

NFPA[®]

555

Guide on Methods for Evaluating Potential for Room Flashover

2017



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NFPA®555

Guide on

Methods for Evaluating Potential for Room Flashover

2017 Edition

This edition of NFPA 555, *Guide on Methods for Evaluating Potential for Room Flashover*, was prepared by the Technical Committee on Hazard and Risk of Contents and Furnishings. It was issued by the Standards Council on May 13, 2016, with an effective date of June 2, 2016, and supersedes all previous editions.

This edition of NFPA 555 was approved as an American National Standard on June 2, 2016.

Origin and Development of NFPA 555

This guide was the first document prepared by the Technical Committee on Hazard and Risk of Contents and Furnishings. The 1996 edition was the first edition, developed in recognition that life safety and property protection can be enhanced by preventing the occurrence of flashover or, at least, by decreasing its probability.

The 2000 edition represented a reconfirmation of the 1996 edition.

The 2009 edition contained a small addition to Chapter 9 for individual fuel packages, along with minor revisions throughout the document. Annex B was completely revised to provide more up-to-date information on room fire models.

The 2013 edition added references in Chapter 9 to NFPA 289, *Standard Method of Fire Test for Individual Fuel Packages*, and to NFPA 556, *Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles*, for use in estimating heat release rates.

The 2017 edition adds new language to Chapter 9 regarding the heat release rates of electrical and optical fiber cables, which were obtained from vertical cable tray tests and cone calorimeter test methods. Additional language in Chapter 9 references new studies on determining the typical heat release curve for residential fires.

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

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

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

Chapter 1 Administration

1.1 Scope.

1.1.1 This guide addresses methods for evaluating the potential for room flashover from fire involving the contents, furnishings, and interior finish of a room. The methods addressed by this guide include prevention of ignition; installation of automatic fire suppression systems; control of ventilation factors; and limitation of the heat release rate of individual and grouped room contents, furnishings, and interior finish.

1.1.2 The accuracy, precision, and relevance of this guide are a function of the accuracy, precision, and relevance of the data from the test methods and calculations used. The principles and concepts presented are among the most reliable available.

The use of these techniques can help to minimize the probability of flashover or delay its occurrence, but might not prevent it.

1.2 Purpose.

1.2.1 The purpose of this guide is to provide tools for individuals or organizations attempting to implement methods to prevent the occurrence of flashover or, at least, to decrease its probability.

1.2.2 Any limitations on the availability of data, of appropriate test procedures, of adequate fire models, or of state-of-the-art scientific knowledge place significant constraints on the procedures described in this guide.

1.2.3 This guide describes some standard tests conducted under controlled laboratory conditions. Such tests should not be deemed to establish performance levels for all situations.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this guide and should be considered part of the recommendations of this document.

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

NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*, 2015 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2016 edition.

NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*, 2016 edition.

NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*, 2016 edition.

NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, 2017 edition.

NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*, 2015 edition.

NFPA 17, *Standard for Dry Chemical Extinguishing Systems*, 2013 edition.

NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*, 2013 edition.

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, 2017 edition.

NFPA 92, *Standard for Smoke Control Systems*, 2015 edition.

NFPA 204, *Standard for Smoke and Heat Venting*, 2015 edition.

NFPA 265, *Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile or Expanded Vinyl Wall Coverings on Full Height Panels and Walls*, 2015 edition.

NFPA 286, *Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*, 2015 edition.

NFPA 289, *Standard Method of Fire Test for Individual Fuel Packages*, 2013 edition.

NFPA 556, *Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles*, 2016 edition.

NFPA 750, *Standard on Water Mist Fire Protection Systems*, 2015 edition.

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2015 edition.

2.3 Other Publications.

2.3.1 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D5537, *Standard Test Method for Heat Release, Flame Spread, Smoke Obscuration, and Mass Loss Testing of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration*, 2014.

ASTM D6113, *Standard Test Method for Using a Cone Calorimeter to Determine Fire-Test-Response Characteristics of Insulating Materials Contained in Electrical or Optical Fiber Cables*, 2011.

ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, 2015.

ASTM E603, *Standard Guide for Room Fire Experiments*, 2013.

ASTM E1321, *Standard Test Method for Determining Material Ignition and Flame Spread Properties*, 2013.

ASTM E1354, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, 2015a.

ASTM E1474, *Standard Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter*, 2014.

ASTM E1537, *Standard Test Method for Fire Testing of Upholstered Furniture*, 2013.

ASTM E1590, *Standard Test Method for Fire Testing of Mattresses*, 2013.

ASTM E1740, *Standard Test Method for Determining the Heat Release Rate and Other Fire-Test-Response Characteristics of Wall Covering or Ceiling Covering Composites Using a Cone Calorimeter*, 2015.

ASTM E1822, *Standard Test Method for Fire Testing of Stacked Chairs*, 2013.

ASTM E2058, *Standard Test Methods for Measurement of Material Flammability Using a Fire Propagation Apparatus (FPA)*, 2013a.

ASTM E2061, *Guide for Fire Hazard Assessment of Rail Transportation Vehicles*, 2012.

ASTM E2067, *Standard Practice for Full-Scale Oxygen Consumption Calorimetry Fire Tests*, 2012.

ASTM E2257, *Standard Test Method for Room Fire Test of Wall and Ceiling Materials and Assemblies*, 2013a.

ASTM E2280, *Standard Guide for the Fire Hazard Assessment of the Effect of Upholstered Seating Furniture Within Patient Rooms of Health Care Facilities*, 2013.

2.3.2 BSI Publications. British Standards Institution, 389 Chiswick High Road, London, W4 4AL, United Kingdom, www.bsigroup.com.

BS EN 50399, "Common test methods for cables under fire conditions. Heat release and smoke production measurement on cables during flame spread test. Test apparatus, procedures, results," 2011.

2.3.3 ISO Publications. International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneve 20, Switzerland.

ISO 9705, *Fire Tests — Full-Scale Room Tests for Surface Products*, 1993.

2.3.4 FM Global Publications. FM Global, 270 Central Avenue, P.O. Box 7500, Johnston, RI 02919-4923.

FM 3972, *Test Standard for Cable Fire Propagation*, 2009.

2.3.5 SFPE Publications. Society of Fire Protection Engineers, 7315 Wisconsin Avenue, Suite 1225 W, Bethesda, MD 20814.

SFPE Engineering Guide for Assessing Flame Radiation to External Targets from Pool Fires, 1999.

SFPE Engineering Guide to Performance-Based Fire Protection, Second Edition, 2008.

SFPE Engineering Guide to Piloted Ignition of Solid Materials Under Radiant Exposure, 2002.

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

UL 1685, *Standard for Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables*, 2015.

UL 1975, *Standard for Fire Tests for Foamed Plastics Used for Decorative Purposes*, 2006.

2.3.7 Other Publications.

ACT/DFA, *Flammability Studies of Selected Fabrics, Flame-Blocking Barriers, and Polyurethane Foams in the California Technical Bulletin 133 and Cone Calorimeter Protocols*, Association for Contract Textiles and Decorative Fabrics, Fort Worth, TX, 1995.

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Chapter 3 Definitions

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

3.2 NFPA Official Definitions.

3.2.1 Guide. A document that is advisory or informative in nature and that contains only nonmandatory provisions. A guide may contain mandatory statements such as when a guide can be used, but the document as a whole is not suitable for adoption into law.

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

3.3 General Definitions.

3.3.1 Contents and Furnishings. Any movable objects in a building that normally are secured or otherwise put in place for functional reasons, excluding (1) parts of the internal structure of the building and (2) any items meeting the definition of interior finish. (*See also 3.3.4, Interior Finish.*)

3.3.2* Flashover. A stage in the development of a contained fire in which all exposed surfaces reach ignition temperatures more or less simultaneously and fire spreads rapidly throughout the space.

3.3.3* Fuel Package. A grouping of one or more furnishings or contents items, or both, whose proximity is sufficiently close that the ignition of one item can be expected to cause the spread of fire to the remaining items in the fuel package.

3.3.4* Interior Finish. The exposed surfaces of walls, ceilings, and floors within buildings. [101, 2015]

3.3.5* Item. A single combustible object within the compartment that is permanent or transient, movable, or fixed.

Chapter 4 Instructions for Use of This Guide

4.1 Procedures. This guide is best used with a proper understanding of its various procedures. Its core consists of five chapters that guide the user through analyses and procedures used to determine the likelihood of a compartment under investigation reaching flashover under fire conditions and to minimize the potential for flashover.

4.2 Illustration of Use. Figure 4.2 illustrates the steps for using this guide in the evaluation of the potential for room flashover.

4.3 Analyses. After conducting the analysis provided in each chapter, the user can determine whether the potential for flashover has been decreased sufficiently or whether additional analysis is necessary. However, the user need not necessarily complete the analysis of each chapter before moving on to another.

4.4 Means of Fire Control. The first considerations in the analysis are the means of fire control, either via the existence of a properly designed and functional automatic suppression system or via techniques for smoke venting or reduction in oxygen availability. These issues are addressed in Chapter 4 and Chapter 5, respectively. A properly designed and functional system of either kind is likely to be a satisfactory means of reducing the potential for flashover.

4.5 Conditions for Further Analyses. If either of the following conditions exists, the user should conduct the analysis specified in Chapters 7 through 10:

- (1) There is neither a properly designed and functional automatic suppression system nor a similarly adequate method of reduction in oxygen availability.
- (2) Added precautions are desired.

4.6 Fuel Packages. Fuel packages should be defined using the concepts in Chapter 8.

4.7 Flashover-Potential Analysis. Chapter 7 contains techniques for predicting flashover in compartments, irrespective of the contents, furnishings, or interior finishes involved. Chapters 8 and 9 indicate how the fire performance of contents, furnishings, or interior finishes can be used to assess the potential for flashover. Chapter 10 explains how the techniques in Chapter 9 can be expanded to include groups of items or products as fuel packages.

4.8* Applications in Codes. The performance-based options commonly included in codes and standards are typical applications where the results of an analysis such as the one performed based on this guide would be useful.

Chapter 5 Automatic Suppression Systems

5.1 General. Automatic suppression systems are the most widely used method for automatically controlling a fire. Consideration should be given to using an automatic suppression system to limit the fire hazard potential in a room in order to reduce the probability of room flashover.

5.2 System Failure. Although automatic suppression systems have an outstanding record of success, it is possible for such systems to fail. Failures are often due to weaknesses in the system that could have been avoided if appropriate attention had been given at the time of design, installation, or inspection. Issues pertaining to system integrity should be addressed carefully to increase the probability of successful operation of a suppression system. If a properly designed and functioning automatic suppression system is used in the design of a room, a fire that occurs in that room is likely to be controlled or extinguished by the suppression system prior to full room involvement (flashover). Figure 5.2 provides a graphic representation of the effect of automatic suppression systems on heat release rate from a fire.

5.3 Hazard Protection. Many standards exist to aid designers in the development of appropriate automatic suppression system design criteria for a wide range of occupancy types and hazards. Because the range and severity of occupancy types and fire types are rather broad, and because protection goals vary from minimal property protection to large-scale life safety, it is essential that hazards be identified and evaluated and that applicable design criteria be employed.

5.4 Evaluation Considerations for Automatic Suppression Systems.

5.4.1 If a recognized design standard is not the basis for a suppression system design or if a unique or innovative suppression system approach is proposed, an evaluation of suppression system capabilities should be considered. Such an approach should include an analysis of the time to activation of the proposed suppression system compared to an evaluation of the “design fire” growth time with respect to the onset of flashover.

5.4.2 Factors that significantly affect an automatic suppression system’s ability to prevent flashover include fire growth rate,

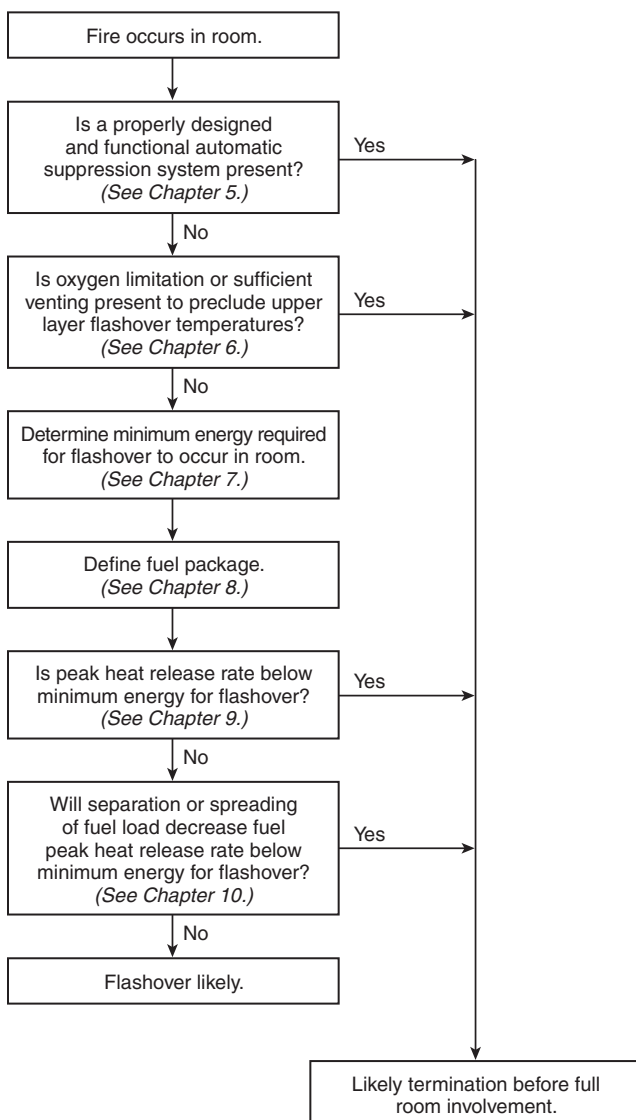


FIGURE 4.2 Flowchart for Use of NFPA 555.

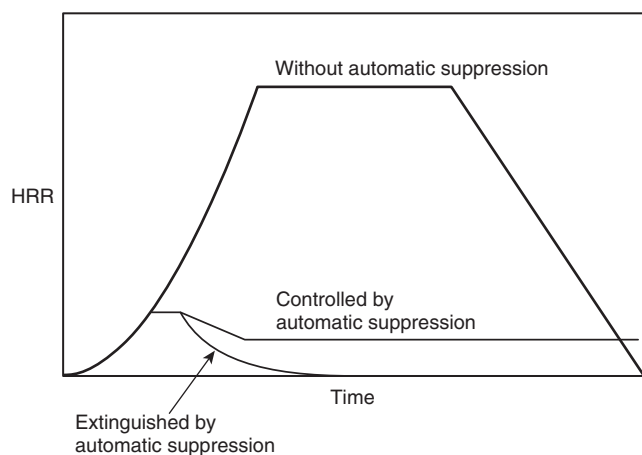


FIGURE 5.2 Effect of Automatic Fire Suppression Systems on Heat Release Rate. (Source: *SFPE Engineering Guide to Performance-Based Fire Protection*, Figure 9–3.)

quantity and arrangement of combustibles, enclosure characteristics, oxygen availability, fire detector (sprinkler) response characteristics, agent application rate (density), agent discharge characteristics, and duration of agent supply. Depending on the circumstances of the hazard and the level of protection required, some or all of the preceding factors might have to be evaluated to establish confidence in an automatic suppression system's ability to reduce the probability of flashover significantly.

5.5 Design, Installation, and Maintenance. The design, installation, and maintenance of automatic suppression systems are covered by a number of NFPA standards, including the following:

- (1) NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*
- (2) NFPA 13, *Standard for the Installation of Sprinkler Systems*
- (3) NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*
- (4) NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*
- (5) NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*
- (6) NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*
- (7) NFPA 17, *Standard for Dry Chemical Extinguishing Systems*
- (8) NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*
- (9) NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*
- (10) NFPA 750, *Standard on Water Mist Fire Protection Systems*
- (11) NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*

Chapter 6 Oxygen Availability and Ventilation

6.1 Considerations. Oxygen availability or ventilation parameters can play a significant role in fire growth, the combustion process, and conditions that influence flashover potential in various types of fire scenarios.

6.1.1 Typical Fire Scenarios. Normal air contains 20.9 percent oxygen, 79.1 percent nitrogen, and traces of other gases. In the combustion process, fuel combines with oxygen in air, and the

size of a resulting fire can be limited by the amount of either fuel or oxygen available for the combustion process. In most common fire scenarios, it should be reasonable to assume that oxygen is supplied to the fire from the surrounding air and that sufficient ventilation or air leakage paths are present to allow a continued supply of air and oxygen. The continued availability of air allows the growth of fire and the continued burning of contents, furnishings, or interior finishes in a compartment.

6.1.2 Tightly Closed Compartments. In fire scenarios in which a compartment is tightly closed or lacks sufficient ventilation or air leakage paths, the available oxygen is consumed in the combustion process until the oxygen volume concentration is reduced to between 8 percent and 12 percent. At these reduced oxygen levels, the flaming combustion of contents, furnishings, or interior finishes in a compartment can cease, and the remaining oxygen will not be consumed. These conditions can prevent the fire from growing to a size sufficient to produce flashover conditions. However, a sudden introduction of air (and oxygen) can result in a highly dangerous, rapid combustion of products of incomplete combustion, called a *backdraft*. A backdraft might occur when doors are opened or windows are broken in the process of manual fire fighting.

6.1.3 Vented Scenarios. In some fire scenarios, there is an abundance of ventilation in the form of a smoke/heat venting means or other exhaust mechanism that relieves sufficient heat and gases from a compartment, precluding the temperature rise conditions necessary to induce flashover (Hinkley, 1988).

6.2 Oxygen Consumption.

6.2.1 Principle of Oxygen Consumption. A determination has been made that the heat released per unit mass of oxygen consumed is nearly constant for most organic fuels. In air-limited fire scenarios, this value can be useful in determining whether the fire duration or maximum heat release rate predicted to cause flashover can be achieved. The value of heat released per unit mass of oxygen consumed is 13.1 kJ/g (on an oxygen basis). The value of heat released per unit volume of oxygen consumed, $\Delta h_c \times \rho_{O_2}$, is 18.7×10^3 kJ/m³ (on an oxygen basis), at 0°C. The corresponding values on an air basis are 3 kJ/g and 3.9×10^3 kJ/m³ (also at 0°C).

6.2.2 Tightly Closed Compartments.

6.2.2.1 In tightly closed compartments, flashover potential exists only if the heat released by the fire can exceed the heat release rate necessary for flashover using the oxygen supply available in the compartment.

6.2.2.2 The duration of burning in a tightly closed compartment can be estimated for steady fires and for unsteady fires in which the heat release rate grows proportionally to the square of time (*t*-square fires). Estimations are based on the volume of the space and the heat release rate as shown in Equation 6.2.2.2a for steady fires and Equation 6.2.2.2b for unsteady (*t*-square) fires.

[6.2.2.2a]

$$t = \frac{V_{O_2}}{\dot{Q}} (\Delta h_c \times \rho_{O_2})$$

[6.2.2.2b]

$$t = \left[\frac{3V_{O_2}}{\alpha} (\Delta h_c \times \rho_{O_2}) \right]^{1/3}$$

where:

 t = time (sec) V_{O_2} = volume of oxygen available to be consumed in combustion process [see 6.2.2.3] (m^3) $\Delta h_c \times \rho_{O_2}$ = heat release per unit volume of oxygen consumed (kJ/m^3) $\dot{Q}$ = heat release rate from steady fire (kW) α = constant governing the speed of fire growth (kJ/sec^3)

6.2.2.2.1 Values of α for typical fire growths are as shown in Table 6.2.2.2.1.

6.2.2.2.2 The maximum heat release rate for the unsteady (t -square) fire can be estimated as follows in Equation 6.2.2.2.2, where t is the time, as determined from Equation 6.2.2.2b:

[6.2.2.2.2]

$$Q = \alpha t^2$$

6.2.2.2.3 The equations consider the energy associated with the mass (or volume) of oxygen consumed in the compartment, and the energy is divided by the anticipated heat release rate of the fire.

6.2.2.3 It can be estimated that the maximum volume of oxygen available to be consumed in the combustion process is approximately half of the total available oxygen, since flaming combustion usually is not sustained once oxygen concentrations fall to the range of 8 percent to 12 percent.

6.2.3 Temperature Rise in Compartment.

6.2.3.1 With the times of fire duration determined from Equations 6.2.2.2a and 6.2.2.2b, Equation 6.2.3.1, based on the compartment volume (containing air as an ideal gas at constant pressure with constant specific heat), can be used to estimate the temperature rise in the compartment and to determine whether temperature conditions are sufficient for flashover (Milke and Mowrer, 1993).

[6.2.3.1]

$$\Delta T = T_0 [\exp(Q_n / Q_0) - 1]$$

6.2.3.2 In Equation 6.2.3.1, Q_n is the net total heat released, which can be determined from Equation 6.2.3.2a or Equation 6.2.3.2b, depending on the type of fire, and Q_0 is the total ambient energy of air in the compartment, calculated using Equation 6.2.3.2c.

Table 6.2.2.2.1 Values of α

Speed of Fire	SI Units	U.S. Customary Units
Slow	$2.93 \times 10^{-3} \text{ kJ/sec}^3$	0.00278 Btu/sec ³
Medium	$11.72 \times 10^{-3} \text{ kJ/sec}^3$	0.01111 Btu/sec ³
Fast	$46.88 \times 10^{-3} \text{ kJ/sec}^3$	0.04444 Btu/sec ³

[6.2.3.2a]

$$Q_n = (1 - X_L) \dot{Q} (\Delta t) \quad (\text{steady fires})$$

[6.2.3.2b]

$$Q_n = (1 - X_L) \frac{\alpha t^3}{3} \quad [\text{unsteady } (t\text{-square}) \text{ fires}]$$

[6.2.3.2c]

$$Q_0 = \rho_0 c_p T_0 V$$

6.2.3.3 The terms used in Equations 6.2.3.1, 6.2.3.2a, 6.2.3.2b, and 6.2.3.2c are described as follows:

X_L = fraction of heat loss to compartment boundaries (typical range, 0.6 to 0.95)

$\dot{Q}$ = heat release rate of the fire (kW)

α = a constant governing the speed of fire growth (kJ/sec^3)

Δt = time period (sec)

ρ_0 = density of air (kg/m^3)

c_p = specific heat of air [$kJ/(kg \cdot K)$]

T_0 = initial air temperature (K)

V = volume of air in compartment (m^3)

6.2.4* Other than the method of analysis outlined using the equations in 6.2.2.2 through 6.2.3.3, there are computer-based models that can evaluate the oxygen depletion, ventilation, and heat transfer effects that impact the flashover potential in tightly closed compartments.

6.3 Venting and Exhaust of Hot Smoke Layer.

6.3.1 Smoke produced from a flaming fire in a space is assumed to be buoyant, rising in a plume above the fire and striking the ceiling or stratifying due to temperature inversion. The space can be expected to begin to fill with smoke, with the smoke layer interface descending. The descent rate of the smoke layer interface depends on the rate at which smoke is supplied to the smoke layer from the plume. This scenario assumes a two-zone model in which there is a distinct interface between the bottom of the smoke layer and the ambient air. For engineering purposes, the smoke supply rate from the plume can be estimated to be the air entrainment rate into the plume below the smoke layer interface.

6.3.2 The heat that is convected upward into the space or compartment results in an increase in temperature in the smoke layer in the space. The provision of vents or mechanical means of exhaust can serve to remove the hot gases from the rising fire plume, which increases the amount of air entrainment and promotes a lower smoke layer temperature. With appropriate consideration given to the amount of venting or exhaust and the expected fire size, the compartment smoke layer gas temperatures can be limited below the 600°C threshold indicator for flashover. Additional guidance and calculation methods can be found in NFPA 92 and NFPA 204.