Smoke Control: Recent Progress and Areas for Improvement

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Overview

- Progress over last ~40 years
- Research needs for improved designs
- Smoke control systems (stair pressurization, zoned smoke control, etc.)
- Systems with mechanical exhaust in atria, covered malls, etc.

Smoke Control Systems

- Terminology in NFPA 92:
  - **Smoke Containment Systems**: Smoke control systems designed to contain smoke to the zone of fire origin, via passive measures of active pressurization.
  - **Smoke Management Systems**: Smoke control systems designed to manage smoke within the zone of fire origin, either to prohibit occupant contact with smoke or to minimize the impact of exposure to smoke.
Design Criteria

- Pressure differences (min. and max.): 0.05 in. w.c. in sprinkler protected buildings (NFPA 92)
- Leakage factors
  - Default values included in codes
- Open doors
**Single Injection**

![Diagram of Single Injection](image)

**Multiple Injection**

- Atlanta Hilton

![Image of Atlanta Hilton](image)

**Barriers**

- Permanent vs. moveable barriers

![Image of Barriers](image)
**Analytical Tools**

<table>
<thead>
<tr>
<th></th>
<th>Origin</th>
<th>Interacting Systems</th>
<th>Unsteady</th>
<th>Smoke Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Calcs</td>
<td>1970s</td>
<td>No</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>ASCOS</td>
<td>1982</td>
<td>Yes</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>CONTAM</td>
<td>1993</td>
<td>Yes</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

**Analytical Tools**

- Hand Calculations – stair pressurization

\[
\Delta p_{\text{bar}} = \Delta p_{\text{bar}} + \frac{F_j H}{1 + \left( \frac{A_{\text{SB}}}{A_{\text{BO}}} \right)^2}
\]

\[
V = \frac{0.3 \times \Delta p_{\text{bar}} \sqrt{\Delta p_{\text{bar}}}}{\rho}
\]

**Smoke Control Challenges in Large Spaces**

- Large undivided area
  - unrestricted horizontal spread
- Tall ceiling heights
  - high smoke production rate
  - reduced sprinkler system effectiveness

*Grand Central Station*
*New York*
Smoke Management Systems: References

- **< 2000**
  - Butcher and Parnell (Smoke Control in Fire Safety Design)

- **2012**
  - Standards –
    - NFPA 92B (2005)
    - NFPA 204 (2002)
    - NFPA 92 (2012)
  - ASHRAE/SFPE publication (Handbook of Smoke Control Engineering)

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Design Criteria

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust capacity</td>
<td>4-6 air changes per hour</td>
<td>Sized to limit descent of smoke layer or PBD</td>
</tr>
<tr>
<td>Activation means</td>
<td>Ceiling-mounted devices</td>
<td>Depends on system goals</td>
</tr>
<tr>
<td>Number of exhaust fans</td>
<td>Unspecified</td>
<td>Avoid plugholing</td>
</tr>
<tr>
<td>Make-up air</td>
<td>Forced supply: % of exhaust</td>
<td>Total equal to exhaust; Max. velocity of 200 fps</td>
</tr>
</tbody>
</table>

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Analytical Tools

- Hand calculations: NFPA 92B
- Zone models: CFAST, ASMET, …
- CFD models: FDS, …
Hand Calculations

Smoke Production Rate (scfm)

Clear Height (ft)

CFD Analyses

Fire Dynamics Simulator (FDS)

Plugholing

High capacity vent may create “hole” in smoke layer
**Make-up Air Supply**

- Provide below smoke layer
  - If provided above smoke layer, adds to smoke layer mass
- Provide at low velocity
  - High velocity may disturb flame, increase entrainment
  - Limit of 200 fpm

**FDS Analysis of Make-up Air Supply**

- **Variables**
  - Distribution of make air points
    - Symmetric
    - Below smoke layer vs. 1 per floor
  - Make-up air supply velocity
    - 100-600 fpm
- **Outputs of interest**
  - Heat release rate of fire
  - Smoke layer interface height
- **Scenario**
  - Atrium: 100 ft cube
  - Fire: 2 wood cribs stacked to simulate 12 pallets (~5 MW peak heat release rate)

*Ref: Kerber and Milke, Fire Tech, 2007*

**Smoke Layer Position**

- 200 fpm
- 600 fpm

Symmetric, 5 MW fire, 600 s
Smoke Layer Position

Symmetric Supply Points
Asymmetric Supply Points

200 fpm, 5 MW fire, 600 s

What’s needed?

- **Policy**
  - Tenability limits
  - Acceptance test procedures

- **Design parameters**
  - Design fire
  - Number and placement of fans
  - Activation

- **Input data for calculations**

Tenability Limits - CO

<table>
<thead>
<tr>
<th>Source</th>
<th>Limit (%)</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Standards</td>
<td></td>
<td></td>
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<tr>
<td>NFPA 101 [2006]</td>
<td>32</td>
<td>Individuals in areas of refuge*</td>
</tr>
<tr>
<td>ISO/TS 13571 [2002]</td>
<td>30</td>
<td>Any application*</td>
</tr>
<tr>
<td>NFPA 130 [2003]</td>
<td>23</td>
<td>Individuals in subway station</td>
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<tr>
<td>Researchers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purser [2002]</td>
<td>30</td>
<td>Healthy 154 lb adult, light activity</td>
</tr>
<tr>
<td>Klees, Heremans and Dougan [1985]</td>
<td>25</td>
<td>Children</td>
</tr>
<tr>
<td>EPA [2000]</td>
<td>5</td>
<td>People with coronary artery disease</td>
</tr>
<tr>
<td>Hinderliter, et al. [1989]</td>
<td>2</td>
<td>People who suffer from angina</td>
</tr>
</tbody>
</table>

* Calculation of limit based on a healthy, 154 lb adult, light activity
Tenability Limits - Visibility

<table>
<thead>
<tr>
<th>Source</th>
<th>Limit (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researcher</td>
<td></td>
</tr>
<tr>
<td>Kingman [1953]</td>
<td>4</td>
</tr>
<tr>
<td>Jin [1978]</td>
<td>10-16</td>
</tr>
<tr>
<td>Indiana Dunes Criteria [1977]</td>
<td>14.8</td>
</tr>
<tr>
<td>Rasbash [1967], Malhotra [1967]</td>
<td>16</td>
</tr>
<tr>
<td>Purser [2000]</td>
<td></td>
</tr>
<tr>
<td>LA School Burn [1977]</td>
<td>25</td>
</tr>
<tr>
<td>English Hospital Study [1977], Rasbash [1975], Collins, Dahir, and Madrzykowski [1990], Purser [2002]</td>
<td>33</td>
</tr>
<tr>
<td>Jin [1981]</td>
<td>39</td>
</tr>
<tr>
<td>LA Fire Dept. [1961]</td>
<td>46</td>
</tr>
<tr>
<td>Jin [1978]</td>
<td>49-65</td>
</tr>
<tr>
<td>Kawagoe &amp; Saito [1967]</td>
<td>65</td>
</tr>
<tr>
<td>Wakamatsu [1968]</td>
<td>80</td>
</tr>
</tbody>
</table>

Acceptance tests

- Use of visible smoke
  - Purpose?
  - Interpretation of results?
  - Meaningful?

Selection of Design Fire

- Consider “worst case”: most demanding impact
- Fuel
  - Composition of commodity
  - Arrangement
- How is fire size limited?
  - Fuel
    - Separation between items
    - Quantity of fuel
  - Method of detection, suppression
    - Manual
    - Automatic
Placement of exhaust fans

- Maximum length of zone served by 1 fan
- Plugholing

Activation

- Activation devices
  - Response time of ceiling-mounted devices in tall spaces
  - Alignment of projected beams
  - Response time of VID systems
- Start-up time for fans

Input data

- Leakage of building assemblies
- Yield of combustion products
  - Large fuel packages, range of ignition conditions
    - Soot yield from ABS foam: 0.1 g/g in FM flammability apparatus, 0.96 g/g in intermediate scale calorimeter.
  - Post-sprinkler operation
  - Gases other than CO, CO₂
- Visibility through smoke
  - Number of participants (average: 10 male, ages 23-37)
  - Varying vision characteristics
Summary

- Significant advances have been made in our understanding of smoke control systems.
  - Design criteria
  - References
  - Analytical tools

Summary

- As a result of these advances, there are increased demands placed on system designers, system designs and on analytical methods to support those designs
  - Analytical tools get used beyond their scope
  - Limited data sources become sanctified