SMOKE CONTROL OVERVIEW
NFPA 92
A Webinar

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SEMINAR GOALS

• Provide an overview of smoke control/NFPA 92
  - Evolution of smoke control
  - Design fundamentals
  - Calculation procedures
  - Building equipment and controls
  - Documentation
  - Testing

CHAPTER 1 – ADMINISTRATION

• Number of large loss fires occurred where smoke was deemed a contribution factor
• Alternatives to fire walls/barriers were sought
• Illinois Institute of Technology research
• NFPA 204M, Guide for Smoke and Heat Venting, adopted in 1961

SMOKE CONTROL HISTORY

SMOKE CONTROL HISTORY 1961-1981


SMOKE CONTROL HISTORY 1982-2006


1983
NFPA 92 Scope and Purpose

NFPA 92A vs NFPA 92B.
What does NFPA 92 cover?
What does it not cover?

Example system types covered
- Smoke management systems (atrium/mall)
- Stair pressurization
- Elevator pressurization
- Zoned smoke control
- Atrium smoke management

Chapter 3 - Definitions

• 1994 Uniform Building Code – contained analytical methods that were based on criteria in NFPA 92A
• 2000 – 2012 International Building Code requires smoke control for:
  - Smoke protected assembly seating
  - Atriums over certain height
  - Underground or windowless buildings
  - Proscenium openings
  - Smokeproof enclosures (stairs, elevators)
• Not required for high-rise buildings
  - “Post-fire” clean up applications

SMOKE CONTROL IN THE CODES

• NFPA 101, Life Safety Code® requirements
  - Smokeproof enclosures (high rises)
    - Vented vestibules
    - Pressurized stair
  - Detention and correctional
  - Covered malls (over two levels)
  - Atrium (over three levels)

CHAPTER 4 – DESIGN FUNDAMENTALS

Goal

Objectives [4.1.2]

Smoke Containment

Methods [4.1.1]

Approaches [4.3]

Design Fundamentals
SMOKE CONTAINMENT – ZONED PRESSURIZATION (4.8)

- Variety of possible design configurations
- Each floor can be a smoke control zone (a and b), or a smoke zone can consist of multiple floors (c and d).
- A smoke zone can also be limited to a portion of a floor (e).
- Parts a, c, and e show all non-smoke zones in the building being pressurized during a fire.
  - This requires large amounts of outside air which may need to be pre-heated in cold climates to prevent damage to building systems.

STAIRWELL PRESSURIZATION – MULTIPLE POINT INJECTION

Fan Types Permitted:
1) Centrifugal fans
2) In-line axial fans

- Injection points and fans can be located at any level.
- The more vertical space between injection points, the harder it is to balance.
- Duct can be located in stair instead of separate shaft.
- Supply air intake required to be separated from all building exhausts, outlets from shafts, vents, etc. (4.6.2)

STAIRWELL PRESSURIZATION – NONCOMPENSATED SYSTEMS

- Does not compensate for changes in pressure differentials or door status
- Single speed fan(s)
- Constant volumetric flow rate
- Pressurization level varies based on how many doors are open or closed
  - Example: Low occupant load buildings such as luxury apartment buildings

STAIRWELL PRESSURIZATION – COMPENSATED SYSTEMS

- Compensates for varying pressure differentials and door statuses and maintains constant pressure differences across openings
- Two Options:
  1. Modulate supply airflow (variable speed fans)
  2. Overpressure relief (dampers, bypass, etc.)

STAIRWELL PRESSURIZATION – COMPENSATED SYSTEMS – OVERPRESSURE RELIEF – BAROMETRIC DAMPERS

- Simplest, least expensive method
- Use adjustable counterweights
- Prone to “chatter” and weather infiltration
- Should not be placed close to supply openings
SMOKE CONTAINMENT DESIGN CRITERIA – PRESSURE DIFFERENCES [4.4.2.1]

<table>
<thead>
<tr>
<th>Design Approach</th>
<th>Reference Section</th>
<th>Notes</th>
</tr>
</thead>
</table>
| Stair Pressurization| 4.6.1             | 1. All doors closed  
2. Design # of doors open |
| Elevator Pressurization| 4.7             | Elevator at recall floor with all elevator doors and hoistway vents open |
| Zoned Pressurization| 4.8.1.2           |                                                                      |
| Ventilator Pressurization| Not specified |                                                                      |
| Refuge Area Pressurization| Not specified |                                                                      |

Table 4.4.2.1.1 Minimum Design Pressure Difference Across Stair/Barrier

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Stair Height (ft)</th>
<th>Design Pressure Difference (in. w.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1</td>
<td>0.15</td>
</tr>
<tr>
<td>N</td>
<td>2</td>
<td>0.14</td>
</tr>
<tr>
<td>XS</td>
<td>2</td>
<td>0.14</td>
</tr>
</tbody>
</table>

1) Minimum = Table 4.4.2.1.1
2) Minimum = determined by designer based on stack effect, buoyancy, etc.
3) Maximum = door opening force
4) Max. pressure differential requirements apply for all smoke control system designs, not just those which utilize the smoke containment approach.

SMOKE MANAGEMENT DESIGN APPROACHES [4.3.2]

1. Natural smoke filling
2. Mechanical smoke exhaust or gravity (natural) venting to maintain smoke layer interface at a predetermined height
3. Mechanical smoke exhaust or gravity (natural) venting to control rate of smoke descent
4. Opposed airflow

Smoke management example: Atrium
**NFPA 92 - Smoke Control System Overview**

**SMOKE MANAGEMENT - MECHANICAL EXHAUST**

- Design objectives of 4.3.2 are generally evaluated by comparing the calculated ASET to RSET.
- Tenability criteria and egress calculations are outside the scope of NFPA 92 (tenability may be added during next code change cycle).
- Tenability criteria are determined by the designer.
- SFPE Handbook of Fire Protection Engineering is a common resource for guidance.
- Visibility criteria usually met first.
- Some codes contain specific requirements regarding design objectives.

**SMOKE MANAGEMENT DESIGN CRITERIA - TENABILITY VS. EGRESS**

- ASET
- RSET
- For example, the 2012 IBC requires that the smoke layer height be maintained 6 ft above highest walking surface.
- NFPA 92 permits exposure to smoke as long as tenability is maintained (see 4.5.1.1).

**SMOKE MANAGEMENT DESIGN REQUIREMENTS - MAKEUP AIR [4.4.4.1]**

- Makeup air must be supplied below smoke layer interface (prevents mixing and the unwanted addition of mass to the smoke layer) [4.4.4.1.1].
- Maximum makeup air velocity limited to 200 ft/min near the plume, unless a higher velocity is supported by an engineering analysis (prevents plume deflection and unwarranted addition of mass to the plume).

**SMOKE MANAGEMENT DESIGN REQUIREMENTS - COMMUNICATING SPACES [4.4.4.2]**

- Communicating spaces include areas directly open to the large-volume space being protected or areas with open passageways which connect the area to the large-volume space being protected.
- Smoke spread into the communicating space must be managed by one of the following three methods:
  1. Maintain smoke layer interface above the opening to the communicating space.
  2. Provide opposed airflow.
  3. Provide a smoke barrier to limit the spread of smoke.
- This means the scenarios within the communicating space must be considered (4.4.4.2.2.1).
- These scenarios often involve balcony spill plumes which can lead to increases in the minimum exhaust rate necessary to protect the large-volume space.
SMOKE MANAGEMENT DESIGN REQUIREMENTS – MINIMUM SMOKE LAYER DEPTH [4.5.1.3]

25% of floor-to-ceiling height

OR

Based on an engineering analysis

SMOKE CONTROL DESIGN REQUIREMENTS – DOOR OPENING FORCES [A.4.4.2.2]

Where:

\[ F = \text{total door-opening force, lb (N)} \]
\[ F_r = \text{force to overcome the door closer and other friction, lb (N)} \]
\[ W = \text{door width, ft (m)} \]
\[ A = \text{door area, ft}^2 \text{ (m}^2) \]
\[ \Delta P = \text{pressure difference across the door, in. w.g. (Pa)} \]
\[ d = \text{distance from the doorknob to the knob side of the door (ft)} \]

SMOKE CONTROL DESIGN REQUIREMENTS – DOOR OPENING FORCES [A.4.4.2.2]

- Min. pressure differential should be in accordance with Table 4.4.2.1.1 [4.7]
- Max. is not specified in NFPA 92, but the intent is to prevent the doors from jamming shut
- Research by John Klote has shown that only a modest force is necessary to open these doors under pressure
- The 2012 IBC specifies a max pressure differential of 0.25 in. w.g. (62.2 Pa)

SMOKE CONTROL DESIGN REQUIREMENTS – ELEVATOR DOOR OPENING FORCES [4.7]

SUMMARY OF REQUIREMENTS FOR PRESSURE DIFFERENTIALS

SMOKE CONTROL DESIGN – OTHER REQUIREMENTS/CONSIDERATIONS

- Activation
  - 4.5.2 says must be by approved means
  - 2012 IBC requires that all mechanical smoke control systems be activated automatically by sprinkler activation or any required detectors
  - IBC also requires means for manual activation accessible to fire department
- System startup [4.5.3]
  - Detection + signal processing + signal transmission + equipment lag, etc.

Table 1: NFPA 92 versus IBC

<table>
<thead>
<tr>
<th>Year</th>
<th>2012 IBC</th>
<th>2012 NFPA 92</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pressurization &amp; Min</td>
<td>0.10</td>
<td>0.05</td>
<td>All doors dead</td>
</tr>
<tr>
<td>Min</td>
<td>0.10</td>
<td>0.05</td>
<td>Dead-locked doors</td>
</tr>
<tr>
<td>Effective tunnel pressurization &amp; Min</td>
<td>0.25</td>
<td>0.05</td>
<td>All doors open</td>
</tr>
<tr>
<td>Min</td>
<td>0.25</td>
<td>0.05</td>
<td>Dead-locked doors</td>
</tr>
</tbody>
</table>

Note 1: In the comparison of NFPA 92 and IBC, the required minimum and maximum design pressure difference criteria for stair and elevator tunnels/passage systems is noted. Note that all quantities are provided in units of in. w.g.
SMOKE CONTROL DESIGN – OTHER CONSIDERATIONS [4.4]

- Wind
- Stack effect
- Buoyancy
- Open doors
- Interactions between various systems
- Stratification

SMOKE MANAGEMENT CALCULATION METHODS [5.1]

- Note that this chapter covers smoke management system calculation procedures rather than smoke containment system calculations, which are often calculated by using other algebraic equations and network models (such as CONTAM)
- Section 5.1 lists three (3) design analysis methods:
  1. Algebraic Equations (see remainder of Ch. 5)
  2. Scale Modeling (not very common)
  3. Compartment Fire Models (see Annex C)
     1. Zone models (CFAST, etc.)
     2. Computational fluid dynamics models (FD5, etc.)

ZONE FIRE MODEL

DESIGN FIRES [5.2]

- Selection of design fires that are representative of the building hazards is the responsibility of the designer and subject to approval by the AHJ
- NFPA 92 does not specify design fires, rather it provides guidance
- During the empirical derivation of the equations in Chapter 5, a variation of about 20% in the plume entrainment was witnessed; therefore NFPA 92 recommends that an “appropriate” safety factor be added to calculated exhaust capacities to account for uncertainty [A.5.1]
- Annex B contains information and guidance regarding the calculation of heat release rate (HRR) per Section 5.2 – the most important variable in the algebraic calculations of Chapter 5
- Section 5.2.2 states that design fires shall be one of the following:
  1. Steady fire with a constant HRR
  2. Unsteady fire with HRR which varies with time
DESIGN FIRES [5.2]

- If a steady design fire is used, the HRR must be based on test data [5.2.3.1]
- Unsteady fires are more common
  - Growth phase is followed by decay phase or steady phase
  - Growth phase can be based on test data or t-squared growth model [5.2.4.1]
  - HRR is permitted to be "capped" at a steady HRR based on test data or "an engineering analysis of fire growth and sprinkler response" [5.2.4.3]
- This is where FDS and DETACT come in

CALCULATIONS - TIPS

- Keep in mind:
  - Equations are provided in English and S.I. units and for unsteady and steady fires
  - The equations can be solved for a number of different variables as desired
  - Must always be aware of assumptions for certain equations
  - Annex K contains example problems illustrating the use of certain equations
  - Exhaust system design revolves around maintaining a balance between the exhaust rate and smoke production rate

CALCULATIONS - SUMMARY

- Section 5.4 – Smoke Layer Calculation
  - Generally used to calculate amount of time for smoke layer depth to descend to a specified height
- Section 5.5 - Rate of Smoke Mass Production
  - Calculations for three types of plumes, each with very different mass entrainment rates and mass flow rates into the smoke layer
    1. Axisymmetric [5.5.1]
    2. Balcony spill [5.5.2]
    3. Window [5.5.3]
- Section 5.6 – Number of Exhaust Inlets
  - Used to calculate the maximum volumetric flow rate per exhaust point without plugholing, which is largely based on the smoke layer depth
- Section 5.7 – Volumetric Flow Rate
  - Used to calculate total required smoke exhaust rate
  - Number of exhaust points required is then calculated using the total required exhaust rate calculated previously

BUILDING EQUIPMENT AND CONTROLS

1. HVAC Equipment
2. Smoke Dampers
   - ANSI/UL 555S, Standard for Smoke Dampers
3. Smoke Control Systems
   - ANSI/UL 864 Standard for Control Units and Accessories for Fire Alarm Systems
   - Category UUKL
4. Materials
   - NFPA 90A
5. Electric Services Installation
   - NFPA 70
CONTROLS FOR STAIRWELL PRESSURIZATION

- Automatic Activation - Operation of any zone of the fire alarm system must cause all stairwell pressurization fans to start, unless an engineering analysis determines that activation of all fans is not necessary.
- Smoke Detection - A smoke detector must be provided in the stair pressurization supply ductwork, and if it senses smoke it must shut down the stairwell pressurization fan.
- Manual Pull Stations - if the system response is identical for all fire alarm zones, then activation via manual pull station is permitted

CONTROLS FOR ZONED SMOKE CONTROL

- Automatic Activation
  - Where smoke detectors, heat detectors, or airflow switches used to activate zoned smoke control, fire alarm zone must coincide with smoke control zone
  - Where smoke detection used, must detect smoke before it leaves smoke zone
- Zoned smoke control shall not be activated from manual fire alarm pull stations

SMOKE CONTROL SYSTEM MANUAL ACTIVATION

- Manual activation only where approved by Authority Having Jurisdiction

CONTROL SYSTEM VERIFICATION

- Means of verifying correct operation must be provided
- Positive confirmation of:
  - Activation
  - Testing
  - Manual Override
  - Power

RESPONSE TIME

- Smoke Containment Systems
  - Fan operation: 60 seconds
  - Completion of damper travel: 75 seconds
- Smoke Management Systems
  - Full operational mode shall be achieved before conditions exceed design smoke conditions

FSCS REQUIREMENTS

- Must be provided for all smoke control systems, at a location acceptable to the Authority Having Jurisdiction
- Must provide logically arranged and labeled status indication, fault conditions, and manual control of all system components
- Operator controls, status indication, and fault indication must be provided for each smoke control zone, each piece of equipment capable of activation for smoke control
- Positive status indication must be provided individually or by zone
- Oh status must be sensed by pressure difference, airflow switch, or other positive proof of airflow
- Diagrams and graphic representations of the system must be used
- FSCS control mode must take priority over manual controls located elsewhere in building
**Chapter 7 - Documentation**

**Detailed Design Report**

1. System Purpose
2. Design objectives
3. Design approach
4. Design assumptions
5. Location of smoke zone(s)
6. Design pressure differences
7. Building use limitations
8. Design calculations
9. Fan and duct specifications
10. Damper specifications
11. Detailed inlet or exhaust inlets site info
12. Detailed method of activation
13. Smoke control system operation logic
14. System commissioning procedures

**Operations and Maintenance Manual**

1. Commissioning procedures and performance
2. Testing and inspection requirements
3. Critical design assumptions and building use limitations
4. Special equipment maintenance requirements
5. Purpose of smoke control system

**Operations and Maintenance Who is Responsible?**

Per NFPA 92, the building owner is responsible for ensuring the systems are tested and maintained in accordance with the O&M Manual, and for keeping records of all testing and maintenance.
CH 8 - TESTING

• Three types of tests
  - Component testing (8.3)
  - Acceptance testing (8.4)
  - Periodic testing (8.6)
• NFPA 3 and NFPA 4
  - Commissioning Life Safety Systems
  - Integrated testing
  - Not referenced by NFPA 92

Section 8.1

ACCEPTANCE TESTING

• Test against design criteria (Chapter 4)
• Start with design documents
  - Should contain description of acceptance testing
  - Review before arriving on site
  - Share with authority having jurisdiction
• Verify completeness of building construction

Section 8.1

COMPONENT TESTING

• Test operation of subsystems and components prior to interconnection
• Verify system is ready for acceptance testing

Section 8.3

COMPONENT TESTING

• Firefighter’s Smoke Control Station
• Test all inputs and outputs
• Test manual overrides

Section 8.4.7

TESTING - SMOKE MANAGEMENT SYSTEMS

• Activate system
• Verify operation of fans, dampers, other equipment
• Measure exhaust capacities and inlet velocities
• Measure force to open egress doors

Section 8.4.5

TESTING - SMOKE CONTAINMENT SYSTEMS

• Measure pressure differentials across smoke barriers with all interior doors closed.
• Leave exterior door open if it would be open during evacuation
• Then measure pressure differentials with number of egress doors open per design
• Measure force to open egress doors with number of doors open per design

Section 8.4.6
DOOR FORCES

- Door forces (8.4.4.5)
  - Per life safety and/or building code
  - 30 lb (13.7 kg) is typical
  - Measure using spring-type scale
  - Record all results!

OTHER TEST METHODS

- “Smoke tests” not required by codes
- Smoke bombs produce cold smoke only
- AHJ may still request demonstration

PERIODIC TESTING

- Maintain components per manufacturer
- Verify
  - Pressure differentials
  - Airflow at makeup supplies and exhaust equipment
- Input/output functions
- Standby power (if applicable)
- Dedicated systems – semiannually
- Nondedicated systems – annually
- NFPA 90A contains additional info

TESTING - DOCUMENTATION

- Record all results on a maintenance log!
- Use a template
- Must be available for inspection

SUMMARY

- Provided an overview of smoke control/NFPA 92
  - Evolution of smoke control
  - Design fundamentals
  - Calculation procedures
  - Building equipment and controls
  - Documentation
  - Testing
- Questions?

THANKS!

- Questions?
  - LinkedIn discussion group for Smoke Control
  - Questions typed in during the presentation will be answered privately/anonymously.