ATRIUM SMOKE MANAGEMENT

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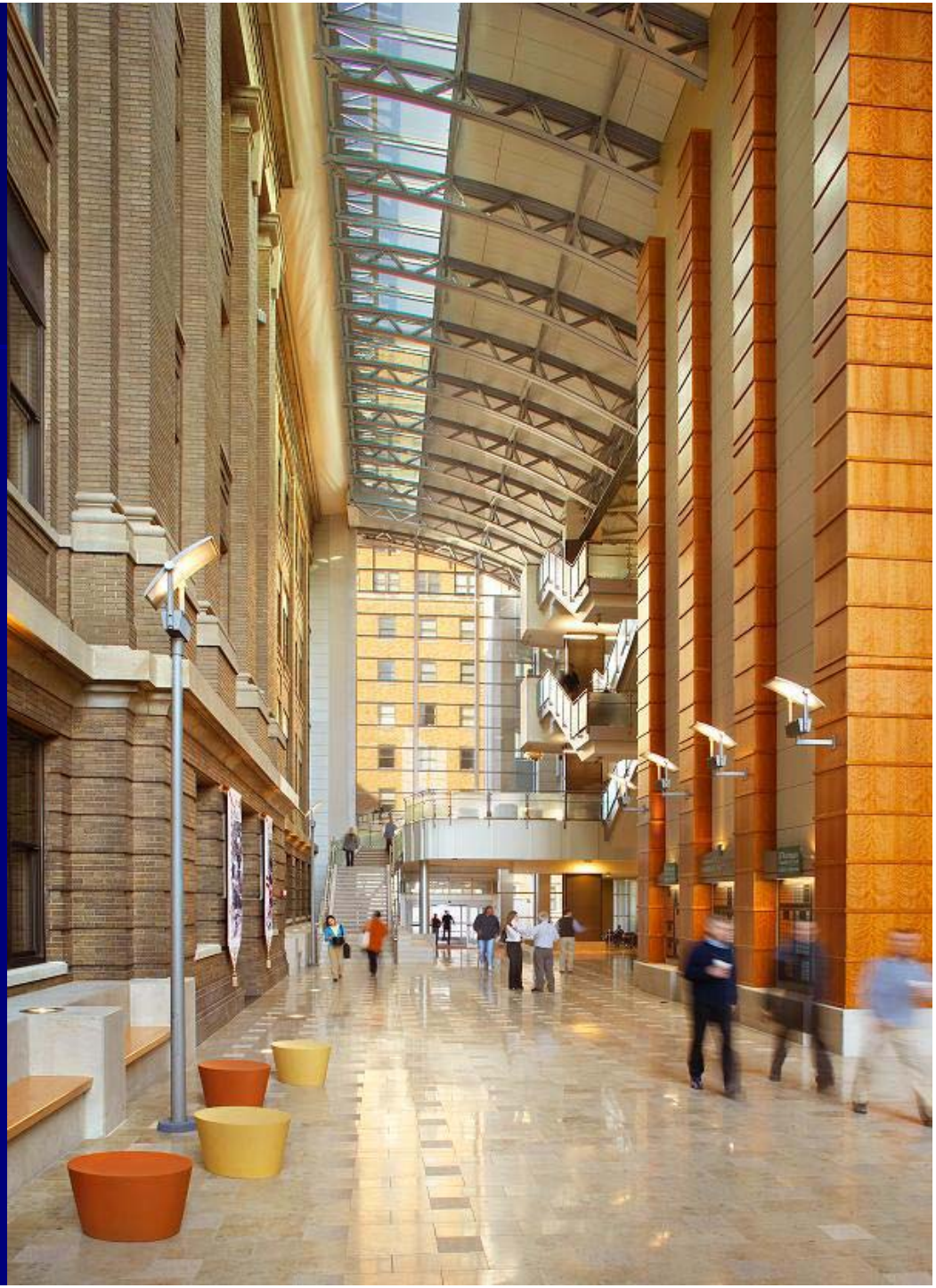
ASHRAE Kansas City Chapter Meeting

December 4, 2006

DUDA'S POSTULATES



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1. Design of a smoke control system for an atrium is not for the meek. But with care and diligence, a general-practice consulting engineer can still design a basic atrium system without a specialist.

2. The answer is not 6 air changes per hour.

3. You will spend at least as much time designing the makeup air side as you will the exhaust side.

OUTLINE

- The Basics
- The Goals
- The Code
- Exhaust Calculations
- Examples
- Equipment Requirements
- Replacement Air
- Other Requirements
- Wrap up

THE BASICS

- Atrium Definition: “A space within a building that extends vertically through two or more floors.”
- Does not include stair shafts and mechanical shafts enclosed in rated construction.
- A smoke control system is required IF the atrium is open to three (3) or more floors. A two-story atrium is generally exempt from smoke control.
- Assembly halls, ballrooms, shopping malls, sports arenas, etc. are required to include smoke control if they meet the definition of an atrium.

THE GOALS

- Maintain tenable conditions for 20 minutes, to protect life but not necessarily property.
- Keep smoke 10 feet above the highest occupied surface within the atrium for 20 minutes.
- Prevent smoke from migrating to other parts of the facility.
- Accommodate a fire of 5,000 BTU/s intensity (roughly one sofa, one chair, and one end table fully engulfed).

EXAMPLE: 4-STORY ATRIUM

THE CODE

- According to the Kansas City website, the applicable Codes are the 2003 International series.
- 2003 IBC Section 909 applies (about 8 pages long).
- Some considerations include stack effect, wind effect, temperature effect, climate (esp. cold climate).
- Three Design Methods:
  - Pressurization Method (909.6)
  - Airflow Design Method (909.7)
  - Exhaust Rate Method (909.8) used in Atria.

THE CODE

- Many formulas are given:
  - Axisymmetric plume (909.8.2) most common.
  - Balcony spill plume (909.8.3)
  - Window plume (909.8.4)
  - Plume against wall (909.8.5)

- Application of 909.8.2 is sufficiently conservative in the majority of basic atria design cases.

909.8.2 Axisymmetric plumes. The plume mass flow rate (m_p), in pounds per second (kg/s), shall be determined by placing the design fire center on the axis of the space being analyzed. The limiting flame height shall be determined by:

$z_l = 0.533 Q_c^{2/5}$ **(Equation 9-3)**

For SI: $z_l = 0.166 Q_c^{2/5}$

where:

m_p = Plume mass flow rate, pounds per second (kg/s).

Q = Total heat output. = 5,000 BTU/s

Q_c = Convective heat output, British thermal units per second (kW). (The value of Q_c shall not be taken as less than $0.70Q$).

z = Height from top of fuel surface to bottom of smoke layer, feet (m).

z_l = Limiting flame height, feet (m). The z_l value must be greater than the fuel equivalent diameter (see Section 909.9).

for $z > z_l$

$m_p = 0.022 Q_c^{1/3} z^{5/3} + 0.0042 Q_c$

MOST COMMON CASE

For SI: $m_p = 0.071 Q_c^{1/3} z^{5/3} + 0.0018 Q_c$

for $z = z_l$

$m_p = 0.011 Q_c$

For SI: $m_p = 0.035 Q_c$

for $z < z_l$

$m_p = 0.0208 Q_c^{3/5} z$

For SI: $m_p = 0.032 Q_c^{3/5} z$

To convert m_p from pounds per second of mass flow to a volumetric rate, the following equation shall be used:

$V = 60\, m_p/\rho$ **(Equation 9-4)**

where:

V = Volumetric flow rate, cubic feet per minute (m^3/s).

ρ = Density of air at the temperature of the smoke layer, pounds per cubic feet (T: in °F) [kg/m^3 (T: in °C)].

EXAMPLE:
INDOOR FOOTBALL STADIUM

EXAMPLE: 3-STORY ATRIUM

EXAMPLE:
HIGH-RISE HOTEL ATRIUM

EXHAUST CALCULATIONS

- Examples using a Spreadsheet . . .

ATRIUM SMOKE EXHAUST DESIGN
2003 INTERNATIONAL BUILDING CODE, SECTION 909.8 (2000 IBC Same)
(for axisymmetric plume only)

	Z	H	t	Q	Qc	p	A	z-1	909.8.2(a)	909.8.2(b)	909.8.2(c)	
protected ht above surface (feet)	height lvl 1 flr to smoke layer	height lvl 1 flr to atrium ceiling	time (sec)	heat release rate BTU/sec	convective release rate BTU/sec	density of air at smoke interface*	area of atrium ceiling (sf)	limiting elevation (feet)	rate of smoke exhaust (cfm)	rate of smoke exhaust (cfm)	rate of smoke exhaust (cfm)	
10	70	75	1200	5000	3500	0.0635	5,000	13.9429	**389,139**	---	---	5 story, 15' per story, walkway on all floors
10	40	75	1200	5000	3500	0.0635	5,000	13.9429	**161,548**	---	---	5 story, 15' per story, highest walkway on 3rd floor
10	180	180	1200	5000	3500	0.0635	2,500	13.9429	**1,824,995**	---	---	18 story hotel, 10' per story, walkway on all floors
10	180	180	1200	5000	3500	0.0635	250,000	13.9429	**1,824,995**	---	---	Indoor football stadium
10	10	104	1200	5000	3500	0.0635	5,000	13.9429	---	---	**26,296**	8 story atrium, but no walking surfaces other than atrium floor

Blue numbers are intermediate steps calculated by Excel
Red numbers are results calculated by Excel
Magenta numbers are permanent fixed numbers dictated by the Code.
Black numbers must be input on each job.

* Density of air (in pounds per cubic feet), at the smoke layer
0.0750 at Standard conditions
0.0710 at 100 degF
0.0635 at 165 degF (temperature at which sprinklers release)
0.0441 at 500 degF
0.0220 at 1000 degF
0.0130 at 1700 degF

EQUIPMENT

- Use UL-Listed Power Ventilator for Smoke Control Systems (UL 725).
- Rated at 500°F for 4 hours.
- Rated at 1000°F for 15 min.
- Available from several manufacturers.
- IBC 2003 requires it to be on standby power.

REPLACEMENT AIR GOALS

1. Intakes remote from smoke exhaust discharge.
2. Velocity less than 200 fpm (1 m/s).
3. Delivered not at the top, but below the smoke layer interface.
4. Reliable and conducive to periodic testing.
5. Controlled to a volumetric rate less than the exhaust rate.

REPLACEMENT AIR GOALS

6. Allow for firefighter's command center override.
7. Avoid or address unintended consequences.
8. Complexity commensurate with operator's ability.
9. Aesthetics.
10. Construction budget.

METHOD A:
PASSIVE REPLACEMENT AIR

- Direct openings to the outdoors.
- Examples: automatic doors or louvers, hinged panels incorporated into a curtainwall.
- This system easily understood by both technical and non-technical persons.
- The installed cost is generally low.
- Passive ventilation is subject to wind effects, stack effect, and other external forces.
- No practical way to heat or cool the replacement air.

EXAMPLE: 3-STORY ATRIUM

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METHOD B:
DEDICATED REPLACEMENT AIR

- An outdoor air handling system dedicated solely to that purpose. The system remains idle under normal circumstances.
- Commonly understood and simple to test.
- The replacement air can be heated, cooled, & filtered.
- Dedicated equipment and controls are less likely to be overridden or modified by building staff because they serve no additional purpose.
- High installed cost.
- The lack of day-to-day use may hide equipment failures from discovery. Regular testing is crucial.

METHOD C: NON-DEDICATED MAKEUP AIR

- Make use of the air handling system(s) that serve the atrium on a day-to-day basis. The base equipment shares both non-emergency and smoke emergency duties.
- Failure of any component is generally discovered and repaired during the course of normal operation.
- The replacement air can be at least partially heated, cooled, filtered, or otherwise treated.
- The installed cost may not be much more than the system the Owner is purchasing anyway.
- Most complex of the methods. The controls and sequences of operation are critical.

METHOD C:
NON-DEDICATED MAKEUP AIR

- Don’t overlook the return air path as a potential path for additional replacement air to the atrium . . .

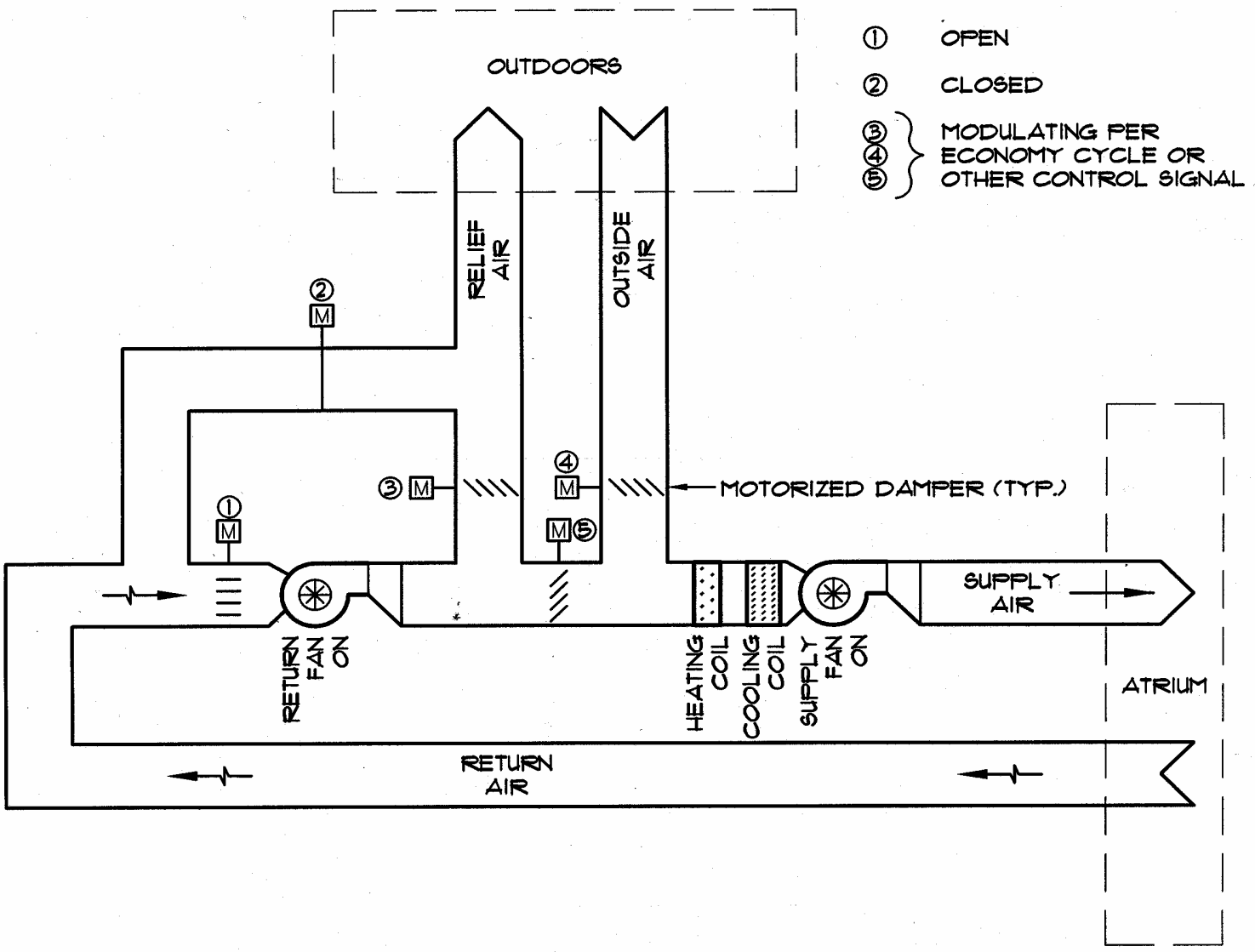

FIGURE 1: ATRIUM HVAC SYSTEM DIAGRAM
NORMAL MODE

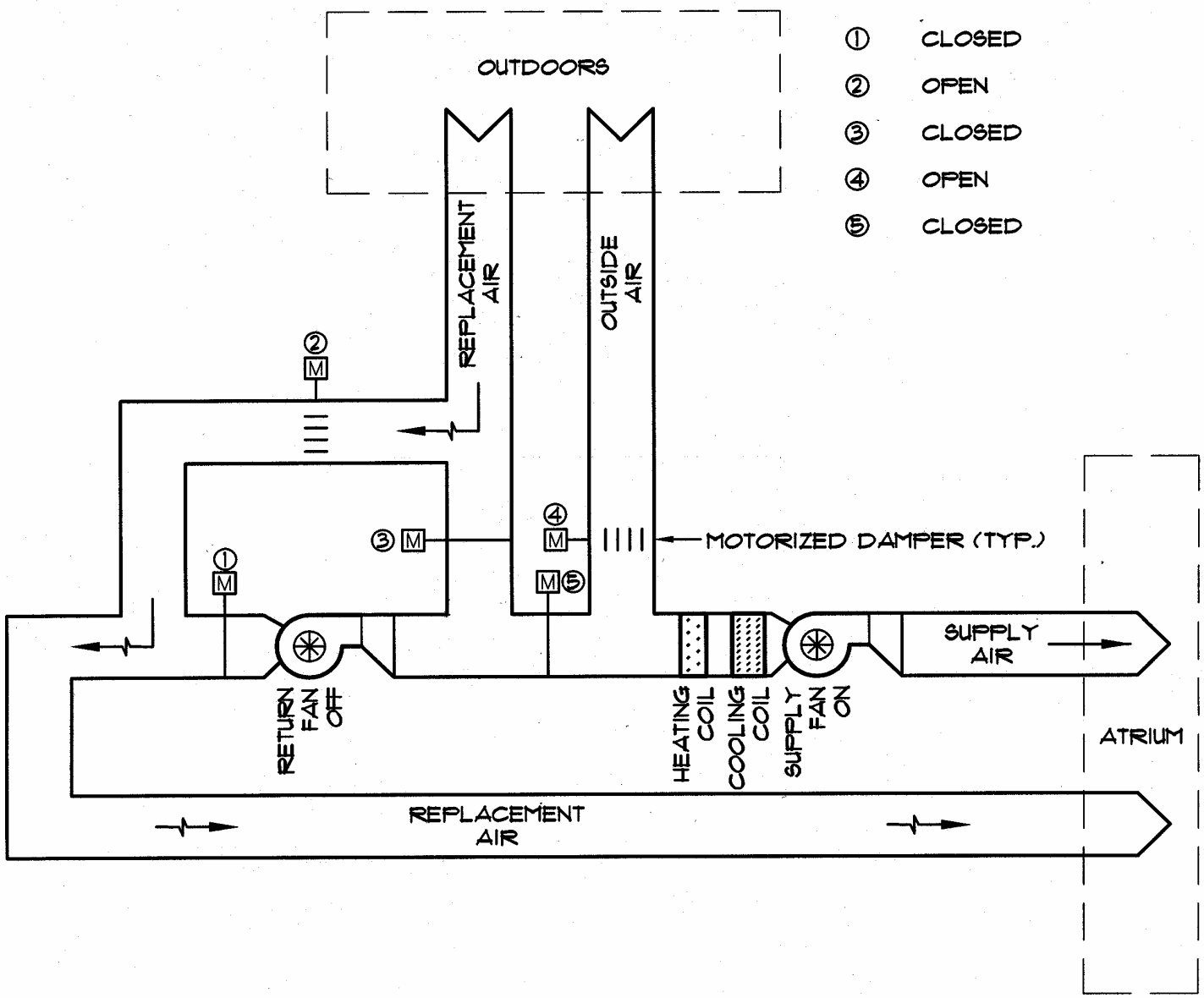

FIGURE 2: ATRIUM HVAC SYSTEM DIAGRAM
SMOKE EMERGENCY MODE

OTHER REQUIREMENTS . . .

- Standby power required for all components. Power connection via 2 different routes. Automatic transfer.
- All wiring of any kind must be in conduit.
- Detection and activation requirements.
- Fire fighter's command post required for override.
- Testing & Acceptance: A test tailored to the particular facility is required. Engineer of record is to recommend a test procedure.

REMEMBER . . .

- Read and understand the Code.
- Input the various formulas into a Spreadsheet.
- The answer is NOT 6 air changes per hour.
- Be prepared to spend as much time on the makeup air side as you do on the exhaust side.
- For atria of unusual configurations or complexity, hire a firm specializing in smoke control and employ CFD.

THANK YOU

Thank you for attending this Seminar.

Questions?

Literature . . .

LITERATURE

- International Building Code. 2003 Edition, Section 909. Falls Church, VA: International Code Council, Inc.
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