HKIE Fire Division CPD Training Course

Design of Smoke Extraction System

February 2018

MEINHARDT

Consulting Engineers . Planners . Managers

1. Objective of smoke control system
2. Types of smoke control system
3. Smoke extraction system calculation
4. Factors affecting smoke generation
5. Consideration in smoke extraction system design

Introduction

Purpose of Smoke Control System

- Smoke kills
- To protect the area of a building where the fire starts
  - To prevent smoke and heat affecting occupants and allow evacuation
- To protect areas of the building beyond where the fire had started
  - To prevent smoke from spreading to other areas

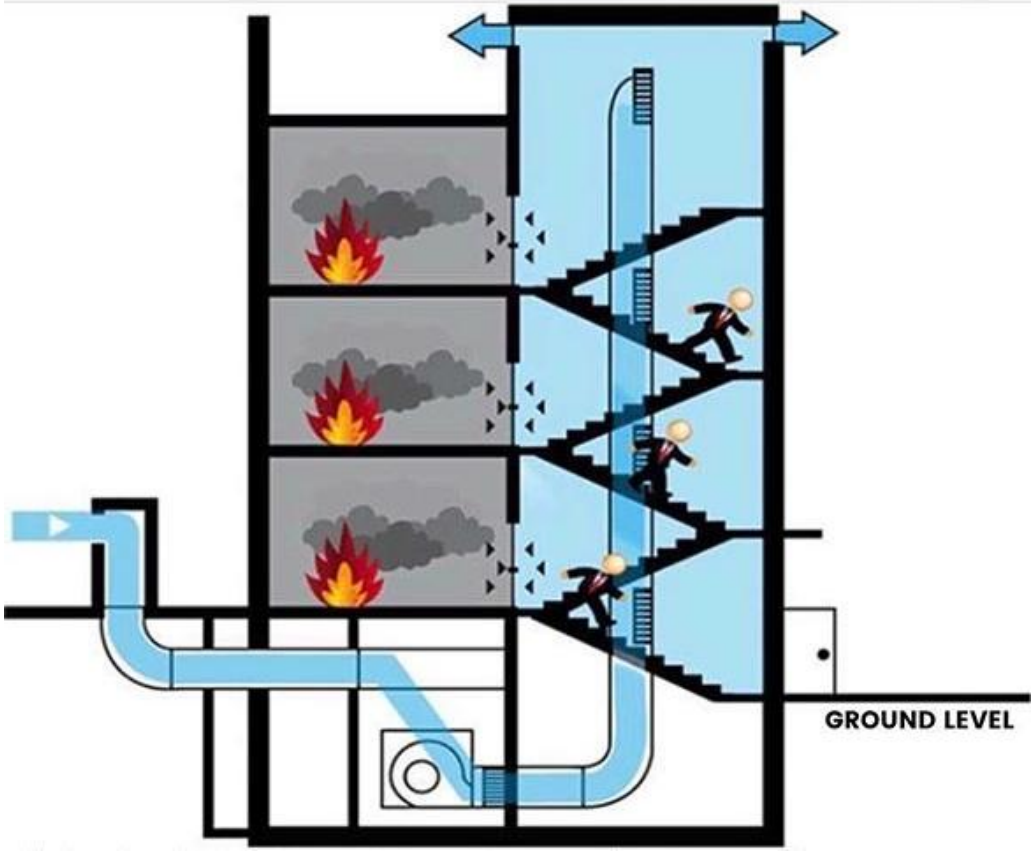
pic source: http://www.beautifuldecay.com/2014/01/06/kevin-cooleys-stunning-photographs-fire-smoke/

MEINHARDT
Consulting Engineers . Planners . Managers

Some Types of Smoke Control Strategy

Some example:

- Maintaining a smoke-free layer (smoke extraction)
  - Static
  - Mechanical
- Enclosure to contain smoke
- Pressurisation

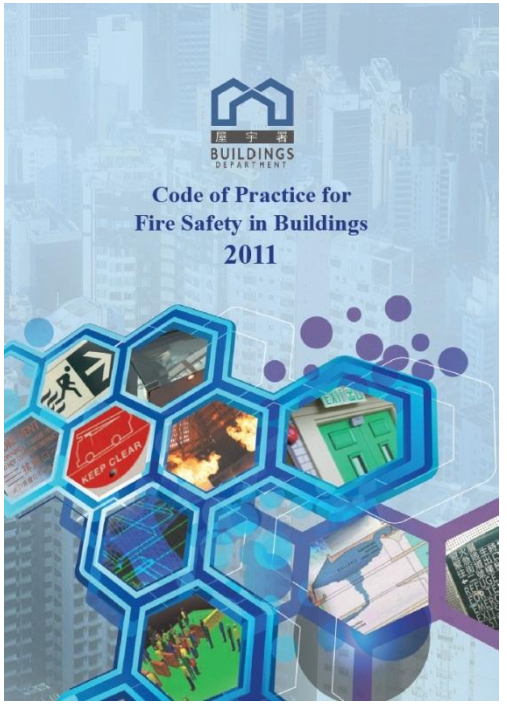


pic source: http://www.construcaocivil.info/en/em-caso-de-incendio-o-sistema-de-pressurizacao-pode-impedir-a-entrada-de-fumaca-na-escada-de-emergencia-para-que-os-usuarios-possam-utiliza-la-como-rota-de-fuga-o-sistema-conta-com-um-conjunt/

Smoke Extraction

- Tenability criteria

  - Smoke layer height: at least 2m from floor level
  - Radiant heat flux: <2.5kW/m^2
  - CO concentration: <1000ppm
  - Visibility: >10m
  - Temperature: <60^{o}C

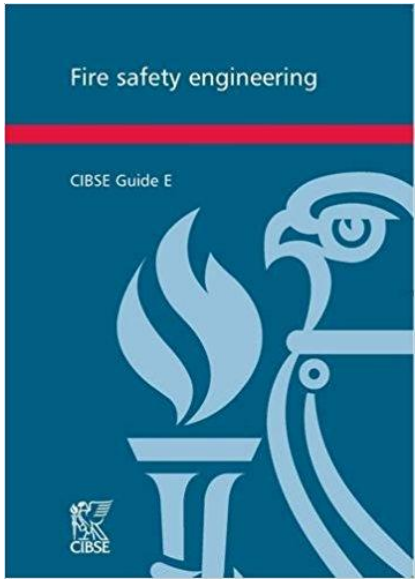


Design of Smoke Extraction System

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction Calculation and Design Guides

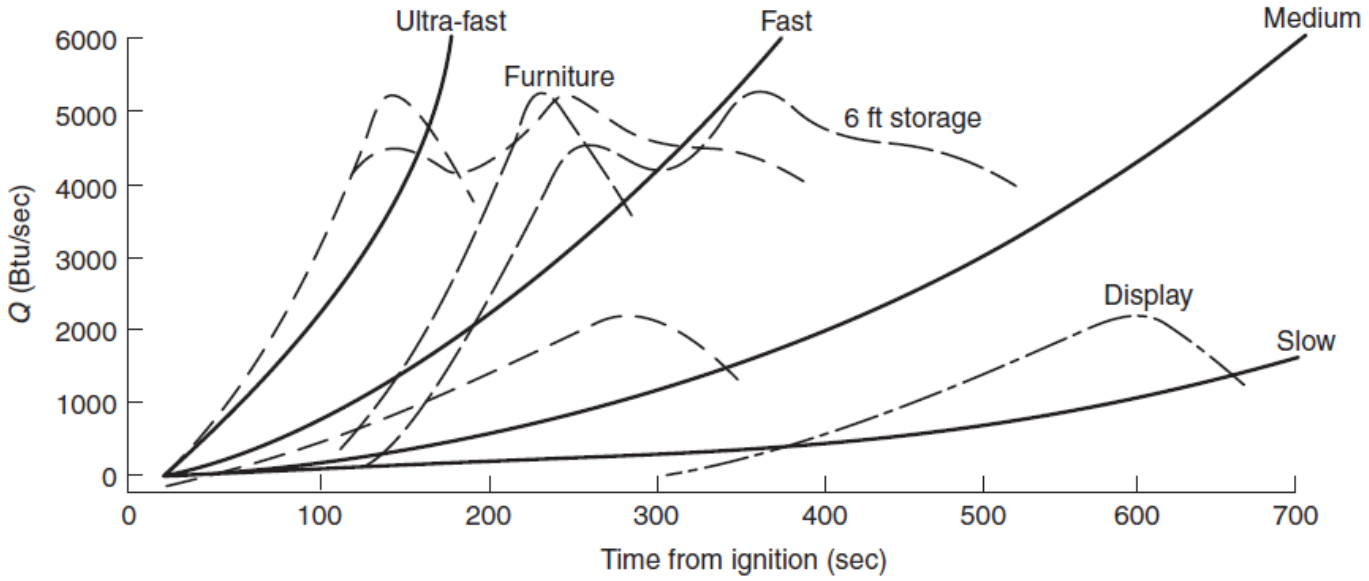
- Quick estimation: ACH
  - Volume is the only factor
- Engineering calculation:
  - CIBSE Technical Memoranda 19 / CIBSE Guide E
  - NFPA 92 - Standard for Smoke Control Systems



MEINHARDT
Consulting Engineers . Planners . Managers

Design Fire Size

- Fuel load controlled fire
- Ventilation controlled fire
- Sprinkler controlled fire
  - Sprinkler height
  - Sprinkler properties
  - Fuel properties (fire growth rate)

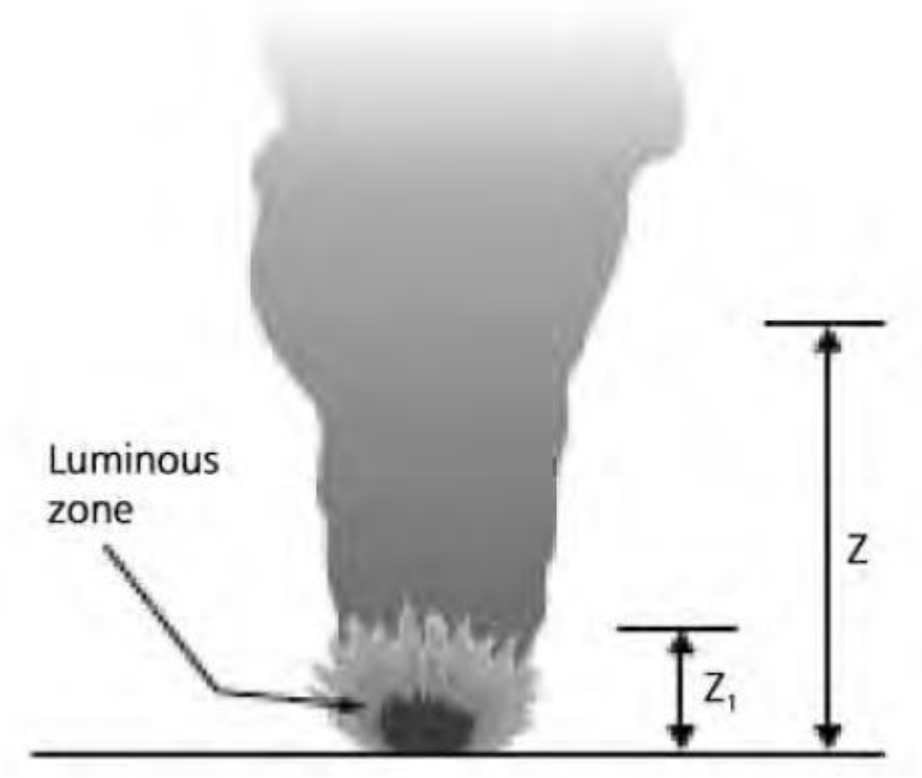


MEINHARDT
Consulting Engineers . Planners . Managers

Type of Fires to Consider

- Axisymmetric Plume

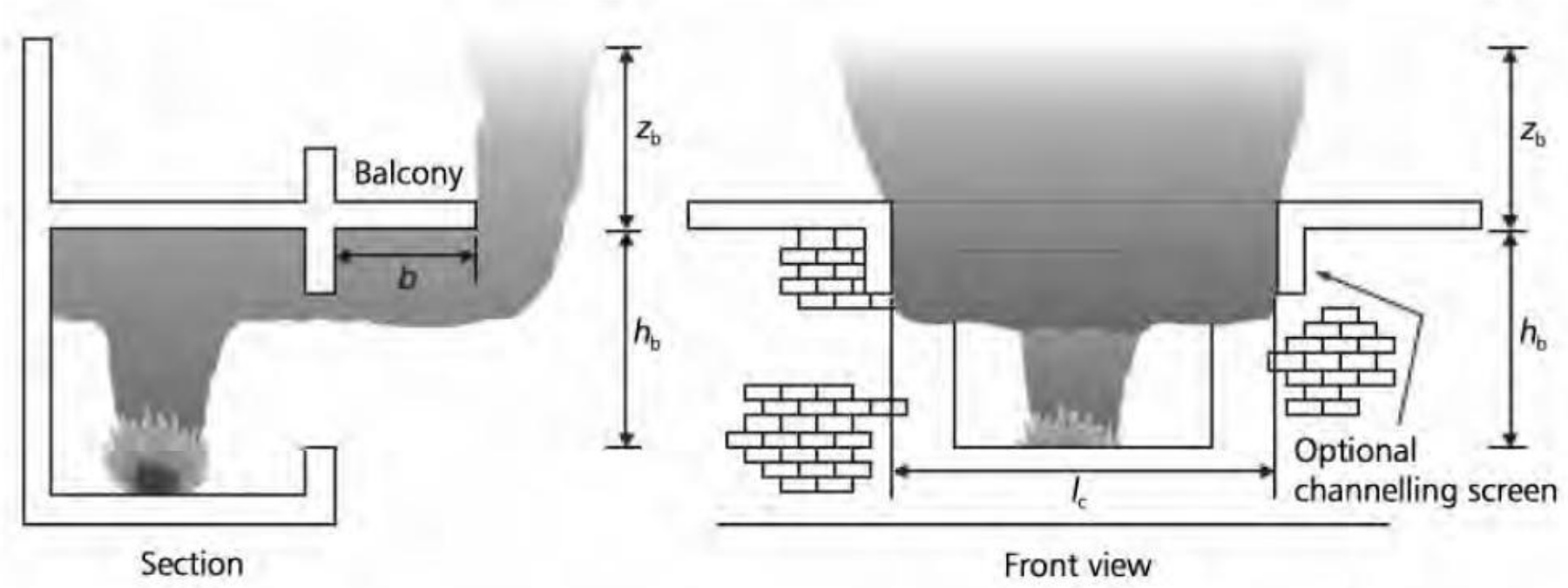
$$M = 0.071\, Q_p^{1/3}\, (z - z_o)^{5/3}$$



Type of Fires to Consider

- Balcony spill plume

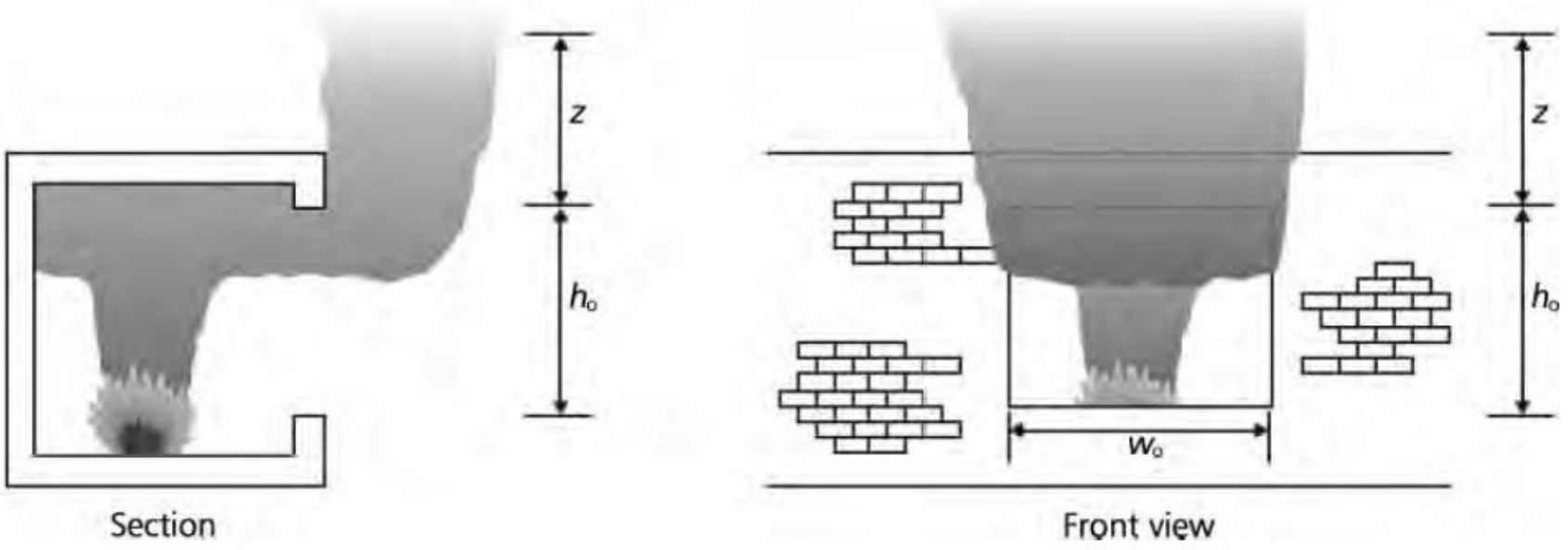
$$M = 0.36\, Q_p^{1/3}\, (w_o + b)^{2/3}\, (z_b + 0.25\, h_b)$$



Type of Fires to Consider

- Window plume

$$M = 0.23\, Q_p^{1/3}\, w_o^{2/3}\, (z_o + h_o)$$



Smoke Extraction Calculation

- Plume temperature

$$T_m - T_o = Q_p / (M c_p)$$

- Mass flow rate to Volume flow rate for mechanical smoke extraction

$$v = M / \rho_o + Q_p / \rho_o T_o c_p$$

- Vent area required for and static smoke extraction

$$M_{out} = \frac{C_d A_{vo} \rho_o [2 g (h - z) (T_s - T_o) T_o]^{1/2})}{T_s^{1/2} [T_s + (A_{vo} / A_{vl})^2 T_o]^{1/2}}$$

Smoke Extraction Calculation

- Critical mass flow rate to prevent plug-hole

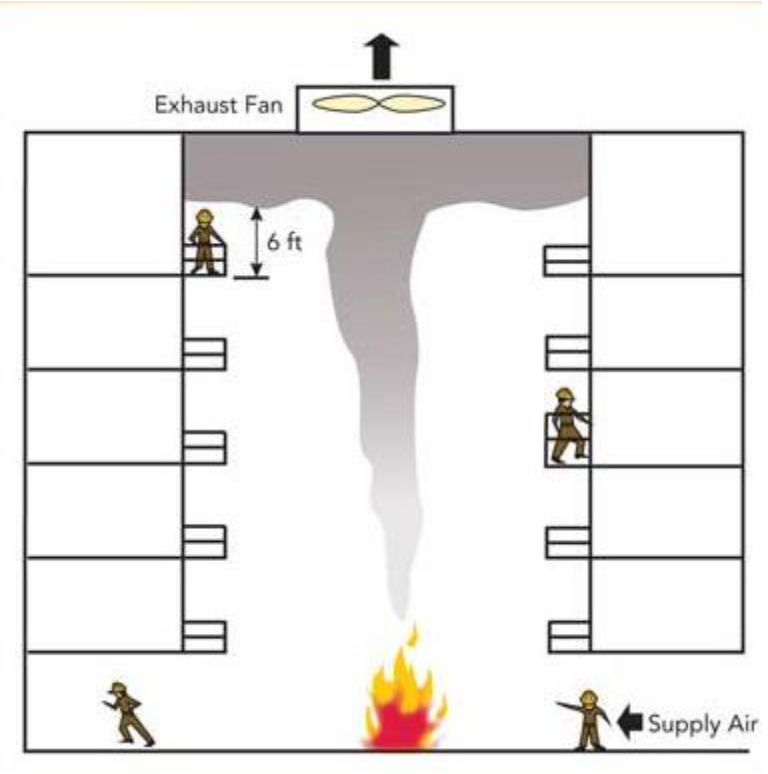
$$M = \beta \, [g \, (h - z)^5 \, (T_s - T_o) \, T_o]^{1/2} \, / \, T_s$$

pic source: http://physicsworld.com/cws/Articles/ViewArticle.do?channel=news&articleId=26947

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction Calculation

- Calculating smoke generation rate at a given height
- Assuming extraction rate same as smoke generation rate
- Ideal scenario
  - Extraction directly above fire
  - Optimum smoke zone size
  - Smooth smoke zone geometry



pic source: http://www.fireengineering.com/articles/print/volume-165/issue-2/features/smoke-management-in-high-rise-structures.html

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction Calculation

- Factors affecting smoke generation rate
  - Axisymmetric

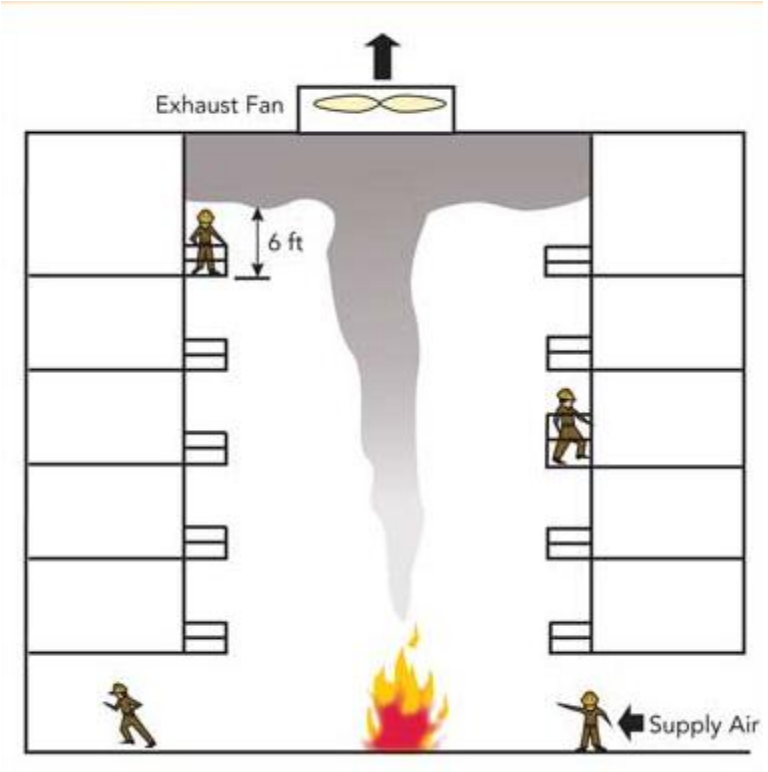
$$M = 0.071\, Q_p^{1/3}\, (z - z_o)^{5/3}$$

  - Balcony Spill Plume

$$M = 0.36\, Q_p^{1/3}\, (w_o + b)^{2/3}\, (z_b + 0.25\, h_b)$$

  - Window Plume

$$M = 0.23\, Q_p^{1/3}\, w_o^{2/3}\, (z_o + h_o)$$



- Smoke zone area NOT a factor on smoke generation rate

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction Calculation

- Vent area required for static smoke extraction

$$M_{out} = \frac{C_d\, A_{vo}\, \rho_o\, [2\, g\, (h-z)\, (T_s - T_o)\, T_o]^{1/2})}{T_s^{1/2}\, [T_s + (A_{vo}/A_{vl})^2\, T_o]^{1/2}}$$

- Smoke depth, temperature and makeup air area also a factor in static smoke extraction

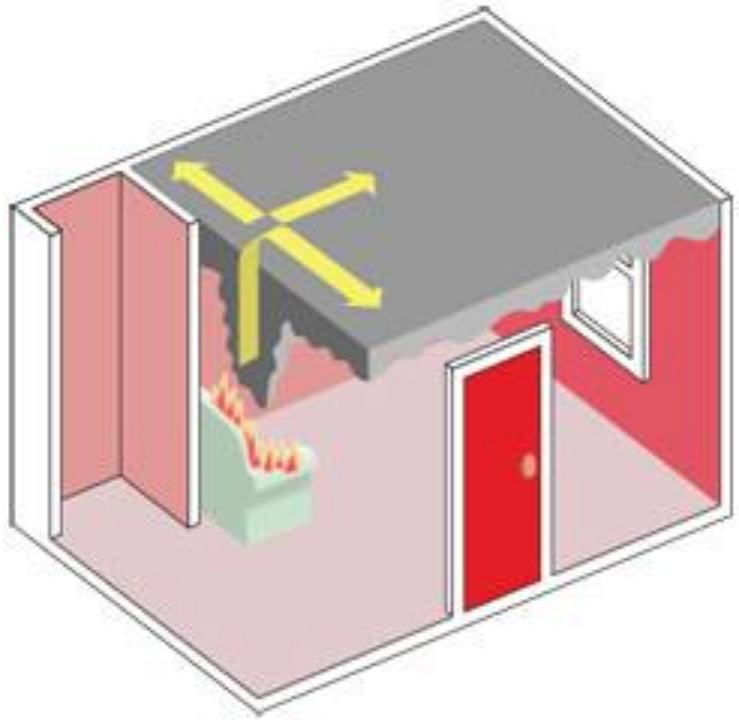
- Extra considerations for static smoke extraction:
  - Outdoor temperature
  - Wind effect

pic source: https://www.coltgroup.com/smoke-control.html
https://www.coltinfo.co.uk/colt-product-library/natural-flap-ventilators/kameleon-5.html

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction System Design

- Maximum smoke zone area: 2000-3000m^2 (CIBSE)
- Smoke zone geometry
- Smoke travel distance
- Boundary fire scenario



pic source: http://www.derbys-fire.gov.uk/campaigns/think-sprinkler/how-sprinklers-work/

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction System Design

- Number of extraction points
- Extraction points location
- Smoke clear height

pic source: https://ifpmag.mdmpublishing.com/testing-the-response-of-smoke-detectors/

MEINHARDT
Consulting Engineers . Planners . Managers

Smoke Extraction System Design

- Makeup air (replacement air) at low level
- 80% of extraction rate
- Natural / Mechanical makeup
- Maximum makeup velocity
- Makeup air can also affect combustion
  - Temperature
  - CO production
  - Visibility

Smoke Extraction System Design

- Suppression system
  - Affects fire size

- Detection system
  - Affects actuation time of smoke extraction system and evacuation

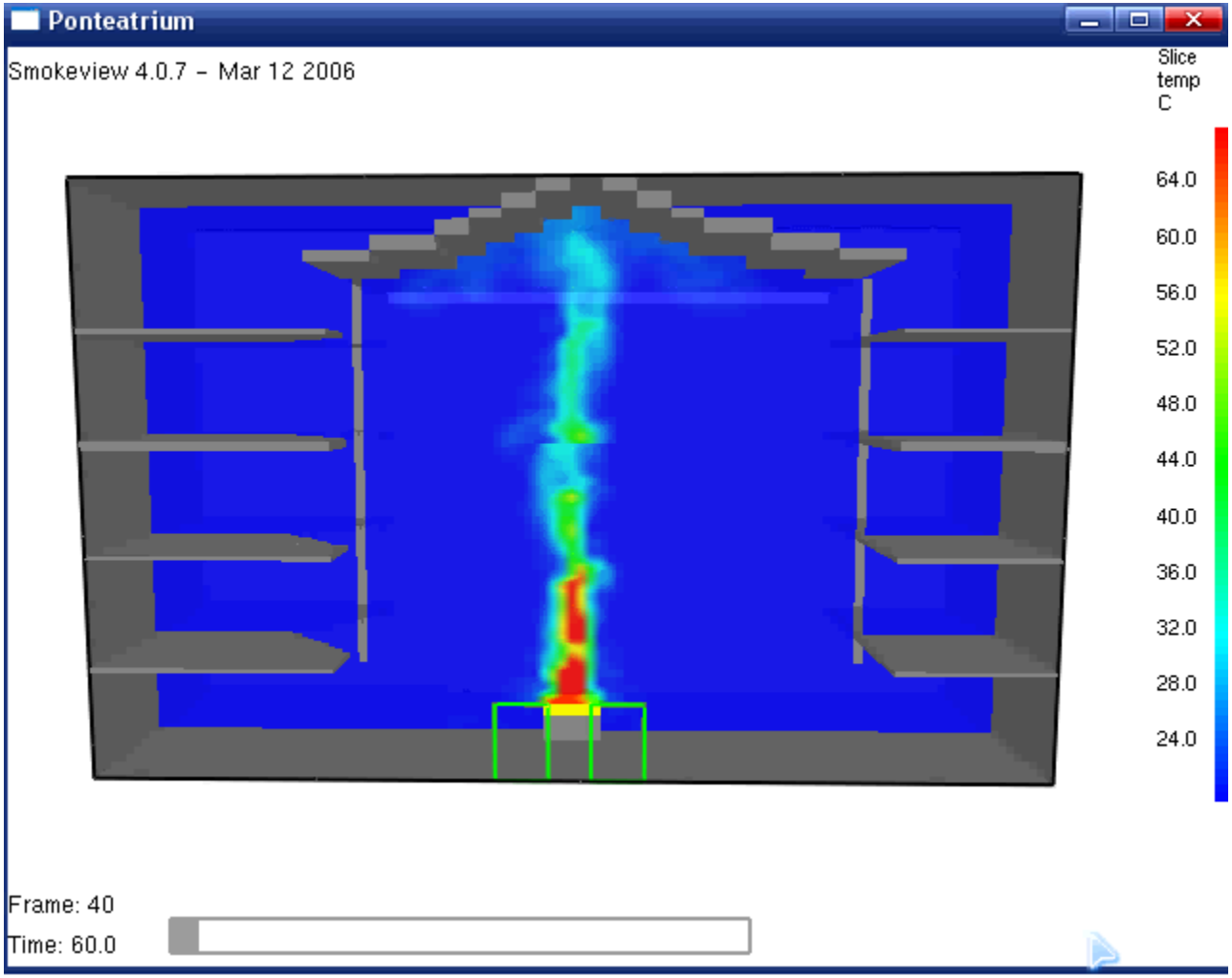
- Smoke barrier
  - Affects smoke zone geometry and effectiveness of smoke extraction system

pic source: https://www.researchgate.net/profile/Wojciech_Wegrzynski

MEINHARDT
Consulting Engineers . Planners . Managers

Verification

- CFD modelling



MEINHARDT
Consulting Engineers . Planners . Managers

Verification

- Hot smoke test

video source: https://www.youtube.com/watch?v=oN_O3WQBGKU

MEINHARDT
Consulting Engineers . Planners . Managers

Thank You

MEINHARDT
Consulting Engineers . Planners . Managers