer boundary.

A.4.1 Design objectives for a vent system can include one or more of the following goals:

(1) To provide occupants with a safe path of travel to a safe area
(2) To facilitate manual firefighting
(3) To reduce the damage to buildings and contents due to smoke and hot gases

A.4.2 Tests and studies provide a basis for the division of occupancies into classes, depending on the fuel available for contribution to fire. Wide variation is found in the quantities of combustible materials in the many kinds of buildings and areas of buildings.

A.4.4.2 The heat release rate of a fire, the fire diameter, and the height of the clear layer above the base of the fire are major factors affecting the production of smoke.

A.4.4.3 Mass flow through a vent is governed mainly by the vent area and the depth of the smoke layer and its temperature. Venting becomes more effective with smoke temperature differentials between ambient temperature and an upper layer of approximately 110°C (230°F) or higher. Where temperature differences of less than 110°C (230°F) are expected, vent flows might be reduced significantly; therefore, consideration should be given to using powered exhaust. NFPA 92 should be consulted for guidance for power venting at these lower temperatures.

The vent designs in this standard allow the fire to reach a size such that the flame plume enters the smoke layer. Flame height may be estimated using Equation 9.2.3.1.

A.4.5.1 The rate of smoke production depends on the rate of air entrainment into a column of hot gases produced by and located above a fire. Entrainment is affected by the fire diameter and rate of heat release, and it is strongly affected by the distance between the base of the fire and the point at which the smoke plume enters the smoke layer.

A.4.5.2 Because smoke production is related to the size of a fire, it follows that, all factors being equal, larger fires produce more smoke. Entrainment, however, is strongly affected by the distance between the base of a fire and the bottom of the hot layer. The base of the fire (where combustion and entrainment begin) should be selected on the basis of the worst case. It is possible for a smaller fire having a base near the floor to produce more smoke than a larger fire with a base at a higher elevation. Air entrainment is assumed to be limited to the clear height between the base of the fire and the bottom of the hot layer. The buoyant plume associated with a fire produces a flow into the hot upper layer. As the plume impinges on the ceiling, the plume turns and forms a ceiling jet. The ceiling jet flows radially outward along the ceiling.

A.4.5.3 Where the possibility of multiple fires and, therefore, multiple plumes exists, smoke production rates increase beyond the rate predicted for a single plume for a fire of equivalent output. Multiple fires are beyond the scope of this standard.

A.4.5.3.2 Plume mass flow above the flame level is based on the concept that, except for absolute scales, the shapes of velocity and temperature profiles at the mean flame height are invariable. This concept leads to an expression for mass flow above the flames that involves the so-called *virtual origin*, a point source from which the plume above the flames appears to originate. The virtual origin might be above or below the base of the fire.

A.4.6.1 It is assumed that openings exist to the outside and therefore no pressure results from the expansion of gases. Also, wind effects are not taken into account because wind might assist or interfere with vent flows, depending on specific circumstances. It is also assumed that the fire environment in a building space is divided into two zones — a hot upper layer and a relatively cool, clear (comparatively free of smoke) lower region. When a fire grows to a size approaching ventilation-limited burning, the building might no longer maintain a clear lower region, and this standard would no longer be applicable. Finally, caution must be exercised when using this standard for conditions under which the upper-gas-layer temperature approaches 600°C (1112°F), because flashover might occur within the area. When a fire develops to flashover or ventilation-limited burning, the relationships provided in this standard are not applicable.

Buoyancy pressure is related to the depth of the hot layer, the absolute temperature of the hot layer, the temperature rise above ambient of the hot layer, and the density of the ambient air. The mass rate of flow of hot gases through a vent is a function of vent area, layer depth, and hot layer temperature. The temperature of the hot layer above ambient affects mass flow through a vent. Maximum flow occurs at temperature differences of approximately 300°C (572°F) above ambient. Flows at other temperature differentials are diminished, as shown in Figure A.4.6.1.

A.4.6.1.2 In order to provide a design that is not dependent on beneficial wind effects, design calculations are carried out that ignore wind effects and that are based only on buoyancy effects (and fan assistance for mechanical systems).

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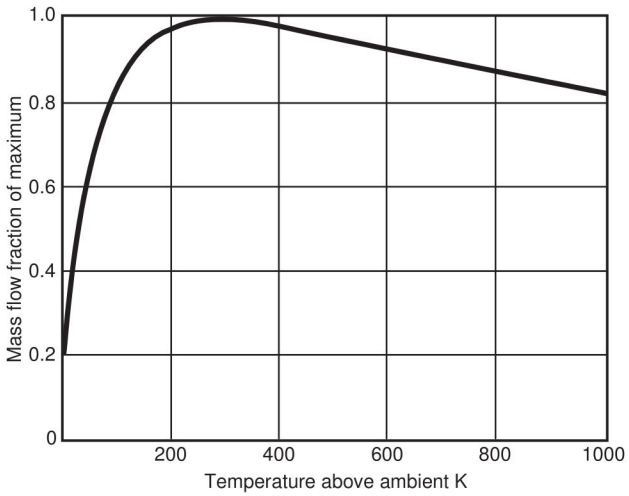


FIGURE A.4.6.1 Effect of Temperature on Mass Flow Through a Vent.

Nevertheless, it is important to consider wind effects since adverse wind effects can reduce or even reverse vent flow. Exhaust vents and air inlets should be located so that under any wind conditions there is an overall wind suction effect from inlet to exhaust.

This is normally achieved when the roof slope is 30 degrees or less and vents have a horizontal clear space at least three times the height difference from any taller structures such as parapets, roof lights, or taller roofs.

Otherwise, if the designer cannot show by calculation or by data that there will be no adverse wind effects, a mechanical smoke extract system should be used.

A.4.6.2 To function as intended, a building venting system needs sufficiently large fresh air inlet openings at low levels. It is essential that a dependable means for admitting or supplying inlet air be provided promptly after the first vent opens.

Δ **A.5.1** There is an ISO standard for vents (ISO 21927-2, *Smoke and Heat Control Systems — Part 2: Specification for natural smoke and heat exhaust ventilators*). The ISO standard is technically equivalent to European (EN) standards for these products. Products that carry the CE mark, which is mandatory for sale of these products within the European Union, are subject to independent testing and ongoing factory production control by Notified Bodies appointed by national governments. The standard is BS EN 12101-2, *Smoke and Heat Control Systems — Part 2: Specification for natural smoke and heat exhaust ventilators.*

A.5.2.1 Compatibility between the vent-mounting elements (e.g., holding power, electrochemical interaction, wind lift, building movement) and the building structure to which they are attached needs to be ensured.

A.5.2.2 To avoid inadvertent operation, it is important that the actuating means be selected with regard to the full range of expected ambient conditions.

A.5.2.3 Dip tanks or discrete solvent storage areas are examples of localized hazards where the vents are to be located directly above such hazard.

A.5.3.1 An automatic mechanism for opening the roof vents is stipulated for effective release of heat, smoke, and gaseous by-products. The means of automatic vent actuation must take the anticipated fire into consideration, and an appropriate means of opening vents should be used. If design objectives cannot be met using heat-actuated devices, smoke detectors with appropriate linkages to open vents or other devices that respond more quickly should be considered for use.

A.5.3.2 Latching mechanisms should be jam-proof, corrosion-resistant, dust-resistant, and resistant to pressure differences arising from applicable positive or negative loading resulting from environmental conditions, process operations, overhead doors, or traffic vibrations.

A.5.3.5 The location of the manual device must be coordinated with tactics of the reporting fire department.

If not actually mounted on the vent, the manual device can be connected to the vent by mechanical, electrical, or any other suitable means, protected as necessary to remain operable for the design period.

A.5.4.1.2 See Figure 5.4.2(b) for the measurement of ceiling height and curtain board depth.

A.5.4.2 The spacing of vents is limited to $4H$ to assure that ceiling jet temperatures at the vent are sufficiently high to operate the thermal actuating mechanism at the vent. The spacing limit specified is designed to achieve ceiling jet temperature above ambient at the nearest vent, not less than half the plume temperature above ambient at the point of plume impact on the ceiling. (See Figure A.5.4.2, which reflects the maximum allowable spacing of $4H$.)

A.5.4.3 The limitation on horizontal distance from a potential fire axis adjacent to a draft curtain or wall is intended to assure ceiling jet temperatures at the vent are sufficiently high to activate the thermal actuating mechanism. The spacing limit specified is designed to achieve ceiling jet temperature above ambient at the nearest vent, not less than half the plume temperature above ambient at the point of plume impact on the ceiling. *(See Figure A.5.4.3.)* This requirement does not reflect the potential for reduced entrainment for a fire adjacent to a wall. This conservatism was knowingly accepted.

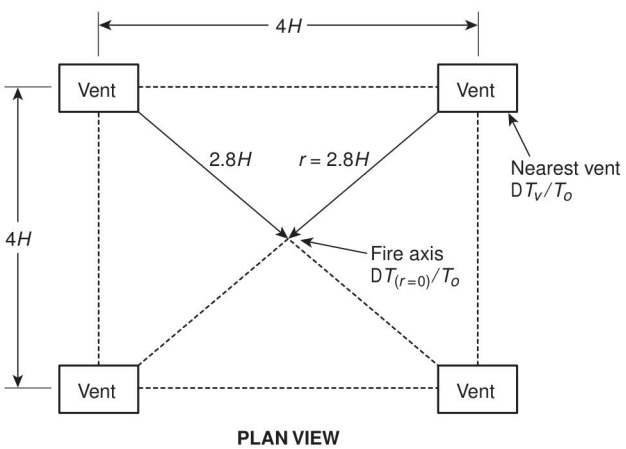


FIGURE A.5.4.2 Vent Spacing in Rectangular Matrix, When $r = 2.8\,H$, $(\Delta T_v/T_o) = 0.5\ (\Delta T(r=0)/T_o)$ (plan view).

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A.6.1 The simplest method of introducing makeup air into the space is through direct openings to the outside, such as doors and louvers, which can be opened upon system activation. Such openings can be coordinated with the architectural design and can be located as required below the design smoke layer. For locations having mechanical smoke exhaust systems where such openings are impractical, a powered supply system could be considered. This could possibly be an adaptation of the building's HVAC system if capacities, outlet grille locations, and velocities are suitable. For such systems, means should be provided to prevent supply systems from operating until exhaust flow has been established, to avoid pressurization of the fire area. For those locations where climates are such that the damage to the space or contents could be extensive during testing or frequent inadvertent operation of the system, consideration should be given to heating the makeup air. See NFPA 92 for additional information on mechanical systems.

A.6.3 Normal practice has been to provide air inlet from low-level air inlets as recommended in previous editions of this standard. In some buildings this may be difficult to achieve, due either to lack of suitable clear wall area or to concerns about loss of security when the air inlets open. In buildings containing more than one curtained area, it can be possible to open vents in curtained areas not affected by smoke to provide inlet air instead. If this is done, then the vents must meet all the requirements of Chapter 6.

A.6.6.3 The inlet air velocity should be limited for three reasons: (1) to avoid disturbing the fire plume and causing excess air entrainment, (2) to limit the degree of depressurization of the space and consequent effects on door opening and closing, and (3) to avoid incoming air hampering escape of occupants.

NFPA 92 sets a limit of 1.02 m/sec (200 ft/min) to minimize disturbance of the plume, which will create more entrainment than anticipated.

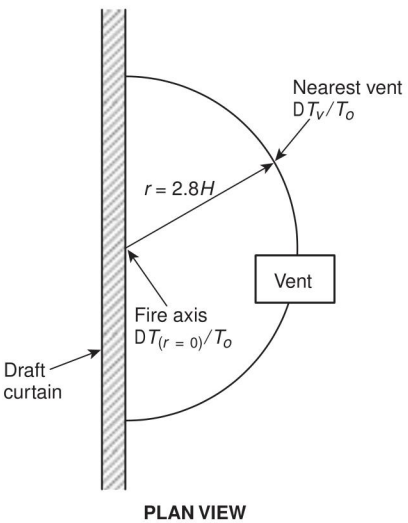


FIGURE A.5.4.3 Vent Spacing near a Draft Curtain, When $r = 2.8H$, $(\Delta T_v/T_o) = 0.5$ $(\Delta T(r = 0/T_o)$ (plan view).

Excess depressurization of the space will increase door opening forces for outward-opening doors and risk slamming closed for inward-opening doors. Neither situation is acceptable.

Research indicates that people can move reasonably freely against an airflow of up to 10 m/sec (32.8 ft/sec).

A.7.1 Draft curtains are provided for prompt activation of vents and to increase vent effectiveness by containing the smoke in the curtained area and increasing the depth of the smoke layer. A draft curtain is intended to be relatively smoke-tight. The function of a draft curtain is to intercept the ceiling jet and the entrained smoke produced by a fire in the building. The curtain should prevent the smoke from spreading along the underside of the roof deck to areas of the building located beyond the draft curtain and should create a hot smoke layer that develops buoyancy forces sufficient to exhaust the smoke through the vent openings in the roof. A full-height partition or wall, including an exterior wall, can serve as a draft curtain.

Δ **A.7.2** Materials suitable for use as draft curtains can include steel sheeting, cementitious panels, and gypsum board or any materials that meet the performance criteria in Section 7.2. There is an ISO standard for draft curtains (ISO 21927-1, *Smoke and Heat Control Systems — Part 1: Specification for smoke barriers*). The ISO standard is technically equivalent to the European (EN) standard for these products. Products that carry the CE mark, which is mandatory for sale of these products within the European Union, are subject to independent testing and ongoing factory production control by Notified Bodies appointed by national governments. The standard is BS EN 12101-1, *Smoke and Heat Control Systems — Part 1: Specification for smoke barriers.*

A.7.3.1 If d_c exceeds 20 percent of H, $H–d_c$ should be not less than 3 m (9.8 ft). For Figure 5.4.2(b), parts (a) through (d), this concept is valid where $\Delta d/d_c$ is much less than 1.

Consideration should be given to minimizing of the expected smoke layer depth with respect to the occupancy. Such arrangement can allow the smoke layer to be maintained above the top of equipment or storage, thus maximizing visibility and reducing nonthermal damage to contents. For buildings of limited height, it can also allow the designer to utilize the primary structural frame to act as a draft curtain (if solid-webbed) or support one (if open-webbed), thus reducing costs.

Also, in a transient situation, prior to achieving equilibrium mass flow, if the smoke layer extends below the top of equipment or storage, that volume displaced by equipment or storage should be subtracted from available space for the smoke layer to accumulate, or the smoke layer depth will extend below that estimated.

A.7.4.1 To ensure that vents remote from the fire within the curtained compartment are effective, the distance between draft curtains or between walls must be limited.

A.7.4.2 From reanalysis of this issue based on Delichatsios [1981], Heskestad and Delichatsios [1978], and Koslowski and Motevalli [1994].

A.8.1 Chapter 8 presents techniques for predicting the heat release rate of various fuel arrays likely to be present in buildings where smoke and heat venting is a potential fire safety provision. It primarily addresses the estimation of fuel concentrations found in storage and manufacturing locations. NFPA 92 addresses the types of fuel arrays more common to the types of building situations covered by that document. The

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methods provided in Chapter 8 for predicting the rate of heat release are based on "free burning" conditions, in which no ceiling or smoke layer effects are involved.

A.8.2.2 The minimum aisle width to prevent lateral spread by radiation, W_{min} in Equation 8.2.3, is based on Alpert and Ward [1984]. The values produced by Equation 8.2.3 can be produced from the following equation if χ_r is assumed to be 0.5:

[A.8.2.2]

$$\dot{q}''_i = \frac{\chi_r}{4\pi r^2}$$

A.8.2.6 The heat release rate is taken as the heat release rate per unit area times the floor area of the fuel concentration. The maximum foreseeable storage height (above the fire base) and associated heat release rate should be considered.

The heat release rate per unit area might be available from listings for a given storage height, such as Table A.8.2.6. To establish estimates for other than specified heights, it can be assumed that the heat release rate per unit area is proportional to the storage height, based on tests (Yu and Stavrianidis, 1991) and the data in Table A.8.2.6 for wood pallets. For fuel configurations that have not been tested, other procedures should be used. See Annex E for estimating heat release rates of other fuel arrays.

There is a distinct possibility that a combustible storage array could collapse before the end of the design interval of the venting system. The design interval might end, for example, when manual firefighting is expected to begin. The fire diameter increases, contributing to increased smoke production (via a lower flame height and virtual origin). However, the heat release rate and fire growth rate after collapse are likely to be smaller than with no collapse. Consequently, it is reasonable to assume that the net effect of collapse is not significant for the calculation procedure.

A.8.3.1 The growth time, t_g, is a measure of the fire growth rate — the smaller the growth time, the faster the fire grows.

A.8.3.2 By comparing Equations 8.3.1 and 8.3.2, the following relation exists:

[A.8.3.2]

$$\alpha_g = \frac{1000}{t_g^2}$$

A.8.3.4 Design objectives and the design interval time, t_r, should take into consideration all of the following critical events:

(1) Arrival and deployment of the emergency response team
(2) Arrival and deployment of firefighters from the public fire department
(3) Completion of evacuation
(4) Other critical events

A.9.1 The procedures in Chapter 9 are based on the automatic activation of vents by a heat-responsive device with an established response time index (RTI) and known activation temperature. These assumptions do not preclude other means of vent activation, as long as the activation time of the alternative means is known or can be calculated using the procedures contained herein or can be established as acceptable by a specific listing, specific test data, or engineering analysis. Activation by heat detectors, smoke detectors, thermoplastic drop-out vent panels, or other approved means is acceptable as long as the design objectives are met.

The equations and procedures for hand calculations in Section 9.2 and the models in Section 9.3 address the venting of limited-growth fires and continuously growing fires.

Table A.8.2.6 Unit Heat Release Rates for Commodities

Commodity	Heat Release Rate (kW per m^2 of floor area)*
Wood pallets, stacked 0.46 m high (6%–12% moisture)	1,420
Wood pallets, stacked 1.52 m high (6%–12% moisture)	4,000
Wood pallets, stacked 3.05 m high (6%–12% moisture)	6,800
Wood pallets, stacked 4.88 m high (6%–12% moisture)	10,200
Mail bags, filled, stored 1.52 m high	400
Cartons, compartmented, stacked 4.5 m high	1,700
PE letter trays, filled, stacked 1.5 m high on cart	8,500
PE trash barrels in cartons, stacked 4.5 m high	2,000
FRP shower stalls in cartons, stacked 4.6 m high	1,400
PE bottles packed in compartmented cartons, stacked 4.5 m high	6,200
PE bottles in cartons, stacked 4.5 m high	2,000
PU insulation board, rigid foam, stacked 4.6 m high	1,900
PS jars packed in compartmented cartons, stacked 4.5 m high	14,200
PS tubs nested in cartons, stacked 4.2 m high	5,400
PS toy parts in cartons, stacked 4.5 m high	2,000
PS insulation board, rigid foam, stacked 4.2 m high	3,300
PVC bottles packed in compartmented cartons, stacked 4.5 m high	3,400
PP tubs packed in compartmented cartons, stacked 4.5 m high	4,400
PP and PE film in rolls, stacked 4.1 m high	6,200
Methyl alcohol	740
Gasoline	2,500
Kerosene	1,700
Fuel oil, no. 2	1,700

PE: polyethylene. PP: polypropylene. PS: polystyrene. PU: polyurethane. PVC: polyvinyl chloride. FRP: fiberglass-reinforced polyester.
*Heat release rate per unit floor area of fully involved combustibles, based on negligible radiative feedback from the surroundings and 100 percent combustion efficiency.

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A.9.1.1 The vent area in a curtained area should not be required to exceed the vent area calculated for the largest limited-growth fire predicted for the combustibles beneath any curtained area. Using sufficiently small concentrations of combustibles and aisles of sufficient width to prevent spread according to Equation 8.2.3, it might be possible to satisfy venting requirements by using vent areas smaller than those required for a vent design and a continuous-growth fire.

A.9.1.4 Many large facilities have buildings or areas subject to differing fire hazards.

A.9.2.2.1 In Figure 9.2.2.1, z_s is the height of the smoke layer boundary above the base of the fire; H is the distance between the base of the fire and the ceiling; d_c is the depth of the draft curtains; d is the depth of the smoke layer; $\dot{m}_p$ is the mass flow rate of hot gas from the fire plume into the smoke layer; $\dot{m}_v$ is the mass flow rate of hot gas out of the vent (or vents) in the curtained area; and A_v is the vent area in the curtained area (total vent area in the curtained area if more than one vent is provided).

The vent area calculated for equilibrium conditions corresponds to the area needed for a long-term steady fire or to the area needed at the end of a design interval for a slow-growing fire. For shorter-term steady fires and for faster-growing fires, the calculated equilibrium vent area will prevent the smoke layer boundary from descending completely to the bottom of the draft curtains. Therefore, equilibrium calculations represent a safety factor in the design.

A.9.2.3.1 The mass flow rate in the plume depends on whether locations above or below the mean flame height are considered (i.e., whether the flames are below the smoke layer boundary or reach into the smoke layer).

A.9.2.4 The calculations in this section assume that the vent is exhausting only smoke from the smoke layer. When the smoke layer is at its design depth, the provisions for avoidance of plugholing in Section 5.4 will ensure that this is so.

However, during part of the time period when the smoke layer is descending to its design height, the vents will extract a mixture of smoke from the smoke layer and the ambient air from below the smoke layer. They will therefore extract less smoke than the calculations indicate, causing the smoke layer to descend at a faster rate.

Existing research has provided formulae to assess at what point a vent starts plugholing, but not to assess the smoke extract rate while a vent is plugholing.

There is therefore no experimentally validated method of assessing the effect of plugholing on the rate of descent of a smoke layer. A method has been published in BS 7346-5, *Functional recommendations and calculation methods for smoke and heat exhaust ventilation systems employing time-dependent design fires.*

A.9.2.4.1 The mass flow rate through the vent is the product of gas density, velocity, and cross-sectional area of the flow in the vent. The velocity follows from equating the buoyancy head across the vent to the dynamic head in the vent, with consideration of the pressure drop across the air inlets. The factor $[(T_o \Delta T)/T^2]^{1/2}$ is quite insensitive to temperature as long as the smoke layer temperature rise, ΔT, is not small. For example, assuming T_o = 294 K, the factor varies through 0.47, 0.50, and 0.47 as the smoke layer temperature rise varies through 150 K, 320 K, and 570 K. At a temperature rise of 60 K, the factor is 0.38, and at a temperature rise of 20 K, it is 0.24, or about one-half its maximum value. Consequently, roof venting by natural ventilation becomes increasingly less effective as the smoke layer temperature decreases. For low smoke layer temperatures, powered ventilation as covered in NFPA 92 should be considered.

Where high upper-layer temperatures of 400 K above ambient are anticipated, 80 percent of the predicted vent flow is expected to be achieved with an inlet area/vent area ratio of 1, whereas it is expected that 90 percent of the vent flow will result from a ratio of 2. Where relatively low upper-layer temperatures, such as 200 K above ambient, are expected, a ratio of inlet air/vent area of 1 would result in about 70 percent of the predicted vent flow, whereas a ratio of 2 would be expected to produce about 90 percent of the predicted vent flow.

A.9.2.4.2 The aerodynamic vent area is always smaller than the geometric vent area, A_v. A discharge coefficient of 0.6 should be reasonable for most vents and for doors and windows that open at least 45 degrees. However, the discharge coefficient can be different for other types of openings. For example, an opening with a louver can have a coefficient ranging between 0.1 and 0.4.

A.9.2.5.4.1 For continuous-growth fires, the earlier the fire is detected and vents actuated, the smaller the fire size at the end of the design interval and the smaller the required vent area. In the case of limited-growth fires, the earlier the fire is detected and the vents actuated, the less likely to occur are an initial underspill of smoke at the draft curtains and smoke layer descent to low heights.

If a design objective is to confine smoke to the curtained area of origin, the time the last required vent opens, t_{vo}, should not exceed the time the smoke layer boundary drops below draft curtains, which can be determined in accordance with Equation A.9.2.5.4.1a for steady fires and Equation A.9.2.5.4.1b for unsteady fires.

[A.9.2.5.4.1a]

$$\frac{z_{si}}{H} = 0.67 - 0.28 \ln\left[\frac{\left(tQ^{1/3}/H^{4/3}\right)}{\left(A_c/H^2\right)}\right]$$

[A.9.2.5.4.1b]

$$\frac{z_{si}}{H} = 0.23\left[\frac{t}{t_g^{2/5}\left(H^{4/5}\right)\left(A_c/H^2\right)^{3/5}}\right]^{-1.45}$$

where:

z_{si} = height of smoke layer interface above the base of the fire
t = time (sec)
Q = total heat release rate
H = ceiling height above base of fire
A_c = curtained area being filled with smoke (m^2)

A.9.2.5.4.2.1 The response data in *NFPA 72* assume extensive, flat, horizontal ceilings.

This assumption might appear optimistic for installations involving beamed ceilings. However, any delay in operation due to beams is at least partially offset by the opposite effects of the following:

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(1) Heat banking up under the ceiling because of draft curtains or walls
(2) The nearest vent or detector usually being closer to the fire than the assumed, greatest possible distance

Fusible links are commonly used as actuators for mechanically opened heat and smoke vents. Where the response time index (RTI) and fusing temperature of a fusible link are known, and assuming that the link is submerged in the ceiling jet, the relationships described in *NFPA 72* for heat-actuated alarm devices can be used to estimate the opening of a mechanical vent.

A.9.2.5.4.3.1 This requirement does not have a parallel in *NFPA 72*. Temperature rise for activation of smoke detectors depends on the specific detector as well as the material undergoing combustion. Limited data on temperature rise at detection have previously been recorded in the range of 2°C to 42°C, depending on the detector/material combination (Heskestad and Delichatsios, 1977).

Δ **A.9.2.5.4.4.1** A computer program known as DETACT-T2 (DETector ACTuation — Time Squared) (Evans and Stroup, 1985) is available for calculating the detection times of heat detectors or fusible links in continuous-growth, *t*-squared fires. DETACT-T2 assumes the detector is located in a large compartment with an unconfined ceiling, where there is no accumulation of hot gases at the ceiling. Thus, heating of the detector is only from the flow of hot gases along the ceiling. Input data consist of ceiling height, time constant or RTI of the detector, operating temperature, distance of the detector from plume centerline, and fire growth rate. The model calculates detection times for smoke detectors *(see 9.2.5.4.3)* based on the predecessor equations. The predecessor equations assume complete combustion of the test fuel used in the experiments used to develop the equations based on the actual heat of combustion:

[A.9.2.5.4.4.1]

$$\frac{u}{\left(\Delta T_g / T_o\right) g H^{1/2}} = 0.59\left(\frac{r}{H}\right)^{-0.63}$$

where:
u = gas velocity at detector site
r = radius from fire axis
ΔT_g = gas temperature rise from ambient at detector
T_o = ambient air temperature
g = acceleration of gravity
H = ceiling height (above combustibles)

However, DETACT-T2 can still be used, provided that the projected fire growth coefficient, α_g, is multiplied by the factor 1.67. In addition, when DETACT-T2 is used, the outputs of heat release rate at detector response from the program calculations must be divided by 1.67 in order to establish heat release rates at detector response.

A.9.2.5.4.4.2 Another program, DETACT-QS (DETector ACTuation — Quasi Steady) [Evans and Stroup, 1985], is available for calculating detection times of heat detectors, fusible links, and smoke detectors in fires of arbitrary fire growth. DETACT-QS assumes that the detector is located in a large compartment with an unconfined ceiling, where there is no accumulation of hot gases at the ceiling. Thus, heating of the detector is only from the flow of hot gases along the ceiling. Input data consist of ceiling height, time constant or RTI of the detector, operating temperature, distance of the detector from the plume centerline, and fire growth rate. The model calculates detection times for smoke detectors *(see 9.2.5.4.3)* based on the predecessor equations. Quasi-steady temperatures and velocities are assumed (i.e., instantaneously, gas temperatures and velocities under the ceiling are assumed to be related to the heat release rate as in a steady fire). Compared to DETACT-T2, DETACT-QS provides a means of addressing fires that cannot be approximated as *t*-squared fires. However, for *t*-squared fires, DETACT-QS is less accurate than DETACT-T2 (if the projected fire growth coefficient is increased as described in 9.2.5.4.4.1 and A.9.2.5.4.4.1), especially for fast-growing fires.

Δ **A.10.1** There is an ISO standard for mechanical smoke extract (ISO 21927-3, *Smoke and Heat Control Systems — Part 3: Specification for powered smoke and heat exhaust ventilators*). The ISO standard is technically equivalent to the European (EN) standard for these products. Products that carry the CE mark, which is mandatory for sale of these products within the European Union, are subject to independent testing and ongoing factory production control by Notified Bodies appointed by national governments. The standard is BS EN 12101-3, *Smoke and Heat Control Systems — Part 3: Specification for powered smoke and heat exhaust ventilators.*

A.10.1.1 Where temperature differences of less than 110°C (230°F) are expected, vent flows might be reduced significantly; therefore, consideration should be given to using powered exhaust. NFPA 92 should be consulted for guidance for power venting at these lower temperatures.

A.10.4 The sizing and spacing of exhaust fan intakes should balance the following concerns:

(1) The exhaust intakes need to be sufficiently close to one another to prevent the smoke from cooling to the point that it loses buoyancy as it travels along the underside of the ceiling to an intake and descends from the ceiling. This is particularly important for spaces where the length is greater than the height, such as shopping malls.
(2) The exhaust intakes need to be sized and distributed in the space to minimize the likelihood of air beneath the smoke layer from being drawn through the layer. This phenomenon is called plugholing.

The objective of distributing fan inlets is therefore to establish a gentle and generally uniform rate over the entire smoke layer. To accomplish this, the velocity of the exhaust inlet should not exceed the value determined from Equation A.10.4.

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For plugholing calculations, the smoke temperature should be calculated as follows:

[A.10.4]

$$T = T_o + \frac{KQ_c}{mC_p}$$

where:
T = smoke layer temperature (°F)
T_o = ambient temperature (°F)
K = fraction of convective energy contained in the smoke layer gases
Q_c = convective portion of heat release (Btu/sec)
m = mass flow rate of the plume (lb/sec)
C_p = specific heat of plume gases (0.24 Btu/lb-°F)

A value of $K = 0.5$ is suggested unless more detailed information is available.

A.10.4.3 The plugholing equation of this paragraph is consistent with and derived from the scale model studies of Spratt and Heselden [1974]. The equation is also consistent with the recent study of Nii, Nitta, Harada, and Yamaguchi [2003].

A.10.4.4 The γ factor of 1.0 applies to ceiling vents remote from a wall. *Remote* is regarded as a separation greater than two times the depth of the smoke layer below the lower point of the exhaust opening.

A.10.4.5 The γ factor of 0.5 is based upon potential flow considerations for a ceiling vent adjacent to a wall. While γ should vary smoothly from 0.5 for a vent directly adjacent to a wall to 1.0 for a ceiling vent remote from a wall, the available data do not support this level of detail in the requirements of the standard.

A.10.4.6 The γ factor of 0.5 is used for all wall vents. Because no data exist for wall exhausts, a value of γ greater than 0.5 could not be justified.

A.10.4.7 Noise due to exhaust fan operation or due to velocity at the exhaust inlet should be limited to allow the fire alarm signal to be heard.

A.11.1 Chapters 4 through 10 represent the state of technology of vent and draft curtain board design in the absence of sprinklers. A broadly accepted equivalent design basis for using sprinklers, vents, and curtain boards together for hazard control (e.g., life safety, property protection, water usage, obscuration) is currently not available. Designers are cautioned that the use of venting with automatic sprinklers is an area of ongoing research to determine its benefit and effect in conjunction with automatic suppression. See Section F.3 for more information.

A.11.2 Smoke and heat vents should be designed not to adversely impact the performance of the automatic sprinkler system. See 20.6.5 of NFPA 13. Testing and computer model studies conducted to date that have addressed the interaction of smoke and heat vents have been limited to control mode sprinklers. Because ESFR sprinklers have not been considered in any such studies, use of the guidance in this document is not applicable to ESFR sprinklers. The RTI is considerably lower than, and the required water discharge per sprinkler is considerably higher than, those of control mode sprinklers. There is concern that early operation of a smoke and heat venting system could adversely affect the performance of the fire suppression provided by ESFR sprinklers.

A.11.3 Figure A.11.3 shows the recommended spacing of sprinklers with respect to the draft curtain locations.

A.12.1 Regular inspection and maintenance is essential for emergency equipment and systems that are not subjected to their intended use for many years.

A.12.2 Various types of approved automatic thermal smoke and heat vents are available commercially. These vents fall into the following two general categories:

(1) Mechanically opened vents, which include spring-lift, pneumatic-lift, or electric motor-driven vents
(2) Thermoplastic drop-out vents, which include polyvinyl chloride (PVC) or acrylic drop-out panels

Thermoplastic drop-out vents do not allow nondestructive operation.

A.12.3.1.4 Vents designed for multiple functions (e.g., the entrance of daylight, roof access, comfort ventilation) need maintenance of the fire protection function that might be impaired by the other uses. These impairments can include loss of spring tension; racking or wear of moving parts; adverse exterior cooling effects on the fire protection release mecha-

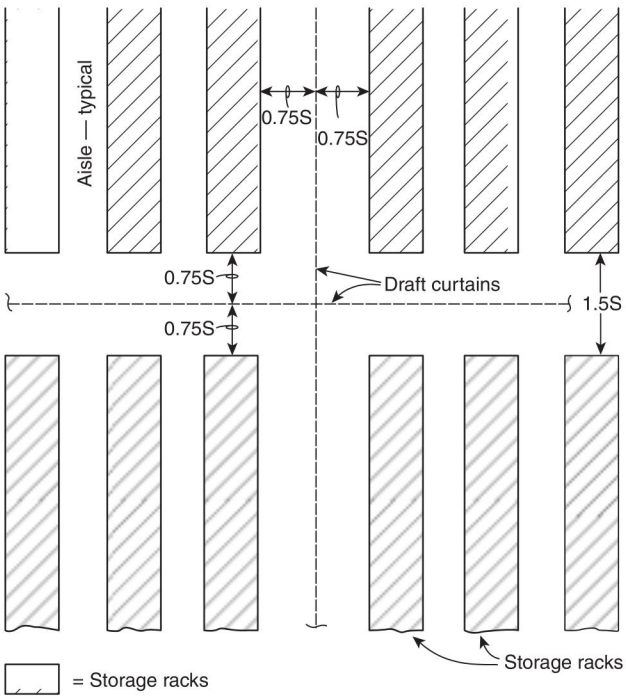


FIGURE A.11.3 Recommended Sprinkler Spacing with Respect to Draft Curtain Locations.

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