SMOKE CONTROL
SYSTEM DESCRIPTION,
RATIONAL ENGINEERING ANALYSIS, and
SPECIAL INSPECTION AND TESTING PROCEDURE

for

RENAISSANCE SUITES AT FLATIRON
BROOMFIELD, COLORADO

Prepared for:

AMPAM COMMERCIAL
3730 E. 48th Ave.
Denver, CO, 80216

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Prepared by:

Alexander Boome Consulting Engineering Ltd.
1500 Howe Street, Suite 104
Vancouver, British Columbia,
Canada, V6Z 2N1
Tel. (604) 685-6191
Fax. (604) 685-4100
E-mail: inquiry@abceltd.com

1.0 <u>INTRODUCTION</u>

The Renaissance Suites at Flatiron is a nine-story, plus Lower Level or Basement, hotel located in Broomfield, Colorado. The building was designed under the 1997 Uniform Building Code plus Broomfield, CO amendments, including section 905. The construction is TYPE I, FIRE RESISTIVE.

This report is intended to provide the rational engineering analysis required by Section 905, describe the smoke evacuation and control systems, and to identify test procedures for the special inspection of the smoke control system upon system completion. The test parameters are per the criteria outlined in Section 905 of the Uniform Building Code as appropriate to the systems designed for this building.

This document is to be <u>only</u> read in conjunction with the project Drawings and Specifications, and the RJA "Conceptual Smoke Control System Design and Performance Specification" for the Renaissance Suites at Flatiron, in Broomfield, Colorado.

2.2.4 <u>STAIRWELLS</u> in Stairs Number, "S-1", and "S-2" are pressurized to the extent of still allowing a door opening force of only 30 pounds (see section 3.1.81). The Stairwell

Pressurization air is not heated. Capacity of the system is 1,000 cfm per door, which allows 2,500 cfm through the roof relief. The ***pressure*** is ***maintained*** in the stairwell ***between*** the range of a minimum of ***0.10*** inches w.g, and maximum of ***0.21*** inches w.g.. The pressure differences are between the Stairwell and the Building, see definitions in equation 3 below.

The maximum static pressure difference between the Stairwell and the Building, at the top of the Stairwell is the sum of the minimum pressure difference (at the bottom) of 0.05 inches plus the pressure drop across the crack at the Vestibule Door (see Section 2.2.5) of 0.05 inches, and the Stack effect (see Section 3.1.2.1) of 0.11 inches, for a total of 0.21 inches. This is acceptable maximum pressure, since it is less than the maximum allowable pressure difference across the Corridor door of 0.35 inches, which corresponds to a maximum door opening force of Thirty pounds (see Section 3.1.81).

The leakage from the stairwells is calculated using EQUATION 3 Leakage from Stairwells (Equation 10.14, page 144, Klote)

$$Q = K_f \times N \times A_{sb}\left(\frac{\Delta p^{3/2}_{sbt} - \Delta p^{3/2}_{sbb}}{\Delta p_{sbt} - \Delta p_{sbb}}\right)$$

where:

Q = volumetric flow rate, cfm

K_f = 1920 = constant at 5,500 feet elevation

$$K_f = \frac{K_g}{\sqrt{\rho}}$$

K_g = 475 unit conversion

$\sqrt{\rho} = \sqrt{0.0614} = 0.2478$

N = number of floors

Δp_{sbt} = pressure difference from stairwell to building at stairwell top, inches w.g.

Δp_{sbb} = pressure difference from stairwell to building at stairwell bottom, inches w.g.

A_{sb} = flow area equivalent, between building and stairwell, ignore parallel flow effects of vestibule, use walls to building, and crack at corridor door.

$$Q = 1920 \times 10 \times A_{sb}\left(\frac{0.21^{3/2} - 0.10^{3/2}}{0.21 - 0.10}\right) = 1920 \times 0.58 \times 10 \times A_{sb}$$

$$A_{sb} = 0.001\,{}^{ft^2}\!/_{ft^2\,wall} \times 504\,ft^2\,stairwell + 0.168\,ft^2\,\text{double door crack}\left(1/16\,inch, gasket\right) = 0.672\,ft^2$$

$$Q = 1127 \times 10 \times A_s = 1127 \times 10 \times 0.672\,ft^2 = \underline{\underline{7{,}573\,cfm}}$$

The pressure difference between the stairwell and the corridor is maintained by the adjustable counterbalanced barometric relief damper. The adjustable counterbalanced barometric relief damper is an "over-pressure" automatic relief louver in the top of the stair that will open if the pressure exceeds the set point of 0.21 inches w.g..

If a door on a non fire floor is opened then excess air can exit thru the barometric relief damper and help keep the door opening force below the minimum.

The approximate total building stairwell effective "all-doors-closed" leakage area for Stair One or Two is 6.72 ft^2, and the leakage per floor is about 757 cfm. In the above calculation (equation 3) I neglected the effect of the vestibule because the parallel path area calculation is most affected by the smallest series area. The smallest series area is the corridor door crack (1/16 inch -tight gasket fit, with 1/16 inch at bottom). Since we are supplying 10,000 cfm and the calculated leakage is 7,573 cfm, then enough air quantity is being supplied, with an allowance for 2,500 cfm relief at the barometric damper at the top of the Stairway..

3 RATIONAL ENGINEERING ANALYSIS

3.1 UBC Section 905.2.2 **Rationality.**

3.1.1 UBC Section 905.2.2.1 **General.** Systems or methods of construction to be used in smoke control shall be based on a rational analysis in accordance with well-established principles of engineering. The analysis shall include. but not be limited by, Sections 905.2.2.2 through 905.2.2.6 below.

3.1.1.1 *Analysis*

The major driving forces causing smoke movement are stack effect, buoyancy, expansion, wind, and the HVAC system. Generally, in a fire situation, smoke movement will be caused by a combination of these driving forces

3.1.2 UBC Section 905.2.2.2 **Stack effect**. The system shall be designed such that the maximum probable normal or reverse stack effects will not adversely interfere with the system's capabilities. In determining the maximum probable stack effects. altitude. elevation. weather history and interior temperatures shall be used.

3.1.2.1 *Analysis*

Since the stairwells are normally heated, reverse stack effect in the winter will not be considered. The driving temperature difference will cause air to flow up the stairwells in a normal flow. In the summer the outside temperature is close to the indoor temperature. Again, a very small temperature difference is present, and will not generate pressure differences large enough to affect the smoke control system. The largest stack effect pressure difference will be at the maximum height above the neutral plane, during the winter. The calculations below are for winter ASHRAE design conditions only.

“When it is cold outside, there often is an upward movement of air within building shafts, such as stairwells, elevator shafts, dumbwaiter shafts, mechanical shafts, or mail chutes. This phenomenon is referred to as normal stack effect. The air in the building has a buoyant force because it is warmer and less dense than the outside air. This buoyant force causes air to rise within the shafts of buildings. The significance of normal stack effect is greater for low outside temperatures and for tall shafts. However, normal stack effect can exist in a one story building.

When the outside air is warmer than the building air, a downward airflow frequently exists in shafts. This downward airflow is called reverse stack effect. The pressure difference due to either normal or reverse stack effect is expressed as:

EQUATION 7, Stack Effect Pressure Difference, density (Equation 5.22, page 67, Klote, 2002)

$$\Delta P = \left(\rho_O - \rho_I\right) g h$$

where

ρ_O = **air density outside the shaft**

ρ_I = **air density inside the shaft**

g = **gravitational constant**

h = **distance from the neutral plane**

The neutral plane is an elevation where the hydrostatic [static] pressure inside the shaft equals the hydrostatic pressure outside the shaft. Using the ideal gas law ($P=\varrho RT$), the above relation can be expressed as:

EQUATION 8, Stack Effect Pressure Difference, Derivation (Equation 5.25, page 67, Klote, 2002),

$$\Delta P = \frac{g \times Patm}{R}\left(\frac{1}{To} - \frac{1}{T_1}\right)h$$

$\Delta P =$ **Pressure difference outside to inside**

$P_{atm} =$ **absolute atmospheric pressure**

$R =$ **gas constant of air**

$To =$ **absolute temperature of outside air**

$T_I =$ **absolute temperature of inside air**

For standard atmospheric pressure of air the above relation becomes:

EQUATION 9, Stack Effect Pressure Difference, temperature (Equation 5.26, page 67, Klote, 2002)

$$\Delta P = K_s\left(\frac{1}{To} - \frac{1}{T_1}\right)h$$

$\Delta P =$ **pressure difference, in H_2O**

$To =$ **absolute temperature of outside air degrees R**

$T_I =$ **absolute temperature of inside air degrees R**

$K_s =$ **coefficient, at 5,500 feet elevation 6.23**

$h =$ **distance above the neutral plane, ft**

Note the above information is from “Design of Smoke Control Systems for Buildings”, John H. Kote, page 6.

Solving EQUATION 9 for the Renaissance Suites at Flatiron, Conditions

Let $T_o = -5^o F + 460 = 455^o R,$

and $T_I = 70^o F + 460 = 530^o R,$

and $h \cong 116/2 = 58 feet,$

then,

$$\Delta P = 6.23\left(\frac{1}{455} - \frac{1}{530}\right)58$$

$$\Delta P = \underline{\underline{01123 \text{ inches w.g.}}} \approx \underline{\underline{011}}$$

For the Renaissance Suites at Flatiron the building is 116 ft tall, with a neutral at the mid-height, with an ASHRAE design “Annual Extreme Daily Mean Minimum Winter Outside Dry Bulb” temperature of -3^0F (however, we are using -5^0F for design) and an inside temperature of 70^0F, maximum pressure difference due to stack effect is 0.11 in H_20. This means that at the top building, a shaft would have a pressure of 0.11 in greater than the outside pressure, due to stack. At the bottom of the shaft, the shaft would have a pressure of 0.05 inches plus 0.05 inches for the pressure drop thru the Vestibule door, or 0.10 inches minimum at the bottom. The top would then have 0.10 plus 0.11, for a total of 0.21 inches, as previously mentioned. This is acceptable since it is less than the 30 lb door opening force of 0.35 inches.

Note: The testing procedure needs to prove that the system can overcome the result of stack effect on a day when the worst-case stack effect occurs.

The stack effect on the day of testing shall be calculated, and the effect shall be subtracted from the design pressure differential. The resulting required pressure shall be used as the pass-fail criteria during measurement by the Special Inspector.

The lowest outside air temperature acceptable for this building, that will allow only 30 pounds of stairwell door opening force due to stack effect is -109.8°F, see below.

Rearranging and solving EQUATION 9,

$$To = \frac{1}{\left(\frac{\Delta P}{K_s \times h} + \frac{1}{T_1}\right)} = \frac{1}{\left(\frac{0.35 in}{623\left(\frac{lb}{ft^2 \times in}\right) \times 58 ft} + \frac{1}{530}\right)} = 3502^\circ R = \underline{\underline{-109.8^\circ F}}$$

As stated below the ASHRAE design “Annual Extreme Daily Mean Minimum Winter Outside Dry Bulb” temperature is -11^0F (normal design is -3^0F, we used -5^0F) . It is unlikely that the Broomfield, CO outdoor temperature will exceed -109.8°F for very long.

“Smoke movement from a building fire can be dominated by stack effect, as evidenced in the following descriptions of different types of smoke movement resulting from normal and reverse stack effect.

In a building with normal stack effect, the existing air currents ... can move smoke considerable distances from the fire origin. If the fire is below the neutral plane, smoke moves with the building air into and up the shafts. This upward smoke flow is enhanced by any buoyancy forces on the smoke existing due to its temperature. Once above the neutral plane, the smoke flows out of the shafts into the upper floors of the building. If the leakage between floors is negligible, the floors below the neutral plane, except the fire floor, will be smoke-free.

Smoke from a fire located above the neutral plane is carried by the building airflow to the outside through openings in the exterior of the building. If the leakage between floors is negligible, all floors other than the fire floor will remain smoke-free. When the leakage between floors is considerable, there is an upward smoke movement to the floor above the fire floor.

... These forces tend to affect the movement of relatively cool smoke in the reverse of normal stack effect In the case of hot smoke, buoyancy forces can be so great that smoke can flow upward even during reverse stack effect conditions." Ibid, page 8.

3.1.9 UBC Section 905.3.3 **Maximum pressure difference.** The maximum air pressure difference across a smoke barrier shall be determined by required door-opening forces. The actual force required to open exit doors when the system is in the smoke-control mode shall be in accordance with Section 1004. The calculated force to set a side-hinged. swinging door in motion shall be determined by

Equation 14, for the door opening force results from the "sum of the moments", and sum of the forces on the door, as shown by Klote, page 105, (2002). The density on either side of the door is the same. The density, and associated elevation are not factors in this equation. Equation 14 does not need a correction for density.

EQUATION 14, Door opening force (UBC 97, Equation (5-1), Section 905.3.2, page 1-97)

$F = F_{dc} + K(WA\Delta P) / 2(W - d)$

WHERE:

$A =$ door area, ft^2.

$d =$ distance from door handle to latch edge, feet.

$F =$ total door opening force, pounds.

$F_{dc} =$ force required to overcome closing device, pounds.

$K =$ 5.2.

$W =$ door width, feet.

$\Delta P =$ design pressure difference, inches water gage.

$\Delta P =$ pressure from lower floor 0.10, plus 0.11 stack, $= 0.21$ inches

3.1.81 ***Analysis***

Solving EQUATION 14 for the maximum door force with the maximum winter stack effect differential is as follows,

EQUATION 14 a, Maximum Door Opening Force at Max Stack Effect

$$F = F_{dc} + K(WA\Delta P) / 2(W - d) =$$

$$10.0 lb + 5.2\left(\frac{lb}{ft^2 \times in}\right)(3.0 ft \times 3.0 ft \times 6.67 ft \times 021 in) / 2(3.0 ft - 25 ft) = \underline{\underline{2192 lb}}$$

Rearranging and solving EQUATION 14 for the maximum stairwell pressurization with only a 30 pound door opening force is as follows,

EQUATION 14 b, Maximum Stairwell Pressure at 30 lb

$$\Delta P = \frac{(F - F_{dc}) \times 2(W - d)}{KWA}$$

WHERE:

A = door area, ft^2.

d = distance from door handle to latch edge, feet.

F = total door opening force, pounds.

F_{dc} = force required to overcome closing device, pounds.

K = 5.2.

W = door width, feet.

ΔP = design pressure difference, inches water gage.

$$\Delta P = \frac{(30lb - 10.0lb) \times 2(3.0ft - 0.25ft)}{5.2\left(\frac{lb}{ft^2 in}\right) \times 3.0ft \times 3.0ft \times 6.67ft} = \underline{\underline{0.35 \text{ inches w.g.}}}$$

As previously stated this is acceptable, since the lowest floor Corridor door pressure is 0.05, plus 0.05 for Vestibule pressure drop, plus stack effect of 0.11, for a total top floor pressure of 0.21 inches, which is less than the 30 lb force pressure drop of 0.35 inches.

3.1.8 905.6.1 **Design Fire General.** The design fire shall be based on a Q of not less than 5,000 Btu per second unless a rational analysis is performed by the designer and approved by the building official.

3.1.8.1***Analysis***

The design fire area for a mercantile or residential occupancy is 100ft^2, Q of 5000 Btu/sec, divided by the heat release rate of 50 Btu/sec/ft$^{2.}$

3.1.8.1 905.6.2.1 **Rational analysis, Factors considered.** The engineering analysis shall include the characteristics of the fuel, fuel load, effects included by the fire. whether the fire is likely to be steady or unsteady.

3.1.8.4.1 ***Analysis***

Two fires can be analyzed, a corridor fire in the high-rise guestroom corridor, and a lower level public space fire.

Fire in the high-rise guestroom corridor,

The hydraulically most remote guestroom corridor sidewall sprinkler is on the nineth floor, head number 502 on the "Firetrol Protection Systems" sprinkler drawings. Head #502 delivers 26.0 gpm to a fire area, at 21.56 psi, this head is about four feet from a non numbered head in the corridor. Assume flow in Corridor heads is 26.0 gpm.

A second head will be involved. Because the corridor is 6.0 feet wide. The head spacing is fifteen-feet-six inches. Since the design fire is 100ft^2, that means that the design fire area is sixteen-feet-six-inches by six feet wide. The second head, it is assumed, delivers 26.2 gpm at 21.9 psi, K=5.60. However only one head is used in the following analysis.

The sensible and latent cooling effect of the sprinklers can be represented as follows,

EQUATION 16, Design fire heat load (by definition, UBC)

For one head, similar to #502,

$$Q_{fire} = Q_c = Q \times 76.54\%$$

WHERE:

Q = **design fire from UBC, Section 905.6.1, Btu/sec.**

Q_{fire} = **total heat of design fire, Btu/Hr.**

$$Q_{fire} = 5{,}000\left(\frac{Btu}{\text{sec}}\right) \times 76.54\% \times 3600\left(\frac{\text{sec}}{Hr}\right) = \underline{\underline{18{,}000{,}000\left(\frac{Btu}{Hr}\right)}} \times 76.54\% = \underline{\underline{13{,}777{,}513\left(\frac{Btu}{Hr}\right)}}$$

Note; UBC 97, 905.5.2.2 requires that Q_c (the convective portion of the Design Fire) be not less than 70% of the Design Fire. Since Q_c is selected at 76.54% of the Design Fire, then it meets the requirement of UBC.