

## NRC Publications Archive Archives des publications du CNRC

### Codes and standards

Lougheed, G. D.

For the publisher's version, please access the DOI link below. / Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

<https://doi.org/10.4224/20374922>

### NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=a604bdd0-27a7-4faf-ac8d-b8328ff74a4f>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=a604bdd0-27a7-4faf-ac8d-b8328ff74a4f>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

**Questions?** Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

**Vous avez des questions?** Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

Short Course  
Smoke Control and Smoke Management  
May 26 - 28, 2010  
Carleton University, Ottawa, Ontario

# Code and Standards

Gary Lougheed  
Fire Research Program  
National Research Council



**Industrial Research Chair in Fire Safety Engineering**  
Department of Civil and Environmental Engineering



# Outline

---

- Requirements North American Building Codes
  - National Building Code (NBC), 2005.
  - International Building Code (IBC), 2006.
- NFPA Standards
  - NFPA 92A – Standard for smoke-control systems utilizing barriers and pressure differences.
  - NFPA 92B – Standard for smoke management systems in malls, atria and large spaces.
  - NFPA 204 – Standard for smoke and heat venting.

# National Building Code

---

- Smoke control for high buildings
- Maintain tenable conditions for significant period of time during fire emergency
  - Occupied floor spaces
  - Exit Stairs
  - Elevators needed to transport firefighters or occupants needing assistance

# National Building Code

---

- Tenability criterion
  - Escape route or refuge area not to contain more than 1% per volume of smoke on the fire floor
  - Based on lower limiting level of visibility of 25 m (or smoke optical density/m of 0.043)

# National Building Code

---

- Provisions
  - Limiting smoke movement
  - Pressurization of stair shafts
  - Connected buildings
  - Mezzanines and openings through floor assemblies
  - Venting to aid firefighting

# National Building Code

---

- Vertical shafts principle passageway for smoke
- Protected exit route from exit stair to outdoors
- Vertical shafts from basement separated at or near ground floor
- Natural venting used to pressurize shaft and limit smoke migration

# National Building Code

---

- Stairways serving floors above lowest exit storey requires vent to exterior at or near the bottom of the stair shaft with an area of  $0.05 \text{ m}^2$  for every door between the stair shaft and the exterior and not less than  $1.8 \text{ m}^2$

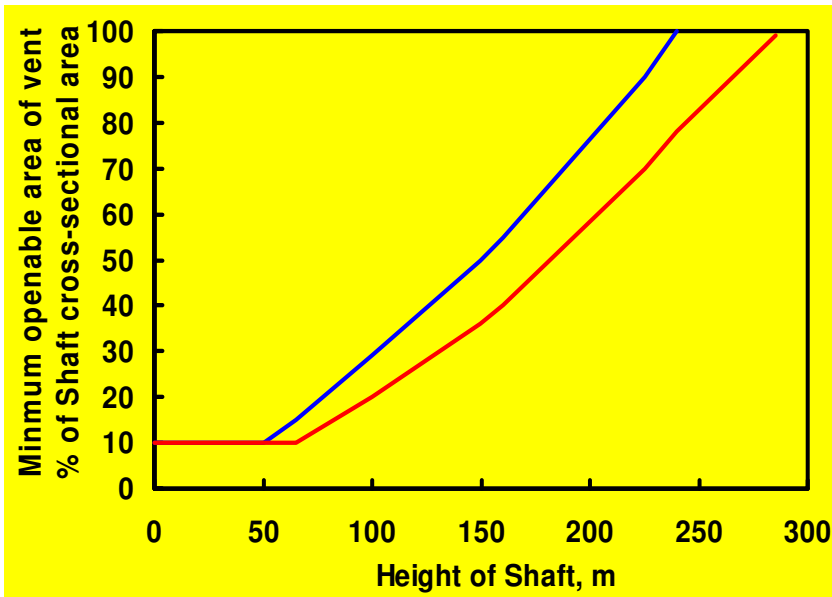


# National Building Code

---

- Stairways serving floors below lowest exit storey requires vent to exterior at or near the top of the stair shaft with an area of  $0.1 \text{ m}^2$  for each storey served by the stair shaft
- Must not contain more than 1% by volume of contaminated air from fire floor for a period of 2 h after the start of the fire
- Air flow at a rate of  $0.47 \text{ m}^3/\text{s}$  for each storey served by the stairway provided at or near bottom of the stair shaft

# National Building Code



- To limit smoke movement from a fire in floor area below the lower exit storey into upper storeys, a vertical shaft should have either:
  - Noncombustible seal or fire stop at floor assembly of the storey immediately below the lower exit storey or
  - Vent to the outdoors at the top with openable area that operates manually with area determined from the graph

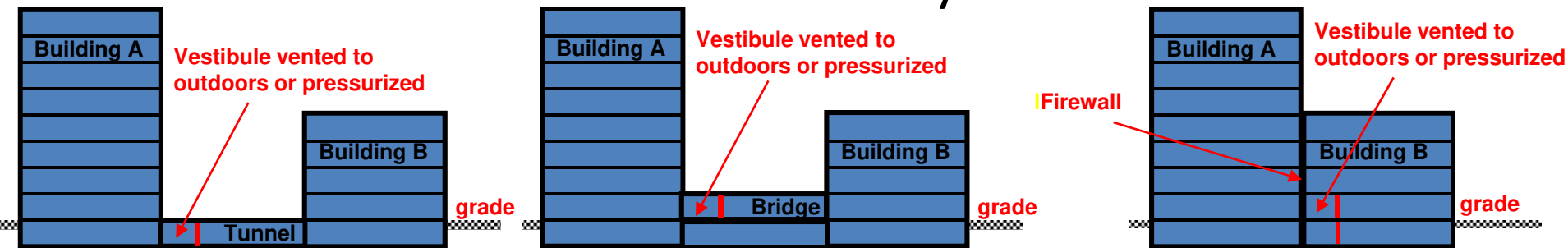
# National Building Code

---

- Stair shafts pressurized to maintain free from smoke
  - Open doors or vents at bottom of stair shaft, or
  - Mechanical methods (minimum pressure of 12 Pa recommended for sprinklered buildings)
- Number of open doors used by persons exiting varies depending on the occupancy, population density and evacuation plan. Assume two doors are open.
- The maximum pressure differential created by a mechanical system should not prevent doors to stair shafts from being opened. Maximum of 90 N is generally specified.

# National Building Code

- Two buildings of unequal height smoke can migrate due to stack effect
  - Vestibule vented to outdoors
    - Area  $10(0.023d + 0.00045a)$  m<sup>2</sup> where d is number of doors with perimeter < 6 m and a is area of enclosing walls (m<sup>2</sup>)
  - Pressurize with mechanical system 12 Pa

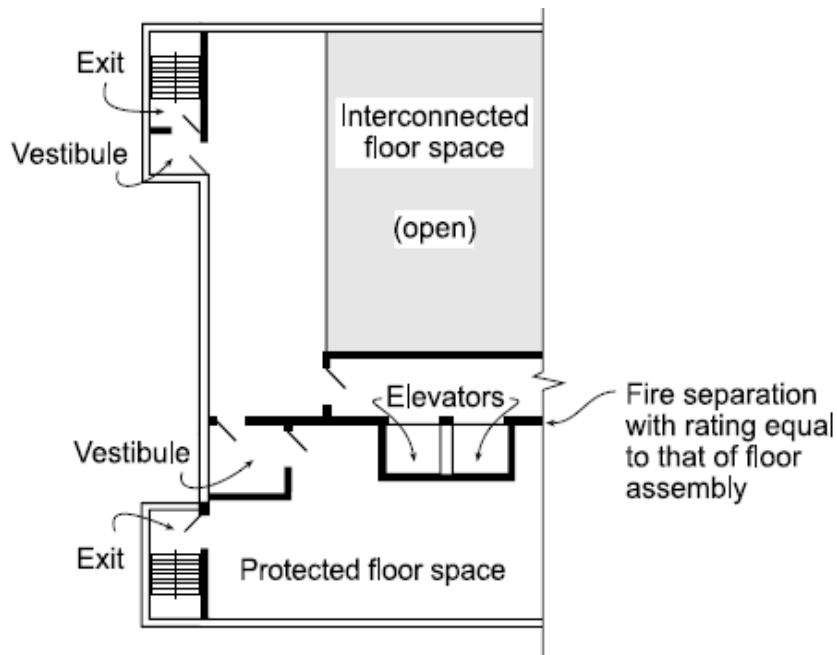


# National Building Code

---

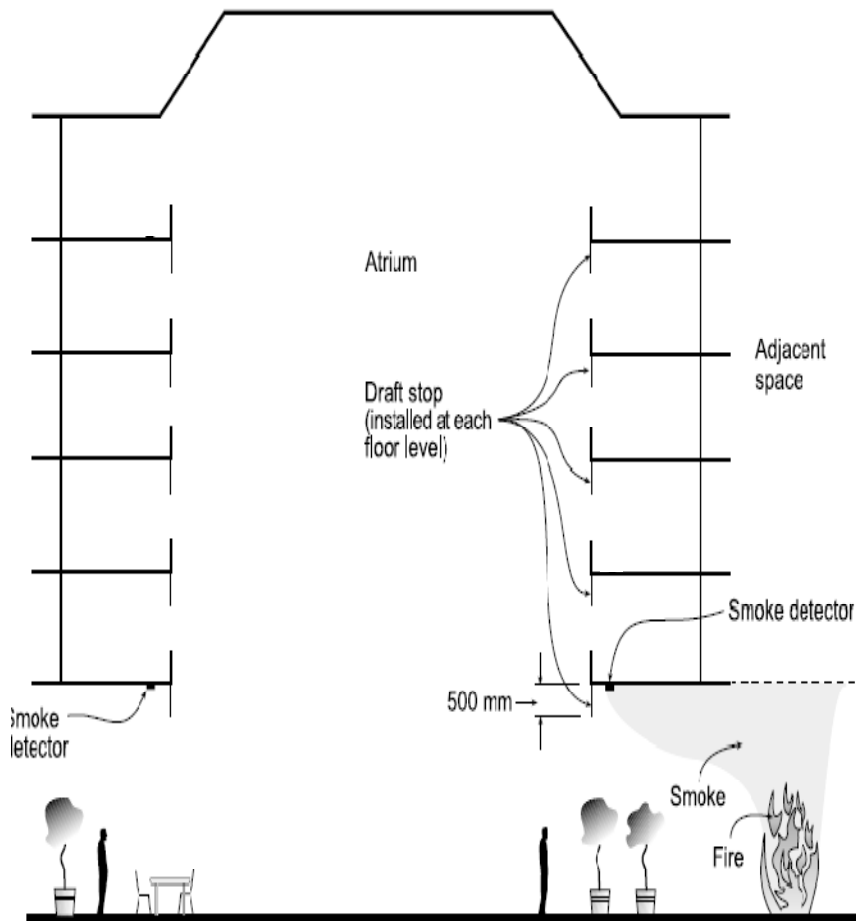
- Mezzanines and openings through floor assemblies
  - Buildings with interconnected floor spaces sprinklered throughout
  - Combustible contents, excluding interior finishes, in floor areas with ceiling height  $> 8$  m limited to 16 g for each cubic meter volume of interconnected floor space
  - Mechanical exhaust system provided to remove air from interconnected floor space at a rate of 4 ACH – operated by fire fighters for smoke removal

# National Building Code



- Mezzanines and openings through floor assemblies
  - Protected floor spaces at each floor with no less than 0.5 m<sup>2</sup> for each occupant on that floor
  - Exits opening into an interconnected floor space protected at each opening by vestibule designed to limit passage of smoke into exit stair shaft to 1% by volume of smoke from the fire

# National Building Code



- Mezzanines and openings through floor assemblies
  - A draft stop not less than 500 mm deep provided at each floor level

# National Building Code

---

- Venting to aid firefighters
  - Windows and wall panels
    - Uniformly distributed along walls of each storey with a total area not  $< 1\%$  of exterior wall area of each storey
    - Openable from interior and identifiable from outside
    - When opened, persons outside building not endangered



# National Building Code

---

- Venting to aid firefighters
  - Shafts or vertical spaces
    - Openings into each storey
    - Unobstructed cross-sectional area
    - Separated from rest of building by fire-rated assembly
    - Opening to outdoors at top
    - Terminate at not < 900 mm above the roof surface
    - Contain no combustible materials or fuel lines
    - Open automatically to only fire floor
  - Building exhaust system
    - May be used if able to maintain exhaust to outdoors at rate of 6 ACH from any floor

# International Building Code

---

- Where smoke control required.
  - Underground buildings – smoke control and smoke-proof enclosures depending depth below grade
  - Hospitals and detention facilities – passive smoke barriers
  - Windowless detention facilities- engineered natural or mechanical smoke control system
  - Warehouse buildings – smoke and heat venting

# International Building Code

---

- Where smoke control required (cont'd).
  - Legitimate stages – proscenium curtain to separate stage from crowd and stage ventilation using automatically opening vents or smoke control system
  - High-rise buildings – smoke proof exit enclosures to maintain tenable conditions
  - Atrium – smoke control required within atrium spaces connecting more than 2 stories

# International Building Code

---

- Section 909
  - Provide tenable environment for the evacuation and relocation of building occupants
- Rational analysis required for each smoke control system
  - Support system used
  - Analysis must include impact of stack effect, temperature of the fire, wind effect, HVAC system, climate, duration of operation and other items specific to the building

# International Building Code

---

- Duration of Operation
  - All portions of passive or active systems must operate for not less than 20 min after detection, or
  - 1.5 times the calculated egress time, whichever is less.

# International Building Code

---

- Smokeproof enclosures for exits
  - Exits of buildings serve floors 22.86 m above lowest level of firefighter access or 9.14 m below the level of exit discharge
  - Interior stairway protected by a 2 hour rated assembly and entered through a vestibule or an open exterior balcony,
  - Require door closures on doors or natural/mechanical ventilation of the stair shaft or vestibule

# International Building Code

---

- Smokeproof enclosures for exits (cont'd)
  - For buildings equipped throughout with sprinklers, vestibule not required if interior exit stairways pressurized to a minimum of 37 Pa and maximum of 87 Pa relative to the building with all doors closed under maximum stack pressure.

# International Building Code

---

- Limiting smoke flow from fire area
  - Passive or active smoke control systems can be used to contain smoke in area of fire origin
  - Mechanical systems used for sprinklered buildings designed to provide a minimum of 12.4 Pa pressure difference
  - Maximum pressure difference determined by door opening and closing forces



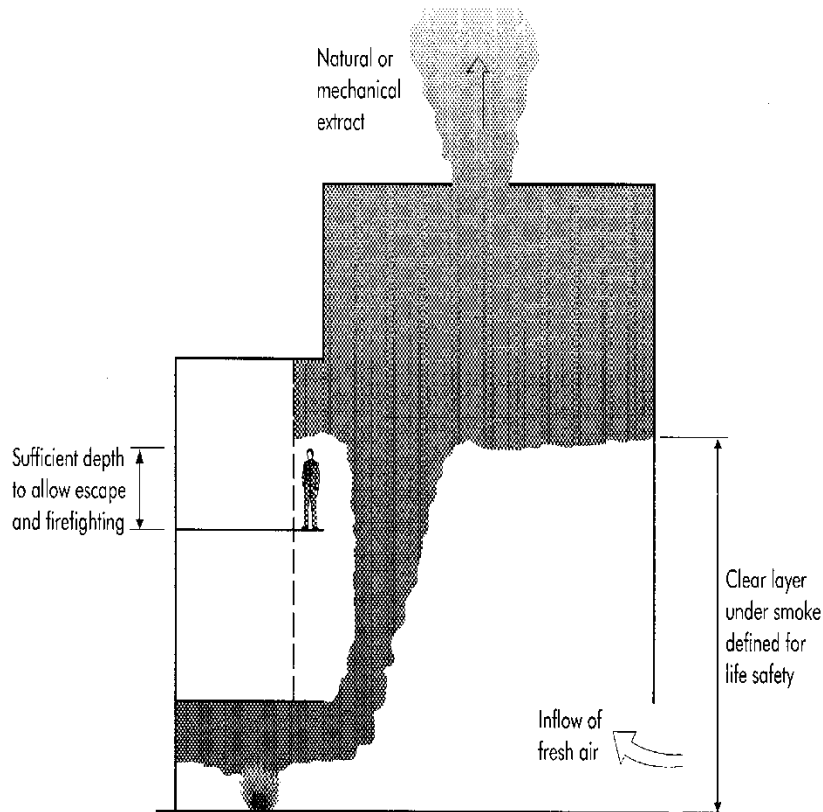
# International Building Code

---

- Atrium requirements
  - Smoke exhaust used to allow safe egress from upper levels of large open spaces
  - With 2006 edition, system designed in accordance with NFPA 92 B 2005.
  - Prior to 2006 required 5 MW design fire unless engineering analysis conducted to demonstrate smaller design fire appropriate.
  - With 2006 edition, design fire size to be determined as part of engineering analysis.

# International Building Code

---



- Atrium requirements
  - Prior to 2006 edition, atrium exhaust systems required to maintain smoke layer height 3 m above highest egress walkway.
  - Some buildings ceiling height < 3 m.
  - 2009 Edition, the required height is 1.8 m.

# International Building Code

---

- 2009 Edition
  - A third (redundant) stairway added for buildings over 128 m in height. Stairway cannot be used to accommodate occupant load.
  - Provisions for using elevators for evacuation. For buildings over 128 m, evacuation elevators can be used in lieu of third stairway.
  - All high-rise buildings require smoke removal system using either natural or mechanical venting.

# NFPA Standards

---

- NFPA Smoke Control Standards
  - Provide the requirements for system design, equipment and controls and testing.
  - Presently 3 standards: 92A, 92B and 204.
  - With the next edition published in 2011, NFPA 92A and 92B will be combined into a single document covering smoke control systems using mechanical systems.

# NFPA Standards

---

- NFPA 92A 2009
  - Provides the requirements for dedicated and non-dedicated smoke control systems using pressure differences to inhibit smoke movement.
    - Dedicated systems use separate hardware
    - Non-dedicated systems use building HVAC system.
  - Includes zoned smoke control, stairwell and elevator pressurization systems, pressurized vestibules and areas of refuge.

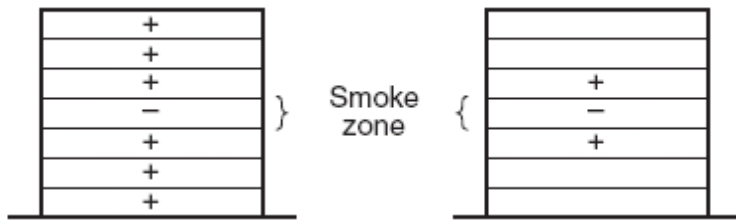
# NFPA Standards

---

- NFPA 92A 2009
  - Pressure differences across barriers.
    - Inhibit smoke from entering means of egress, stairwells, elevator shafts , areas of refuge.
    - Maintain tenable environment in means of egress or refuge areas.
    - Inhibit smoke migration from smoke zone.
    - Provide conditions outside smoke zone the enable emergency response personnel to conduct search and rescue operations and locate and control the fire.
    - Contribute to life safety and property protection.

# NFPA Standards

---



## NFPA 92A 2009

- Pressure differences across barriers.
  - Minimum pressure for sprinklered building 12.5 Pa
  - Minimum pressure difference for non-sprinklered building 25 to 45 Pa depending on the ceiling height.
  - Maximum pressure difference must not cause the maximum force permitted by codes to begin opening a door to be exceeded.

# NFPA Standards

---

- NFPA 92A 2009
  - Equipment and controls.
    - Typically use HVAC systems.
    - Outside air used for pressurization.
    - Automatic activation within 10 s after command received from control panel.
    - Firefighters' smoke control station provided and should include status indication, fault indication and manual control.
    - Smoke detector located in supply duct.
    - Equipment suitable for application.



# NFPA Standards

---

- NFPA 92A 2009

- Testing.

- Tested against specific design objectives.
    - Test complete smoke control sequence: normal mode, automatic smoke control, manual override and return to normal.
    - Pressure differences measured under design conditions.
    - Door opening forces measured under design conditions.
    - If more than one smoke control system installed, systems tested in combination.
    - Periodic testing – dedicated semi-annually, nondedicated annually.

# NFPA Standards

---

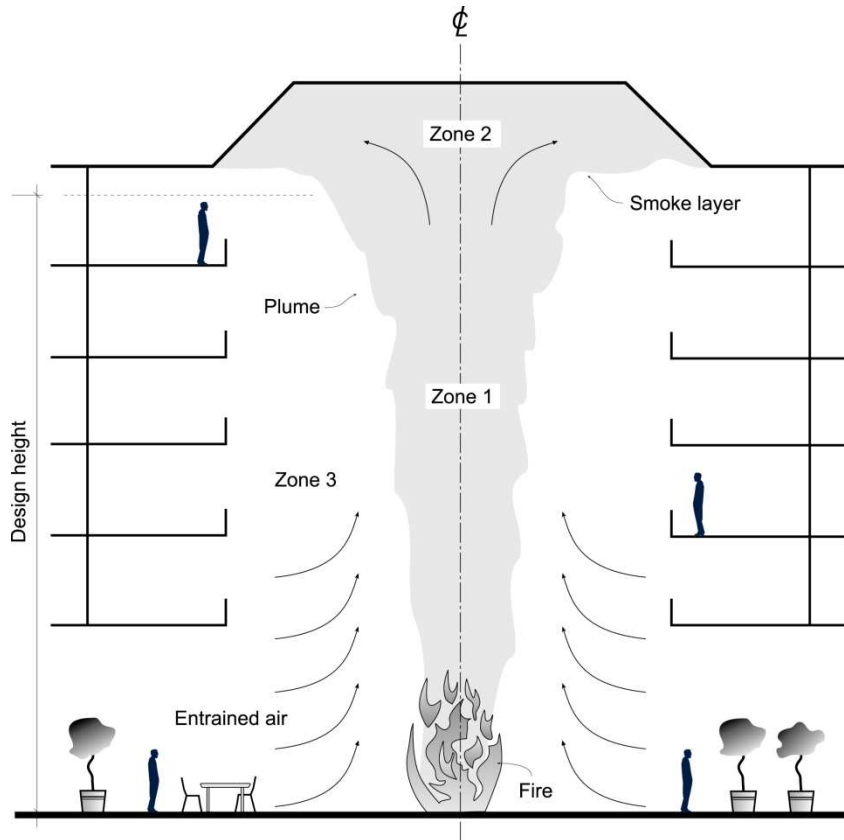
- NFPA 92B 2009
  - Provides the requirements for implementing smoke management systems in large volume spaces – atrium, malls, arenas, stadium, etc.
  - Maintain tenable environment in the means of egress from the large volume space.
  - Maintain smoke layer interface to a predetermined elevation.
  - Control and reduce migration of smoke between the fire area and adjacent areas.
  - Includes algebraic equations for use in estimating smoke production and determining fan capacity required to meet design objective.

# NFPA Standards

- NFPA 92B 2009

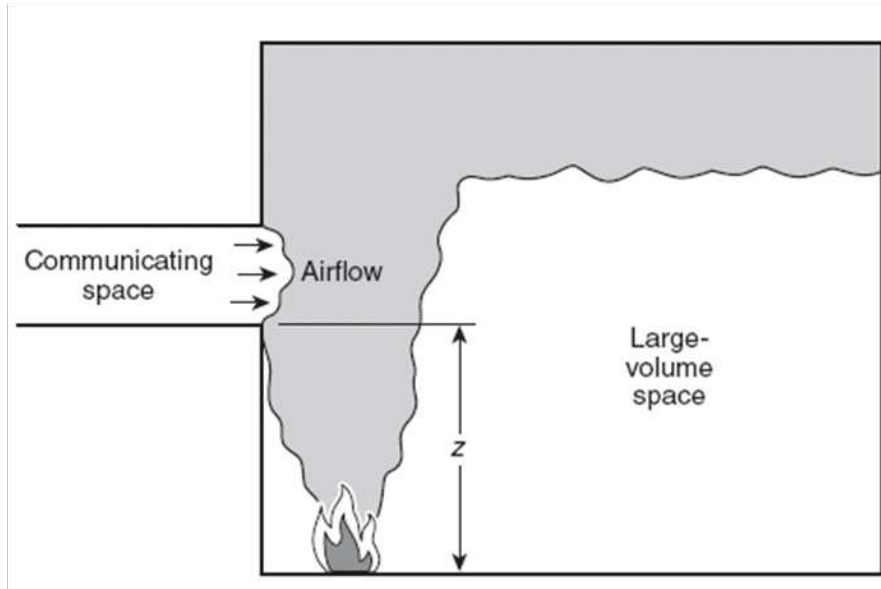
- Design basis parameters.

- Design fire size and location(s).
    - Height, cross-sectional area of large volume space.
    - Height, cross-sectional area of each unseparated adjacent space.
    - Type and location of occupancies adjacent to large volume space.
    - Barriers separating adjacent space from large volume space.
    - Egress routes from large volume space.
    - Areas of refuge, if any.



# NFPA Standards

---



- NFPA 92B 2009
  - Design approaches.
    - Smoke-filling.
    - Mechanical smoke exhaust to maintain layer above a design height.
    - Mechanical smoke exhaust to delay smoke layer descent.
    - Natural smoke venting.
    - Opposed airflow.

# NFPA Standards

---

- NFPA 92B 2009
  - Design limitations
    - Minimum design smoke layer depth 20% of atrium height or engineering analysis.
    - Automatic operation.
    - Reach full operation prior to conditions in space reaching design smoke conditions.
    - Remain operational for the duration required.

# NFPA Standards

---

- NFPA 92B 2009
  - Design tools
    - Algebraic equations.
    - Zone models.
    - Physical models.
    - CFD models.

# NFPA Standards

---

- NFPA 92B 2009
  - Algebraic equations.
    - Smoke filling with fire in atrium space.
      - Location of first indication of smoke.
      - Steady fire.
      - Unsteady (t-squared) fire.
    - Smoke production.
      - Fire on floor of atrium – axisymmetric plume.
      - Balcony spill plumes.
        - » Fire in compartment adjacent to atrium.
      - Window plume.
        - » Ventilation limited fire in adjacent space.

# NFPA Standards

---

- NFPA 92B 2009
  - Opposed airflow.
    - Airflow used to minimize smoke movement between adjacent spaces.
      - Limit migration of smoke produced in adjacent space into atrium.
      - Limit migration of smoke in plume from entering adjacent space.
      - Limit migration of smoke in smoke layer from entering adjacent space.
    - For airflow into atrium, airflow velocity  $< 1$  m/s to ensure smoke plume or smoke layer not disrupted.



# NFPA Standards

---

- NFPA 92A 2009
  - Testing.
    - Tested against specific design objectives.
    - Where appropriate to the design, measure
      - Total volumetric flow rate.
      - Airflow velocities.
      - Airflow direction.
      - Door-opening forces.
      - Pressure differences.
      - Ambient conditions – indoor and outdoor temperatures, wind conditions.
  - Periodic testing of all systems.

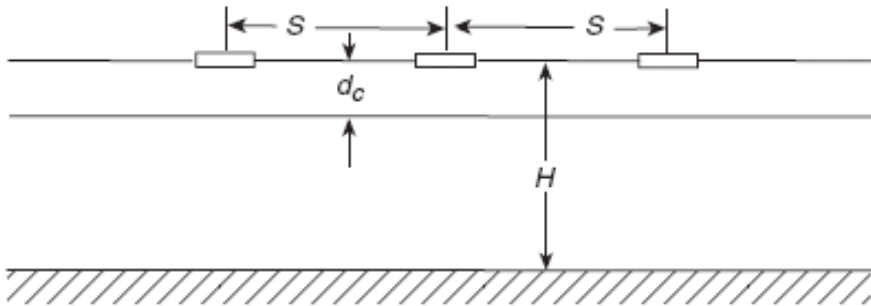
# NFPA Standards

---

- NFPA 92A 2009
  - Other considerations.
    - Smoke detection and potential for smoke stratification.
    - Plugholing.
      - Limit effectiveness of system.
      - Discussed in later presentation.
    - Make-up air.
      - Provide make-up air using openings or mechanical system.
      - Airflow velocity limited to 1 m/s at plume.

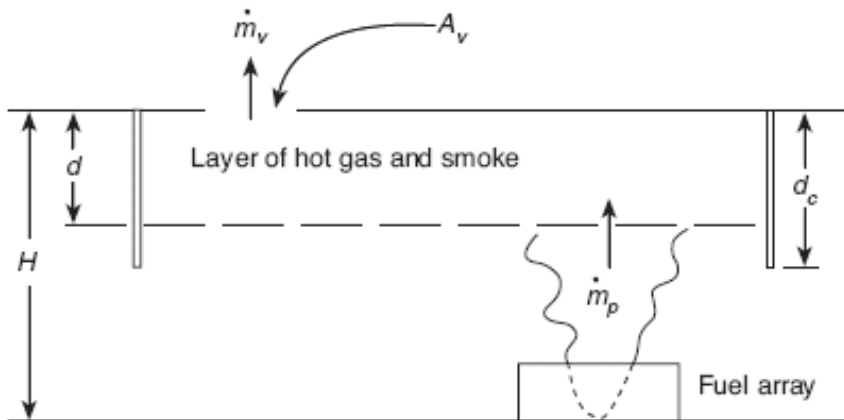
# NFPA Standards

---



- NFPA 204 2007
  - Provides the requirements for smoke and heat venting from buildings using natural/gravity venting.
  - Typical application is warehouses to limit damage to stored materials.

# NFPA Standards



- NFPA 204 2007
  - Design basis parameters.
    - Layout of curtained areas.
    - Draft curtain depth.
    - Type of detection.
    - Design interval time for maintaining a clear height.
    - Vent area per curtained area.
    - Distribution of vents.
    - Air inlet area.

# NFPA Standards

---

- NFPA 204 2007

- Vents.

- Thermoplastic drop-out panels.
    - Automatic opening panels activated by fusible links, smoke detection, sprinkler water flow, etc.
    - Designed to open by manual means.
    - Vents other than drop-out panels fail in open position.
    - Area of vent  $< 2d^2$  where  $d$  is the design depth of smoke layer.
    - Total area meet design requirement.

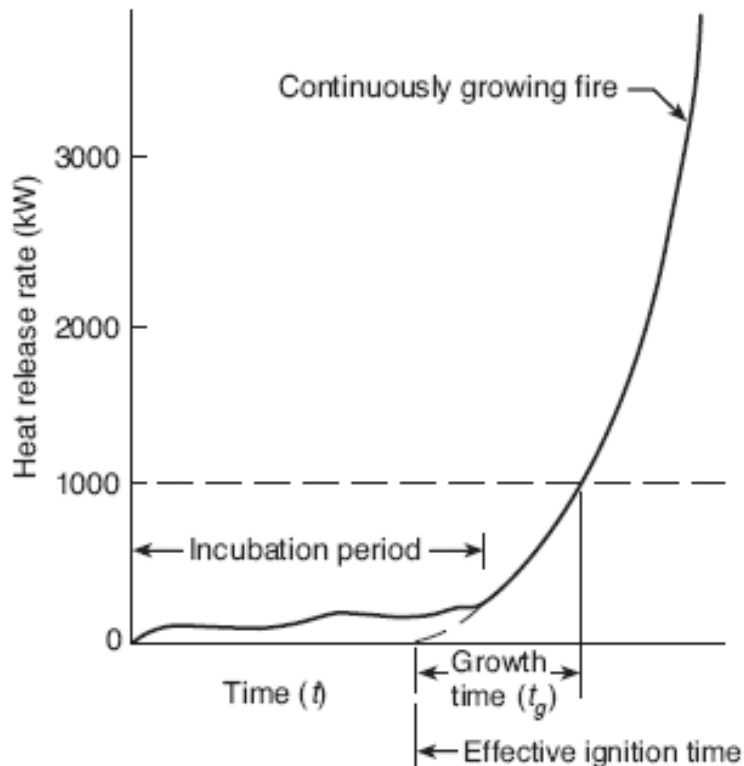
# NFPA Standards

---

- NFPA 204 2007
  - Draft curtains.
    - Non-combustible material.
    - Ensure activation of vents.
    - Increase vent effectiveness by increasing smoke layer depth.
    - Confine smoke for design duration.
    - Length or width of curtained area cannot be  $> 8$  times the height of the space.

# NFPA Standards

- NFPA 204 2007



## Design Fire.

- Steady fires in buildings with concentrated combustibles.
- Growing fires based on test data or t-squared fire growth.
- Fire continues to grow over design interval.

Vents sized to maintain smoke layer interface boundary above design height for the design time interval.

Design time interval selected depending on the design objective.

# NFPA Standards

---

- NFPA 204 2007
  - Sizing Vents.
  - Use algebraic equations, zone models (Lavent) or CFD models.
  - Smoke production.
    - Axisymmetric plume equation.
    - Includes virtual origin.
  - Equation for mass flow rate through vent.
    - Vent area, smoke layer depth, smoke layer temperature



# NFPA Standards

---

- NFPA 204 2007
  - Detection.
    - Heat or smoke at the vent location.
    - Activation of fire protection system.
    - Heat or smoke detectors.
  - Sprinklered buildings
    - 2007 – Design based on performance analysis.
    - 2010 – Provides guidance for combined smoke and heat venting in buildings with control mode sprinklers.
    - Vents not to open until after first two rings of sprinklers activate.
    - All vents in design area open automatically.

# Summary

---

- Requirements North American Building Codes
  - National Building Code (NBC), 2005.
  - International Building Code (IBC), 2006.
- NFPA Standards
  - NFPA 92A – Standard for smoke-control systems utilizing barriers and pressure differences.
  - NFPA 92B – Standard for smoke management systems in malls, atria and large spaces.
  - NFPA 204 – Standard for smoke and heat venting.