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DONNEES POUR LE CALCUL DES CONDUITS DE FUMEE

SOMMAIRE

On propose souvent un conduit de fumée comme moyen de diminuer la quantité de fumée à l'étage atteint par un incendie et de réduire le transfert de la fumée à d'autres étages. Le présent article étudie l'application d'un conduit de fumée, puis élabore une méthode de calcul des dimensions du conduit. Il contient également un tableau des dimensions de conduits de fumée en fonction des paramètres suivants: la hauteur de l'édifice, la surface de plancher et la caractéristique de fuite des murs de tels conduits.

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Basis for the Design of Smoke Shafts

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National Research Council of Canada

How do you determine the required size of smoke shafts, and what is a proper application of them? These are questions examined by the authors.

SMOKE shaft is defined in this paper as a vertical shaft of noncombustible construction that extends from the bottom to the top of a building and has openings at the top to the outside and openings to floor spaces at each story. These openings are sealed with dampers. In the event of a fire, only the damper on the fire floor and the top outside damper are opened to exhaust smoke from the fire floor to outside. The smoke shaft is intended primarily to assist in preventing smoke from spreading. This is achieved by the venting action of the smoke shaft, which creates suction pressures in the fire compartment and which, in turn, induce flow of air from adjacent areas into the fire compartment.

Smoke spread from the fire compartment to the various parts of a building can occur under the mechanism of local stack action caused by high temperature in the fire compartment, thermal expansion, and stack action caused by building heating during cold weather. These mechanisms can result in pressures in the fire compartment that are higher than those in adjacent areas with a consequent flow of smoke into them. Of the three mechanisms, studies indicate that building stack action during cold weather creates the greatest potential for smoke spread from floor to floor in the event of fire.[1] It is suggested, therefore, that smoke shafts be designed to inhibit the spread of smoke under this condition.

OPERATION OF SMOKE SHAFTS

To illustrate the operation of a smoke shaft, a 6-story building with vertical shafts is considered. Figure 1 shows the pressure and flow patterns of such a building caused by building stack action during cold weather with no smoke shaft being present. It is assumed that the leakage openings in the exterior and interior walls of a building are uniformly distributed, so that the neutral pressure plane of a building is located at midheight. It is seen that for any story below midheight, the pressures of the floor

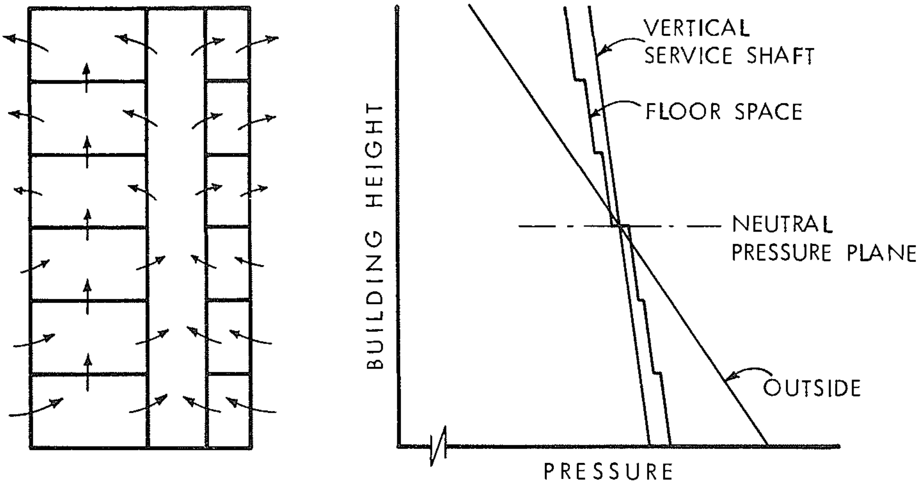

Figure 1. Pressure and flow patterns caused by stack action.

spaces are higher than those in the vertical service shafts at the same level. The reverse is the case for stories above midheight. If a fire occurs in a story below midheight, smoke can spread from the fire floor to upper floors through the vertical service shafts. If a fire occurs in a story above midheight, the pressure pattern caused by building stack action would tend to inhibit such movement. By venting the fire floor located below midheight with a smoke shaft, pressures in the fire floor can be reduced, so that these pressures are lower than those in the vertical service shafts at the same level as well as in the floors above and below; thus the smoke is confined within the fire floor enclosure (Figure 2). The size of smoke shaft required is that necessary to provide sufficient venting of the fire floor to achieve this condition.

If there is a large opening, e.g., broken windows, in the exterior walls of a fire floor located at low level, the pressures in the fire floor will approach those of outside and are likely to exceed those of the vertical service shafts, such as elevator and stair shafts, at the same level. Under this condition, a smoke shaft would be ineffective in preventing smoke spread into the vertical shafts and upper floors. A smoke shaft is, therefore, more effective in windowless buildings.

The required suction pressures in the floor spaces depend on the pressure differences across the walls of the vertical service shafts. In Figure 1 the pressure differences are represented by the horizontal distance between the lines that denote the shaft and floor space pressures. The greatest adverse pressure difference occurs at the bottom level of the building, and hence the greatest venting action is required by the smoke shaft at that level. Stories at or near ground level therefore establish minimum size requirements of smoke shafts.

In Figure 2, the smoke shaft pressure, assuming no pressure losses inside the shaft, is indicated by a dotted line. As the smoke shaft is open to out-

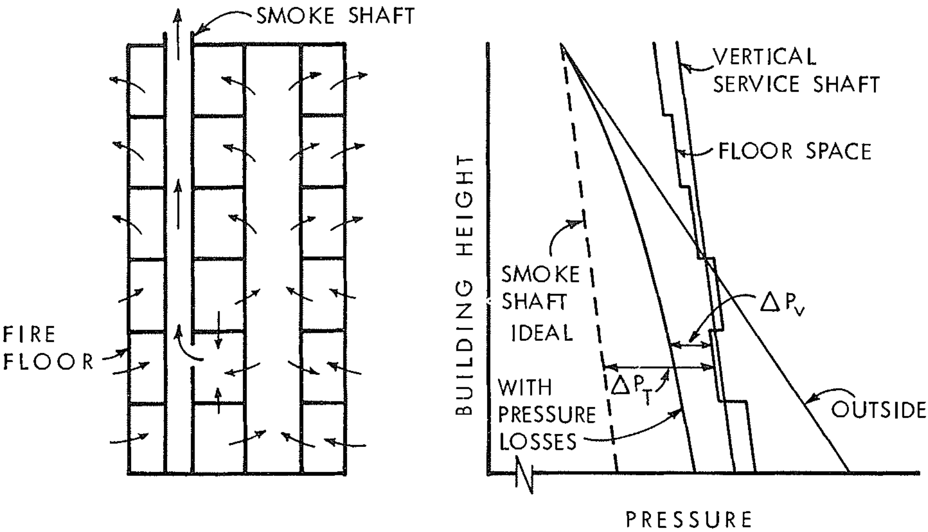

Figure 2. Pressure and flow patterns with smoke shaft operation.

side at the top, pressure at the top level of the smoke shaft is equal to that of outside. Assuming an air temperature inside a smoke shaft equal to that of the building (assumption of a low temperature fire), the slope of the line representing the smoke shaft pressure is the same as that of the floor space pressure. The total pressure, ΔP_T, acting across the vent opening at the bottom is represented by the horizontal distance between the lines that denote floor space and smoke shaft pressures.

The theoretical value of ΔP_T for an idealized situation is, in fact, one-half of the pressure difference due to stack action and is given by

$$\Delta P_T = 3.8\, H \left(\frac{1}{T_o} - \frac{1}{T_i} \right) \qquad (1)$$

where ΔP_T = total pressure acting across the vent opening with no pressure losses inside smoke shaft, inch of water; H = building height, ft; T_o = outside temperature, degree Rankine; and T_i = inside temperature, degree Rankine.

The values of ΔP_T were calculated using Equation 1 and are plotted against building height for various outside temperatures in Figure 3, based on an inside temperature of 75° F. The exhaust of gases through the smoke shaft causes a decrease in building pressures which results in the shifting of the floor space pressure characteristic to the left of the pressure diagram of Figure 2. This results in a lower effective value of ΔP_T and hence, in the calculation of smoke shaft sizes, 80 percent of the values in Figure 3 are recommended.

Thus far it has been assumed that no pressure losses occurred inside the smoke shaft. Friction, momentum, and dynamic pressure losses can occur

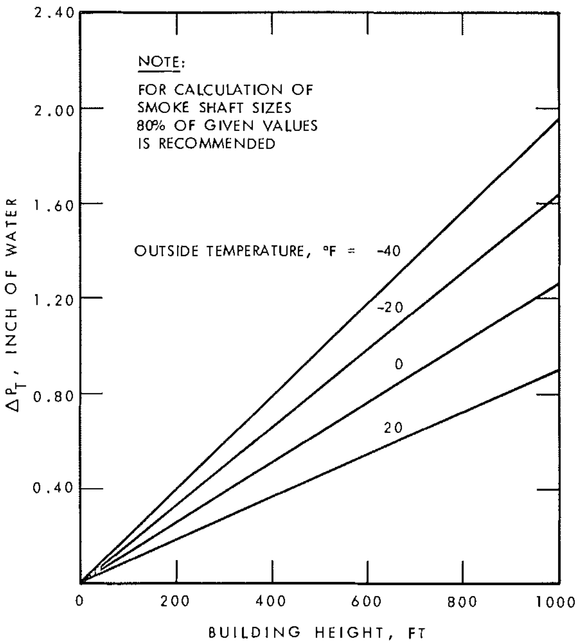

Figure 3. Available total pressure vs. building height.

inside the smoke shaft as a result of gas flow through the open vent of the fire floor as well as through leakage openings in the walls of the smoke shaft. The smoke shaft pressure characteristic, including pressure losses, is also illustrated in Figure 2. The actual pressure difference across the open smoke vent ΔP_v is less than ΔP_T; the difference between the two values represents the pressure losses inside the smoke shaft.

The flow requirement to achieve the desired venting action depends on the pressure differences across the walls of the vertical shafts (see Figure 1), which in turn depends on the total stack effect and the airtightness of the various interior and exterior separations of a building. The required flow rate through the smoke shaft was determined for a 20-story model building with assumed leakage areas in the various separations consistent with airtightness measurements on several multistory buildings.[1] A plan dimension of 120 ft by 120 ft was assumed for the model. The air flow characteristics of the 20-story building were simulated with the aid of a digital computer.[2] With outside temperature of 0° F, the required flow rate to equalize pressures across the walls of the vertical shafts at the first floor level was 6600 cfm. This value was extrapolated for buildings of various heights, floor areas, and outside temperatures using the following relationship:

$$Q_v \alpha FA \tag{2}$$

$$Q_v \alpha (H)^{\frac{1}{2}} \tag{3}$$

$$Q_v \alpha \left(\frac{T_i - T_o}{T_o}\right)^{\frac{1}{2}} \tag{4}$$

where Q_v = required flow rate through floor vent of smoke shaft, and FA = floor area of a typical floor.

Using these relationships, flow requirements of a building with a typical floor area of 20,000 ft² for various outside temperatures and building heights were calculated. These are given in Figure 4.

EQUATIONS FOR THE CALCULATION OF SMOKE SHAFT SIZES

The size requirement of a smoke shaft depends on the total pressure available and the required venting capacity. The total pressure is the sum of the various pressure losses and it can be expressed as follows: Total pressure (ΔP_T) = pressure loss across floor vent (ΔP_v) + friction pressure loss inside shaft (ΔP_f) + momentum pressure loss inside shaft caused by leakage flow through shaft walls (ΔP_m) + exit pressure loss (ΔP_e).

(a) ΔP_v = entrance loss plus bend loss minus static pressure regain from

vent to shaft $= K^1 \dfrac{\rho V_1^2}{2g} - \left(\dfrac{\rho V_1^2}{2g} - \dfrac{\rho V_2^2}{2g}\right),$

where ρ = air density, V_1 = velocity through floor vent, V_2 = velocity inside shaft at floor vent level, and K^1 = combined loss coefficient (a

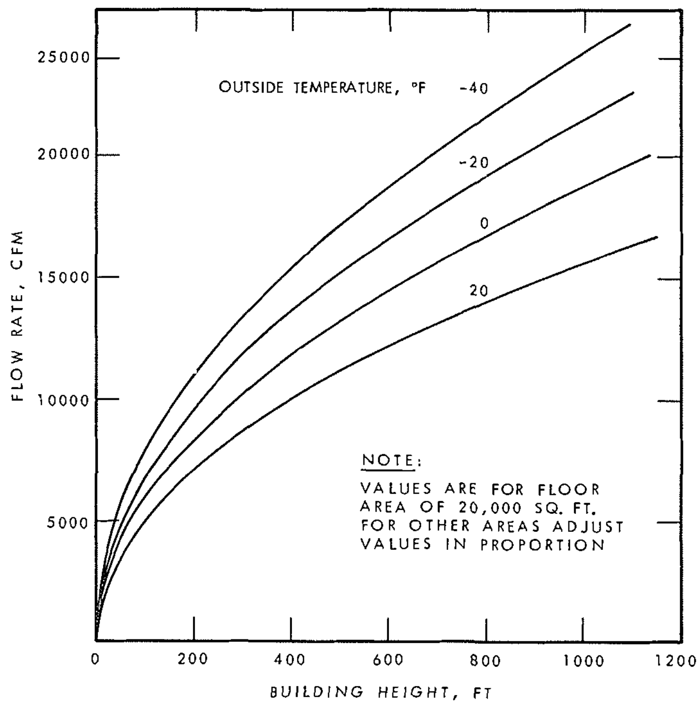

Figure 4. Required venting capacity of smoke shaft.

value of 2.8 was assumed; 1.5 for entrance loss and 1.3 for bend loss).

(b)
$$\Delta P_f = f \frac{L}{D_s} \frac{\rho[(V_2 + V_3)/2]^2}{2g}$$

where f = friction factor, L = height of shaft, D_s = equivalent diameter of shaft, and V_3 = velocity at top of shaft below exit.

(c)
$$\Delta P_m = 2\left(\frac{\rho V_3^2}{2g} - \frac{\rho V_2^2}{2g}\right)$$

(d)
$$\Delta P_e = \frac{1}{C_d^2}\left(\frac{\rho V_4^2}{2g} - \frac{\rho V_3^2}{2g}\right)$$

where V_4 = Exit velocity at top of the shaft and C_d = Discharge coefficient at exit opening.

Summing up all the losses, we have,

$$\Delta P_T = K^1 \frac{\rho V_1^2}{2g} - \left(\frac{\rho V_1^2}{2g} - \frac{\rho V_2^2}{2g}\right) + f \frac{L}{D_s} \frac{\rho[(V_2 + V_3)/2]^2}{2g} + 2\left(\frac{\rho V_3^2}{2g} - \frac{\rho V_2^2}{2g}\right) + \frac{1}{C_d^2}\left[\frac{\rho V_4^2}{2g} - \frac{\rho V_3^2}{2g}\right] \quad (5)$$

The right hand side of equation (5) can be arranged as follows:

(a)
$$\text{Let } K \frac{\rho V_1^2}{2g} = K^1 \frac{\rho V_1^2}{2g} - \left(\frac{\rho V_1^2}{2g} - \frac{\rho V_2^2}{2g}\right)$$

where K is a factor to be determined

$$= \left[K^1 - 1 + \left(\frac{V_2}{V_1}\right)^2\right] \frac{\rho V_1^2}{2g}$$

$$= \left[K^1 - 1 + \left(\frac{A_v}{A_s}\right)^2\right] \frac{\rho V_1^2}{2g}$$

therefore,

$$K = K^1 - 1 + \left(\frac{A_v}{A_s}\right)^2 \quad (5a)$$

where A_v = Area of shaft vent opening and A_s = Cross-sectional area of smoke shaft.

(b) Let XV_2 = average velocity through smoke shaft where X is a factor to be determined.

$$XV_2 = \frac{V_2 + V_3}{2} = \frac{V_2 + (V_2 + Q_l/A_s)}{2}$$

so

$$X = 1 + \tfrac{1}{2}\left(\frac{Q_l}{A_s V_2}\right)$$

but

$$A_s V_2 = Q_v$$

therefore

$$X = 1 + \tfrac{1}{2}\,\frac{Q_l}{Q_v} \tag{5b}$$

where Q_l = total leakage flow through walls of smoke shaft and Q_v = flow through shaft vent opening

(c) Let $M\,\dfrac{\rho V_2^2}{2g}$ = momentum pressure losses, where M is a factor to be determined

$$\frac{M\rho V_2^2}{2g} = 2\left[\frac{\rho V_3^2}{2g} - \frac{\rho V_2^2}{2g}\right] = 2\,\rho\left[\frac{(V_2 + Q_l/A_s)^2}{2g} - \frac{V_2^2}{2g}\right]$$

therefore

$$M = \left[4\,\frac{Q_l}{Q_v} + 2\left(\frac{Q_l}{Q_v}\right)^2\right] \tag{5c}$$

(d) Let $N^1\,\dfrac{\rho V_2^2}{2g}$ = exit pressure loss, where N^1 is a factor to be determined

$$N^1\,\frac{\rho V_2^2}{2g} = \left(\frac{1}{C_d}\right)^2\left[\frac{\rho V_4^2}{2g} - \frac{\rho V_3^2}{2g}\right]$$

$$= \frac{1 - \left(\dfrac{A_e}{A_s}\right)^2}{C_d^2}\,\frac{\rho V_4^2}{2g} \quad (\text{since } A_s V_3 = A_e V_4)$$

$$= \frac{1 - \left(\dfrac{A_e}{A_s}\right)^2}{C_d^2}\,\frac{\rho}{2g}\left[\frac{Q_v + Q_l}{A_e}\right]^2$$

where A_e = Area of opening at exit

$$= \frac{\left(\dfrac{A_s}{A_e}\right)^2 - 1}{C_d^2}\,\frac{\rho}{2g}\left[\frac{Q_v}{A_s}\left(1 + \frac{Q_l}{Q_v}\right)\right]^2$$

$$= \frac{\left(\dfrac{A_s}{A_e}\right)^2 - 1}{C_d^2}\,\frac{\rho V_2^2}{2g}\left(1 + \frac{Q_l}{Q_v}\right)^2$$

therefore

$$N^1 = \frac{\left(\frac{A_s}{A_e}\right)^2 - 1}{C_d^2}\left(1 + \frac{Q_l}{Q_v}\right)^2$$

$$= N\left[\left(\frac{A_s}{A_e}\right)^2 - 1\right]$$

where

$$N = \frac{1}{C_d^2}\left(1 + \frac{Q_l}{Q_v}\right)^2 \qquad (5d)$$

(e) Finally from flow continuity

$$V_2 = \left(\frac{Q_v}{A_v}\right)\left(\frac{A_v}{A_s}\right) \qquad (5e)$$

Substituting Equations 5a, 5b, 5c, 5d, and 5e into Equation 5 yields:

$$\Delta P_T = \left[K + f\frac{L}{D_s}X^2\left(\frac{A_v}{A_s}\right)^2 + M\left(\frac{A_v}{A_s}\right)^2 + N\left[\left(\frac{A_s}{A_e}\right)^2 - 1\right]\left(\frac{A_v}{A_s}\right)^2\right]\frac{\rho}{2g}\left(\frac{Q_v}{A_v}\right)^2$$

rearranging,

$$A_v = Q_v\left[\left(\frac{\rho}{2g}\right)\frac{K + f\frac{L}{D_s}X^2\left(\frac{A_v}{A_s}\right)^2 + M\left(\frac{A_v}{A_s}\right)^2 + N\left[\left(\frac{A_s}{A_e}\right)^2 - 1\right]\left(\frac{A_v}{A_s}\right)^2}{\Delta P_T}\right]^{\frac{1}{2}} \qquad (6)$$

To determine the value of A_v, value of $\frac{Q_l}{Q_v}$ is required for the calculation of X, M, and N. It can be expressed as follows:

$$\frac{Q_l}{Q_v} = \frac{A_l}{A_v}\left[\frac{(\Delta P_v + \Delta P_T - \Delta P_e)\ /2}{\Delta P_v}\right]^{\frac{1}{2}}$$

For simplicity ΔP_e, when it applies, can be neglected; this will result in a conservative value of A_v

$$= \frac{A_l}{\sqrt{2}\,A_v}\left(1 + \frac{\Delta P_T}{\Delta P_v}\right)^{\frac{1}{2}}$$

and
$$\frac{A_l}{A_v} = n\varphi$$

where A_l = total leakage area of shaft walls, including leakage area around closed dampers; n = number of floors; φ = leakage parameter (%) expressed as a ratio of leakage areas of shaft per floor to an open vent area; and $(\Delta P_v + \Delta P_T)/2$ = the approximate mean pressure drop across leakage openings.

Now
$$\Delta P_v = K \frac{\rho V_1^2}{2g}$$
$$= K \frac{\rho}{2g} \left(\frac{Q_v}{A_v}\right)^2$$

Then
$$\frac{Q_l}{Q_v} = \frac{n\varphi}{\sqrt{2}} \left[1 + \frac{2g\ \Delta P_T}{\rho K} \left(\frac{A_v}{Q_v}\right)^2\right]^{\frac{1}{2}} \tag{7}$$

ΔP_T and Q_v are given in Figures 3 and 4. K, A_l/A_v, A_v/A_s, A_s/A_e, f, and L depend on the construction of the smoke shaft and are input to the equations. The solution of A_v requires the use of Equations 5a, 5b, 5c, 5d, 6 and 7, and involves a trial and error calculation. Initially a value of A_v is assumed and using Equation 7 a value of Q_l/Q_v is obtained. This value is used to calculate values of K, X, M and N from equations 5a, 5b, 5c and 5d, which are inserted into Equation 6 to solve for A_v. If the assumed and the calculated values of A_v do not agree, then the average of the two values is used for the next trial. The iterative calculation is repeated until the correct value of A_v is obtained. This procedure is facilitated with the use of a digital computer. The solution can also be obtained using a graphical method. If A_s and A_l are known as for an existing shaft, then the procedure for calculation is to assume a value for A_v and calculate A_l/A_v and A_s/A_v. Using these values Q_l/Q_v can be calculated from Equation 7. A_v is then calculated from Equation 6. This procedure is repeated until an agreement is obtained between the assumed and calculated values.

The values of ΔP_T and ΔQ_v for the calculation of smoke shaft sizes were based on the pressure differences caused by building stack action. Where a mechanical exhaust is used, the value of Q_v is that necessary to create adequate suction pressure on the fire floor under the condition of little stack action and is limited by the maximum permissible pressure difference (0.04 in. of water) across the stair doors of the fire floor. A value of six to eight air changes per hour is suggested. The value of ΔP_T for this case is the static pressure drop across the induced draft fan. The required shaft size can then be calculated as before. The required fan capacity is the sum of Q_v and Q_l. The selection of shaft and fan sizes are based on the assumption that all building air handling systems are shut down during a fire emergency.

CALCULATION OF SMOKE SHAFT SIZES

Using Equations 6 and 7, smoke shaft sizes were calculated for various building heights, floor areas and outside air temperatures. The floor vent area and the cross-sectional area of the shaft were assumed to be the same ($A_s/A_v = 1$) as this will give the minimum cross-sectional area of the shaft and hence the most economical size in terms of construction and use of rentable space. Also the opening at the top and the cross-sectional area of the shaft are assumed to be the same [$A_s/A_e = 1$]. The interior surface of the smoke shaft was assumed to be relatively smooth (relative roughness of 0.001) with a friction factor of 0.025[3]. Vent sizes were also calculated with variation in the ratio of leakage area of walls per story to floor vent open area (φ) from 0 to 0.05. The calculated vent sizes are given in Table 1. Table 1 indicates that the vent sizes are approximately proportional to the floor areas. Calculation of vent sizes for various outside temperatures indicated that they are independent of outside temperature where it is below building temperature.

Figure 5 illustrates the vertical distribution of pressure losses for a smoke shaft 240 ft high with leakage parameter φ of 3 percent. Outside temperature was assumed to be at 0° F. The variation of pressure losses caused by friction and momentum change are shown in this graph. It is seen that, for this case, pressure losses due to momentum change are greater than those caused by friction. It is expected that pressure losses due to momentum change become more significant as the value of φ increases. It is also shown that the flow of the smoke shaft at the top is almost twice as great as that through the floor vent at the bottom as a result of the leakage flow through the walls of the smoke shaft.

Figure 6 illustrates the effect of leakage parameter φ of the shaft walls on the required vent sizes. With shaft walls of airtight construction, a vent and shaft size of 15 ft^2 is adequate for a building up to 1,000 ft in height. With an increase in the leakage parameters φ, there is a significant increase in the required smoke shaft sizes. For example, with a φ of 5 percent there is a large increase in the smoke shaft sizes with building height; from the graph it would appear that the practical smoke shaft size is limited to a building of 300 ft in height.

The foregoing indicates that the size of smoke shaft depends greatly on the shaft wall leakage and, therefore, the necessity of ensuring a relatively airtight shaft wall construction. Leakage openings can occur between closed damper and frame and between frame and wall as well as in the wall itself. For masonry wall construction the leakage area in terms of equivalent orifice area is approximately 0.025 ft^2 per 100 ft^2 of wall area using data for a 13–in. plain brick wall at 0.30 in. of water pressure difference obtained from laboratory measurements.[4] For a smoke shaft and vent

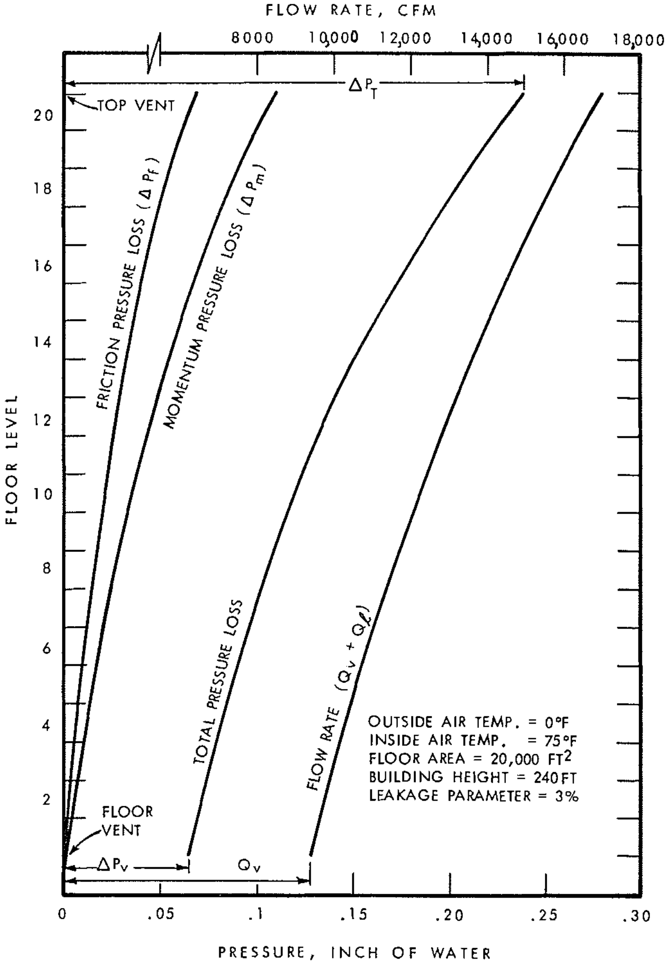

Figure 5. Pressure losses and flow distributions in a smoke shaft for a 20-story building.

size of 15.0 ft,[2] the value of φ using this leakage area would be approximately 0.3 percent neglecting damper leakage. Depending on the type of masonry construction and workmanship under field conditions, the value of φ can be as high as 1.5 percent based on unpublished field measurements. If the surface of the masonry walls is parged then the value of φ would be expected to be less than 1 percent. A metal liner inside the smoke shaft with sealed joints or smoke shaft of monolithic concrete construction would also greatly reduce the possibility of significant leakage flow.

Cracks formed between closed damper and frame and between frame and shaft wall are another potential source of leakage. Using recommended clearances for a single blade fire damper construction of 3/8–in. vertical clearance and 1/32–in. horizontal clearance,[5] the leakage opening for a 3–ft by 5–ft damper represents a value of φ of 1.5 percent. A leakage opening between frame and shaft wall of 1/16 in. gives a total leakage para-

TABLE 1. *Minimum Sizes of Floor Vent Opening and Cross-Sectional Area of Smoke Shaft (ft^2)*

Floor Area Sq. ($Ft.^2$)	*Building Height (ft)* 60	120	240	360	480	600	720	840	960
					Leakage Parameter = 0%				
2,000	1.0	1.1	1.3	1.5	1.6	1.8	1.9	2.0	2.1
5,000	2.2	2.5	2.9	3.2	3.5	3.8	4.0	4.2	4.4
10,000	4.3	4.8	5.4	5.9	6.4	6.8	7.2	7.5	7.8
20,000	8.3	9.1	10.1	10.9	11.7	12.4	13.0	13.6	14.1
30,000	12.2	13.4	14.7	15.6	16.8	17.6	18.4	19.2	19.9
40,000	16.1	17.5	19.1	20.3	21.7	22.7	23.7	24.7	25.5
50,000	20.0	21.7	23.5	24.8	26.5	27.6	28.8	30.0	31.0
60,000	23.9	25.8	27.8	29.3	31.2	32.5	33.9	35.2	36.2
					Leakage Parameter = 1%				
2,000	1.0	1.2	1.5	1.9	2.3	2.8	3.5	4.4	5.7
5,000	2.3	2.7	3.4	4.1	4.9	5.8	7.0	8.5	10.6
10,000	4.4	5.1	6.2	7.3	8.7	10.2	12.1	14.5	17.6
20,000	8.5	9.8	11.6	13.5	15.8	18.3	21.3	25.2	30.0
30,000	12.6	14.3	16.8	19.3	22.5	25.8	30.0	35.1	41.4
40,000	16.7	18.8	21.9	25.1	29.0	33.2	38.3	44.5	52.3
50,000	20.7	23.2	27.0	30.7	35.4	40.3	46.3	53.8	62.9
60,000	24.8	27.7	32.0	36.2	41.7	47.4	54.3	62.8	73.2
					Leakage Parameter = 2%				
2,000	1.0	1.3	1.8	2.5	3.8	6.2	13.3	48.8	961.7
5,000	2.4	2.9	4.0	5.3	7.6	11.6	21.7	64.0	1011.4
10,000	4.6	5.5	7.3	9.5	13.2	19.4	33.6	86.2	1087.8
20,000	8.8	10.5	13.5	17.4	23.5	33.4	54.7	125.3	1235.4
30,000	13.1	15.4	19.6	24.9	33.3	46.4	74.1	160.7	1378.0
40,000	17.3	20.2	25.6	32.2	42.7	59.0	92.7	194.6	1509.7
50,000	21.5	25.0	31.4	39.5	52.0	71.3	110.5	226.6	1642.5
60,000	25.7	29.7	37.3	46.6	61.1	83.4	128.2	258.4	1768.0
					Leakage Parameter = 3%				
2,000	1.1	1.4	2.2	3.8	9.1	72.8			
5,000	2.5	3.1	4.7	7.7	16.2	93.8			
10,000	4.7	5.9	8.7	13.5	26.6	124.8			
20,000	9.2	11.3	16.1	24.3	45.4	180.2			
30,000	13.6	16.5	23.3	34.6	63.0	230.9			
40,000	17.9	21.8	30.4	44.7	80.1	279.3			
50,000	22.3	26.9	37.3	54.6	96.6	326.5			
60,000	26.6	32.1	44.2	64.4	112.9	372.2			
					Leakage Parameter = 4%				
2,000	1.1	1.5	2.8	7.2	265.0				
5,000	2.5	3.4	5.9	13.6	309.7				
10,000	4.9	6.4	10.7	23.1	378.7				
20,000	9.5	12.2	19.8	40.4	504.7				
30,000	14.1	17.9	28.6	56.9	622.0				
40,000	18.6	23.5	37.2	72.9	732.8				
50,000	23.1	29.1	45.7	88.7	841.0				
60,000	27.6	34.7	54.2	104.2	944.6				

TABLE 1. — *continued*

Floor Area Sq. (Ft.²)	*60*	*120*	*240*	*360*	*480*	*600*	*720*	*840*	*960*
				Building Height (ft)					
				Leakage Parameter = 5%					
2,000	1.1	1.6	3.7	35.0					
5,000	2.6	3.7	7.7	52.8					
10,000	5.1	6.9	13.9	79.0					
20,000	9.9	13.3	25.6	126.2					
30,000	14.6	19.5	36.8	170.5					
40,000	19.3	25.6	47.8	213.2					
50,000	24.0	31.7	58.7	254.8					
60,000	28.7	37.7	69.5	295.3					

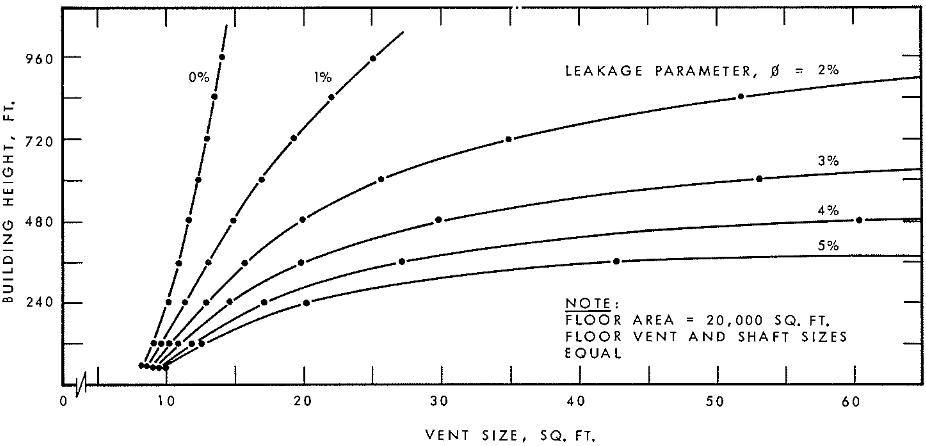

Figure 6. Effect of leakage parameter on size of smoke shaft.

meter due to a fire damper of 2 percent. With a gasketed damper, however, the leakage parameter can be expected to be less than 1 percent.

From these considerations, it is seen that the value of φ can range from less than 1 percent for tight wall and damper construction to approximately 5 percent for loose wall and damper construction. For tall buildings, according to Table 1 there is a significant economy in smoke shaft sizes with tight wall and damper construction. The above is based on $A_s/A_v = 1$. If A_s/A_v is greater than 1 then the values of φ would be higher.

Flow through a given smoke shaft with a high temperature gas at the inlet can also be calculated by using equations developed in this paper. For this case, the value of ΔP_T due to building stack action should be increased by an amount corresponding to the stack action resulting from the difference between mean smoke shaft temperature and the value of 75° F assumed in this paper. Because of cooling of gases caused by heat losses through the shaft wall and dilution caused by leakage flow, the determination of mean gas temperature for a given inlet temperature requires trial and error calculations.

SUMMARY

Equations for the sizing of smoke shafts to prevent smoke migration under the condition of building stack action have been developed. A low temperature fire was assumed with smoke shaft temperature at inside ambient temperature. Under this condition, the operation of the smoke shaft depends only on building stack action. The venting action is, therefore, greater during cold weather than mild weather. When inside and outside temperatures are equal, there will be no stack action and hence no venting action. The assumption of a low temperature fire was considered to be the critical one, as a high temperature fire would result in the passage of hot gases through the smoke shaft, which can result in greater venting action. The rate of flow of hot gases for a given smoke shaft can be calculated from equations given in this paper. These equations can also be used to calculate shaft and fan sizes if the fire floor is to be vented with an exhaust fan. With window breakage on the fire floor at a low level during cold weather, venting of a fire floor with a smoke shaft, either with or without an exhaust fan, will no longer prevent the spread of smoke into upper floors.

Smoke shaft sizes are presented for various floor areas, building heights and shaft wall leakage areas. These values indicate that the leakage parameter is an important factor in sizing a smoke shaft. This factor becomes more significant as the building height increases. The use of smoke shafts for tall buildings, therefore, necessitates a shaft wall of relatively airtight construction.

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[5] Underwriters' Laboratory, Inc., UL 555, "Standard for Fire Dampers."

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