Introduction

The purpose of this rational analysis is to support the design of the John Knox Village Courtyards -Building E smoke control system in accordance with IBC Section 909.4. The analysis covers the types of smoke control systems, methods of operation, the supporting systems, and the construction methods to be utilized.

The atrium is a 4-story space connecting the new John Knox Village Courtyards -Building E to the existing Courtyards B and Courtyards C buildings. As required by IBC Section 404.5, the atrium is provided in accordance with Section 909.

Type of Smoke Control System

The smoke control system is designed utilizing the Exhaust Method detailed in IBC Section 909.8 to ensure the height of the lowest horizontal surface of the smoke layer interface shall be maintained not less than 6 feet (1829 mm) above a walking surface that forms a portion of a required egress system within the smoke zone. As required by IBC Section 909.8, the smoke control system was designed in accordance with NFPA 92.

Methods of Operation

<u>Normal Conditions</u>

During normal conditions the smoke control system is inactive, and an independent packaged roof top air handling unit provides conditioning for the atrium space.

<u>Fire Events</u>

The smoke evacuation system through the fighter's smoke control panel upon:

- Detection of smoke by the detectors located within the atrium.
- Flow on the zoned automatic sprinkler system serving the atrium.
- Manual controls of the fighter's smoke control panel accessible to the fire department at the ground floor vestibule.

Upon activation signal from the fire fighter's smoke control panel, the smoke evacuation system shall:

- Activate door actuators to open both sets of automatic doors in atrium ground level vestibule and ground level door in in the atrium corridor E100, adjacent elevator 1, and the motorized intake dampers on floors 3 and 4.
- The system shall also activate door actuators to close doors to primary corridors on each floor of doors connecting to the E, B and C buildings.
    - Smoke doors on each floor shall not be held shut by system.
    - Actuators shall disengage a magnetic hold open system on doors connecting to the corridors, allowing for manual operation of doors to facilitate egress.

- Upon sending signal to door actuators listed above, the system shall delay 15 Seconds (adjustable) before sending signal to smoke evacuation fans for activation. This delay allows for the stabilization of the door positions and to allow opening of the intake dampers.
    - Upon receipt of signal, exhaust fans SVEF-1,2 &3 fans shall start and ramp up to design cfm.

<u>Fire fighter's smoke control panel</u>

The fire fighter's smoke control panel provide control capability over the complete smoke control system equipment within the building as follows:

- On-auto-off control over each individual smoke exhaust fan.
- Open-auto-close control over individual dampers and door hold opens.
- On-off or open-close control over smoke control system.

The control panel also provides status indicators shall be provided for all smoke control equipment.

Supporting Systems

The following systems support smoke control:

- **HVAC Systems**: During a fire event the roof top air handling unit is disabled by the fire alarm or duct mounted smoked detector.
- **Power Supply**: All elements of the smoke control system including all fans, fire alarm, actuators and controls are provided with emergency power by the natural gas generator to ensure continued operation during emergencies.
- **Emergency Communication System**: When enabled by the fire alarm all audible and visual alarms are activated by the fire alarm system during smoke events.

6. Analysis

The analysis was performed in accordance with IBC Section 909.4 and NFPA 92 the Standard for Smoke Control Systems. Utilizing the and the Handbook of Smoke Control Engineering (Klote et al. 2012). An algebraic method for a steady fire analyzed multiple fire locations on floors and associated anticipated design fires. The design fires are based on considerations for anticipated furnishings, likely transient fuels including holiday decorations. The calculations size the smoke exhaust system to:

- Maintain a steady smoke layer height when there is a steady design fire in the atrium with an axisymmetric plume.
- Maintain a steady smoke layer height when there is a steady design fire on one of the balconies.
- Calculates the number and locations of exhaust inlets to prevent plug holing of the smoke layer.

In accordance with IBC Section 909.4 these equations account for the stack effect on smoke movement within the atrium, the temperature rise during a fire event. All components have been located and sized for both air flow and wind speed to ensure make up air velocity does not exceed 200 fpm. The exhaust fans are located and oriented to discharge smoke to prevent infiltration to the atrium make up intakes.

The analysis was performed at ASHARE weather data expected peak annual temperature and humidity conditions and is sized based on the most conservative condition at peak summer temperature. Air inlets and exhausts are located to prevent snow or ice blockage.

All portions of the smoke control systems are capable of continued operation after detection of the fire event for a period of not less than 20 minutes. The exhaust fans are rated for a maximum operating temperature of 400˚F which significantly exceeds the peak calculated smoke layer temperature of 118˚ F.

The exhaust fans and associate intakes provide a steady exhaust rate of 61,260 CFM based on the most stringent of the analysis fire scenarios to ensure the height of the lowest horizontal surface of the smoke layer interface shall be maintained not less than 6 feet above the walking surfaces that form a portion of a required egress system within the smoke zones.

Rational analysis performed by:

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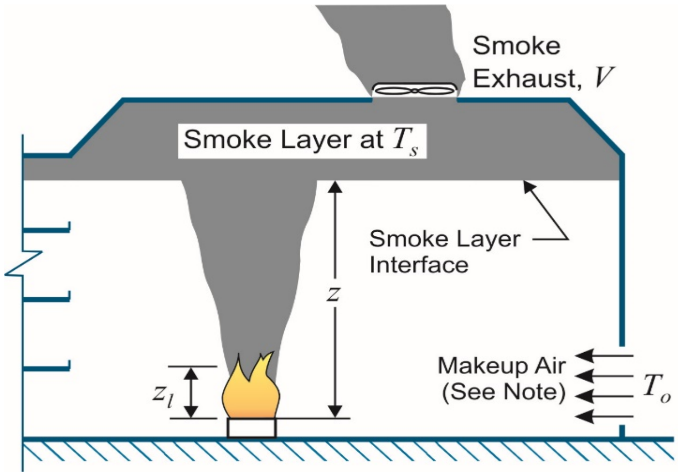
Project: John Knox Village Courtyards -Building E

Routine 1: Atrium Smoke Exhaust with an Axisymmetric Plume



Notes:

1. Makeup air is shown as being supplied by an opening or openings to the outside, but it can also be supplied by mechanical fans.
2. For calculating the volumetric flow rate of smoke exhaust, a value of K_s = 1.0 needs to be used except when another value of K_s is supported by test data or an engineering analysis.
3. For smoke control design, a value of χ = 0.7 is almost always used, and other values should be supported by engineering data.

$$Q_c = \chi\, Q$$

$$z_l = 0.533 Q_c^{2/5}$$

$$m = 0.022 Q_c^{1/3} z^{5/3} + 0.0042 Q_c \quad \text{for } z > z_l$$

$$m = 0.0208 Q_c^{3/5} z \quad \text{for } z \le z_l$$

$$T_s = T_o + \frac{K_s Q_c}{m C_p}$$

$$\rho_s = \frac{144\, p_{atm}}{R(T_s + 460)}$$

$$V = 60 m / \rho_s$$

where

C_p = specific heat (0.24 Btu/lb-°F).

Q = heat release rate of the fire (Btu/s).
Q_c = convective portion of heat release rate of fire (Btu/s).
z = distance from base of fire to smoke layer interface, (ft).
z_l = limiting elevation (ft).
m = exhaust mass flow (lb/s).
R = gas constant (53.34 ft lbf/lbm/°R).
T_s = smoke layer temperature (°F).
T_o = ambient or outdoor temperature (°F).
K_s = fraction of convective HRR in smoke layer.
ρ_s = smoke density (kg/m^3).
p_{atm} = atmospheric pressure (psi).
V = volumetric flow of smoke exhaust (cfm).
χ = convective fraction (dimensionless).

Input:

Q =	616	Btu/s
z =	37.00	ft
T_o =	92.4	^{o}F
p_{atm} =	14.70	psi
K_s =	1.0	(See note 2 above)
χ =	0.70	(Almost always 0.70)

Output:

Q_c =	431	Btu/s
z_l =	6.03	ft
m =	70.1	lb/s
T_s =	118.0	^{o}F
ρ_s =	0.06866	lb/ft^3
V =	61,258	cfm

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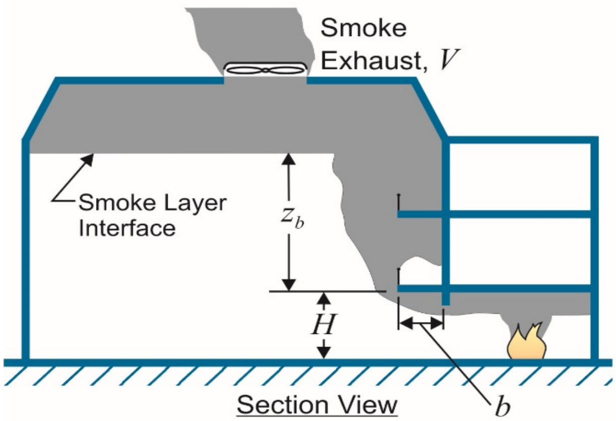
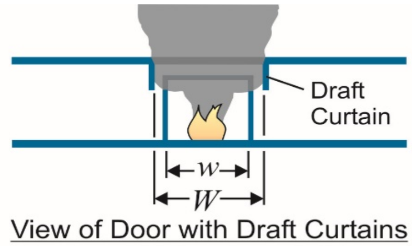
Routine 2: Atrium Smoke Exhaust with a Balcony Spill Plume





Notes:
1. Makeup air is not shown.
2. In the absence of draft curtains, the effective value of W needs to be calculated as $W = w + b$.
3. For calculating the volumetric flow rate of smoke exhaust, a value of K_s = 1.0 needs to be used except when another value of K_s is supported by test data or an engineering analysis.
4. For smoke control design, a value of χ = 0.7 is almost always used, and other values should be supported by engineering data.

$$Q_c = \chi\, Q$$

For region 1 (z_b < 50 ft):

$$m = 0.12\left(QW^2\right)^{1/3}\left(z_b + 0.25H\right)$$

For region 2 ($z_b \geq$ 50 ft and W < 32.8 ft):

$$m = 0.32Q_c^{1/3}W^{1/5}\left(z_b + 0.098W^{7/15}H + 19.5W^{7/15} - 49.2\right)$$

Region 3 ($z_b \geq$ 50 ft and 32.8 ft $\leq W \leq$ 45.9 ft):

$$m = 0.062\left(Q_c W^2\right)^{1/3}\left(z_b + 0.51H + 52\right)$$

$$T_s = T_o + \frac{K_s Q_c}{mC_p}$$

$$\rho_s = \frac{144\,p_{atm}}{R(T_s + 460)}$$

$$V = 60m / \rho_s$$

where

b	= distance from the opening to the balcony edge (ft).
C_p	= specific heat (0.24 Btu/lb-°F).
H	= height of balcony above fuel (ft).
K_s	= fraction of convective HRR in smoke layer.
m	= exhaust mass flow (lb/s).
p_{atm}	= atmospheric pressure (psi).
Q	= heat release rate of the fire (Btu/s).
Q_c	= convective heat release rate of fire (Btu/s).
R	= gas constant (53.34 ft lbf/lbm/°R).
T_o	= ambient or outdoor temperature (°F).
T_s	= smoke layer temperature (°F).
V	= volumetric flow of smoke exhaust (cfm).
W	= width of the spill (ft).
w	= width of the opening from the area of origin (ft).
z_b	= height of the plume above the balcony edge (ft).
χ	= convective fraction (dimensionless).
ρ_s	= smoke density (lb/ft^3).

Input:

Q =	550	Btu/s
H =	11.30	ft
W =	6.50	ft (See note 2 above)
z_b =	17.30	ft
T_o =	92.4	°F
p_{atm} =	14.70	psi
K_s =	1.0	(See note 3 above)
χ =	0.70	(Almost always 0.70)

Note: Flow is in region 1.

Output:

Q_c =	385	Btu/s
m =	68.9	lb/s
T_s =	115.7	°F
ρ_s =	0.06894	lb/ft^3
V =	59,981	cfm

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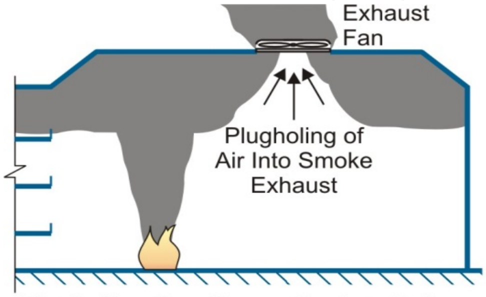
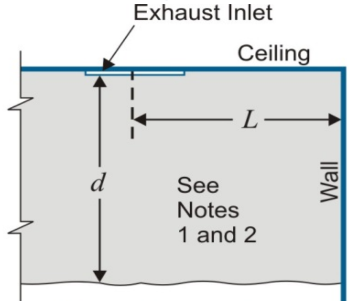
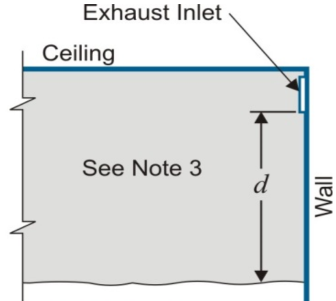
Routine 4A: Preventing Plugholing with Rectangular Inlets



Plugholing Can Cause System Failure



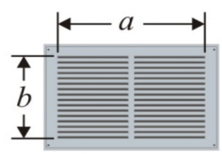
Ceiling Mounted Inlet



Wall Mounted Inlet

Notes:

1. For a ceiling mounted exhaust inlet with $L < 2\,D_i$, $\gamma = 0.5$.
2. For a ceiling mounted exhaust inlet with $L \geq 2\,D_i$, $\gamma = 1$.
3. For a wall mounted exhaust inlet, $\gamma = 0.5$.
4. d/D_i must be greater than 2.
5. V_e must be less than or equal to V_{max}.
6. The edge-to-edge distance between inlets must not be less than S_{min}.
7. For plugholing calculations, a value of K_s = 0.5 needs to be used except when another value of K_s is supported by test data or an engineering analysis.



Rectangular Inlet Grille

$$T_s = T_o + \frac{K_s Q_c}{m C_p} \qquad (T_s \ \&\ T_o \text{ are in } ^\circ\text{C})$$

$$V_{max} = 452 \gamma\, d^{5/2} \left(\frac{T_s - T_o}{T_o} \right)^{1/2} \qquad (T_s \ \&\ T_o \text{ are in } ^\circ\text{R})$$

$$D_i = \frac{2ab}{a+b}$$

$$S_{min} = 0.065 V_e^{1/2}$$

where

a	= length of the inlet (ft).
A_f	= free area of inlet grille ($A_f = abA_r$) (ft^2).
A_r	= ratio of free area to total grille area.
b	= width of the inlet (ft).
C_p	= specific heat (0.24 Btu/lb-°F).
d	= depth of smoke layer below the lowest point of the exhaust inlet (ft).
D_i	= effective diameter of the inlet (ft).
K_s	= fraction of convective HRR in smoke layer.
m	= exhaust mass flow (lb/s).
N	= number of inlets (dimensionless).
Q_c	= convective heat release rate of fire (Btu/s).
S_{min}	= minimum edge-to-edge separation between inlets (ft).
T_o	= ambient temperature (°F or °R).
T_s	= temperature of smoke layer (°F or °R).
V	= volumetric flow of smoke exhaust (cfm).
V_e	= volumetric flow rate of one exhaust inlet ($V_e = V/N$) (cfm).
v_i	= average velocity at inlet ($v_i = V_e/A_f$) (fpm).
V_{max}	= maximum volumetric flow rate without plugholing (cfm).
γ	= exhaust location factor (dimensionless).

Input:

Q_c =	616	Btu/s
T_o =	92.4	°F
m =	70.09	lb/s
V =	61,258	cfm
d =	8.50	ft
γ =	1.0	(See notes 1, 2 and 3)
K_s =	0.5	(See note 7 above)
a =	3.00	ft
b =	3.00	ft
N =	3	Number of Inlets
A_r =	0.96	(In the absence of better data, 0.5 is suggested.)

Output:

T_s =	110.7	°F
V_{max} =	17,333	cfm
V_e =	20,419	cfm
S_{min} =	9.29	ft (See note 6 above.)
D_i =	3.00	ft
d/D_i =	2.83	
v_i =	2363	fpm

Check 1: The requirement of note 4 above is satisfied.

Check 2: CAUTION: The requirement of note 5 above is not satisfied.