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Tamura, G. T.; Tsuji, K.

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by G.T. Tamura and K. Tsuji

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RÉSUMÉ

La ventilation est un moyen efficace d'empêcher la fumée provenant d'un foyer d'incendie de se propager aux chemins de retraite et aux étages supérieurs des bâtiments de grande hauteur. Un système d'extraction de fumée se compose d'une gaine verticale comportant à chaque étage un volet d'obturation (normalement fermé) et, en partie haute, un aspirateur. En cas de feu, le volet d'obturation de l'étage sinistré s'ouvre et l'aspirateur se met en marche. L'air des locaux voisins est alors aspiré dans la zone sinistrée et la fumée est évacuée à l'extérieur par la gaine. Un tel système exige un bon dimensionnement de la gaine de désenfumage et l'utilisation d'un aspirateur de capacité suffisante. On présente ici une méthode de conception simplifiée avec calculs à l'appui. Les valeurs mesurées concordent assez bien avec les valeurs calculées en ce qui a trait à la perte de pression totale et au débit d'évacuation du système de désenfumage d'un immeuble à bureaux de 34 étages.

No. 2933

Simplified Method for Designing a Mechanical Smoke Exhaust System for High-Rise Buildings

G.T. Tamura
ASHRAE Member

K. Tsuji

ABSTRACT

Venting is an effective way to prevent smoke from spreading from a fire area into escape routes and upper floors of high-rise buildings. A smoke exhaust system consists of a vertical shaft with dampered openings on each floor (normally closed) and an exhaust fan at the top of the shaft. In the event of fire, the damper on the fire floor is opened and the exhaust fan operated to vent the fire floor. This induces air from the surrounding spaces to flow into the fire floor enclosure and the smoke to exit through the exhaust shaft to outdoors. Such a system requires the proper size of smoke shaft and exhaust fan capacity. A simplified design procedure and example calculations are presented. Measured and calculated values are in good agreement for total pressure loss and exhaust rate of a smoke exhaust system for a 34-story office building.

INTRODUCTION

The major paths of smoke migration from the fire region to the upper floors of high-rise buildings are stairwells, elevators, and various service shafts. In the interest of life safety, therefore, it is necessary to prevent entry and movement of smoke into and up such shafts by keeping the pressures in the fire floor enclosure lower than those in the shafts. This can be achieved by venting the fire floor enclosure with a smoke shaft that relies for its operation on stack action due to fire temperature or building heating during cold weather, or both. In the absence of stack action owing to low fire temperature and mild weather, an exhaust fan at the top of the smoke shaft can be activated. This approach to smoke control is effective for year-round operation, provided the windows of the fire floor remain intact to maintain the required pressure differential across the fire floor enclosures. This may well be the case in a building with a sprinkler system.

The design of a smoke exhaust system involves selecting the appropriate size of exhaust shaft and exhaust fan capacity. It is desirable to keep the shaft as small as possible to conserve floor space but large enough to prevent large pressure losses that would require too large an exhaust fan. Moreover, large pressure losses lead to wide variations in the venting rate from floor to floor, being least on the lower floors and greatest on the upper floors. Smoke exhaust systems must provide a venting rate on the ground floor that does not create pressure differences on the top floor sufficient to interfere with the operation of stair doors. This paper presents a simplified version of the procedure for determining flow rate and static pressure, which dictate the size of fan and smoke exhaust shaft required in high-rise buildings (Tamura and Shaw 1973).

G.T. Tamura is a senior research officer, Division of Building Research, National Research Council of Canada, Ottawa, Canada, K1A 0R6; and K. Tsuji is associate professor, University of Osaka Prefecture, Osaka, Japan (former DBR guest worker, January 1983 to January 1984).

EQUATIONS FOR PRESSURE LOSSES AND FLOW RATES

In the model for flow through a smoke shaft, illustrated in Figure 1, it is assumed that all leakage openings in the walls of the shaft can be represented by a single orifice at mid-height of each floor. The equation describing the pressures in a smoke shaft between the i th and i+1 floors is*

$$P_{s,i} - P_{s,i+1} = \left[\frac{\rho_i}{g_c}\left(\frac{Q_{s,i}}{A_s}\right)^2 - \frac{\rho_{i-1}}{g_c}\left(\frac{Q_{s,i-1}}{A_s}\right)^2\right] + \frac{g}{g_c}\rho_i H + f\frac{H}{D_s}\frac{\rho_i}{2g_c}\left(\frac{Q_{s,i}}{A_s}\right)^2 \quad (1)$$

The first, second, and third terms on the right side of Equation 1 represent pressure differences due to momentum increase, column weight of air, and frictional losses, respectively.

Using the equation of continuity, mass flow rate at the level of the ith floor, $\rho_{s,i}\, Q_{s,i}$, can be expressed as

$$\rho_{s,i}\, Q_{s,i} = \rho_{s,i-1}\, Q_{s,i-1} + \rho_{f,i}\, Q_{\ell,i} \quad (2)$$

where $\rho_{f,i}\, Q_{\ell,i}$, the leakage flow between the ith and i+1 levels is given by

$$\rho_{f,i}\, Q_{\ell,i} = \alpha\,(\phi_s + \phi_d)\, A_d \sqrt{2g_c\, \rho_{f,i}\,(P_{f,i} - P_{s,i})} \quad (3)$$

Measured values of ϕ_s and ϕ_d, leakage areas for various shaft walls and fire dampers, are given in Table 1. $\phi = \phi_s + \phi_d$ is the leakage parameter of the shaft, characterizing the total leakage area of the shaft per floor in terms of damper area.

The flow rate through an open smoke damper on the fire floor is given by

$$\rho_{f,F}\, Q_d = \alpha A_d \sqrt{2g_c\ \rho_{f,F}\ \delta P_d} \quad (4)$$

where $\delta P_d = P_{f,F} - P_{s,F}$

For a building of N floors, Q_T (total exhaust flow rate) and P_T with first floor venting are

$$Q_T = Q_{s,N} = Q_d + \sum_{i=2}^{N} Q_{\ell,i} \quad (5)$$

$$P_T = \delta P_{f,1} + \delta P_{d,1} + \frac{\rho_{s,N}}{g_c}\left(\frac{Q_T}{A_s}\right)^2 + \sum_{i=1}^{N} f\frac{H}{D_s}\frac{\rho_{s,i}}{2g_c}\left(\frac{Q_{s,i}}{A_s}\right)^2 - \frac{g}{g_c}NH(\rho_i - \rho_s) - \frac{g}{g_c}NH(1-\gamma/2)(\rho_o - \rho_i) \quad (6)$$

where $\delta P_{f,1} = P_{o,1} - P_{f,1}$.

The first and second terms on the right side represent the pressure differences across the floor enclosure of the first floor and the open damper of the first floor; the third and fourth terms represent the total pressure drop due to momentum increase and total friction pressure loss inside the smoke exhaust shaft. The fifth and sixth terms represent the stack effect between building and smoke exhaust shaft, and between outside and inside the building, respectively. Both terms are zero when the temperatures (and densities) in the shaft, floor space, and outside are equal, as considered in the calculation for the worst operating condition. P_T is, in effect, the pressure rise that takes place between the inlet and discharge sides of the fan. Pressure losses at the fan inlet and discharge ducts must be added to P_T in Equation 6 to determine the required fan static pressure.

The pressure difference across the top floor enclosure, when vented, can be calculated by

$$\delta P_{f,N} = P_T \frac{\delta P_{f,1}/\delta P_{d,1}}{1 + \left(\delta P_{f,1}/\delta P_{d,1}\right)} \quad (7)$$

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*Symbols are defined in the Nomenclature.

where P_T is calculated from Equation 6, δP_d from Equation 4, and $\delta P_{f,1}$ is the required pressure difference across the fire floor enclosure to prevent smoke spread to adjacent spaces.

DESIGN CONSIDERATIONS

The foregoing equations indicate that the design of a smoke exhaust system depends on the following factors:

-- Required exhaust rate and pressure difference across the enclosure of the fire floor and the leakage characteristics of the fire floor enclosure,
-- Allowable maximum pressure difference across stair doors,
-- Smoke shaft characteristics (damper area, shaft cross-sectional area, leakage areas of shaft wall and closed damper),
-- Building dimensions (floor area, floor height, and number of floors).

In the absence of building stack action, the required pressure difference across the fire floor enclosure to overcome the fire pressures is about 0.10 in of water (25 Pa) according to measurements taken by De Cicco et al. (1972) and Butcher et al. (1969). The exhaust flow rate required to achieve this pressure difference depends on the airtightness of the enclosure of the fire floor. Based on measurements in several buildings (Tamura and Shaw 1978; Tamura 1982), the required exhaust rate is about six air changes per hour for most office buildings with central HVAC systems and about four air changes per hour with compartmented HVAC systems.

The size of the damper will affect the size of the exhaust shaft, which should be kept to a minimum to conserve floor space although large enough to permit proper venting of the fire floor. With this in mind, the required damper size can be expressed in terms of A_d/A_f (ratio of damper area to floor area). The pressure drop across the damper for various values of A_d/A_f at a venting rate of six air changes per hour is given in Figure 2. For $A_d/A_f = 0.001$ and floor heights from 9.9 to 13.7 ft (3.0 to 4.2 m), the pressure drop ranged from 0.16 to 0.34 in of water (40 to 85 Pa). Increasing the value of A_d/A_f results in lower pressure drops; conversely, decreasing it results in higher values. Figure 3 shows the effect of A_d/A_f on the total exhaust rate and pressure loss for a building 20 stories high, ϕ (leakage parameter) of 0.03, and a floor area of 21 500 ft^2 (2000 m^2). For A_d/A_f below 0.001, $P_T - \delta P_{f,1}$ varies in inverse proportion to $(A_d/A_f)^2$, whereas the total exhaust rate, Q_T, changes only slightly.

Figure 4 indicates that when A_d/A_s is reduced from 1.0 to 0.5, in effect doubling the shaft area, the total pressure loss is reduced by 60%; below 0.5 the reduction is small. $P_T - (\delta P_{f,1} + \delta P_{d,1})$ was found to be proportional to $(A_d/A_s)^3$, whereas the reduction in the total exhaust rate, Q_T, was only 15%.

Based mainly on the values of total pressure loss shown in Figures 2, 3, and 4, values of $A_d/A_f = 0.001$ and $A_d/A_s = 0.50$ were selected as a basis for sizing the smoke exhaust shaft to permit use of a low-pressure exhaust fan without large shaft areas. With these values, the total exhaust rates, Q_T, per 21 500 ft^2 (2000 m^2) floor area and total pressure losses, P_T, were calculated; they are given in Tables 2, 3, and 4 for fire floor venting rates of four, six, and eight air changes per hour, respectively. These are for buildings of 4 to 100 floors, leakage parameter, ϕ, of the smoke exhaust shaft of 0 to 0.05, floor areas between 10 700 and 65 000 ft^2 (1000 to 6000 m^2), and floor-to-floor height of 12 ft (3.6 m). For fan selection, fan inlet and discharge losses must be added to the values of total pressure losses in the tables.

Figure 5 illustrates the increase in total pressure loss and total exhaust rate with increase in number of floors. The pressure difference and the venting rate of the first floor are design values and are therefore constant, regardless of building height. The pressure differences and the venting rate of the top floor (indicated by dashed lines) are, as expected, greater than those of the first floor, and increase with building height. A maximum pressure difference of 0.30 in of water (75 Pa) across the floor enclosure was selected from the point of view of difficulty of door operation. Where this limit was exceeded, the values of total pressure loss and exhaust rate were omitted from Tables 2, 3, and 4. The maximum venting rate for the top floor is, in effect, limited to 1.73 times that of the first floor.

Figures 6 and 7 show that the total exhaust rate is proportional to both floor area and floor height. The total pressure loss, however, remains fairly constant with floor area greater than 10 700 ft^2 (1000 m^2), as shown in Figure 6, but it increases proportionally with floor height as shown in Figure 7.

Since high temperatures are to be expected, heat-rated fans, ductwork, and shaft should be considered in the design of a smoke exhaust system (Klote and Fothergill 1983). As well, installation of end switches on dampers should be considered to indicate fully open or fully closed damper positions at the central alarm and control facility; during a fire this will ensure that only the fire damper on the fire floor is open, and during maintenance it will facilitate checking of the operation of each damper.

SIMPLIFIED DESIGN PROCEDURE

1. Assume A_d/A_f (ratio of damper to floor area) = 0.001, and A_d/A_s (ratio of damper to shaft area) = 0.5.
2. Decide on the required exhaust rate at the fire floor, depending on the air leakage characteristic of the floor enclosure: buildings with compartmented HVAC system - 4 air changes per hour; buildings with central HVAC system - 6 ach; buildings with central HVAC system and loose interior construction of floor enclosure - 8 ach.
3. Estimate ϕ (leakage parameter) of the smoke exhaust shaft using Table 1.
4. With selected exhaust rate from step (2) and leakage parameter from step (3), obtain values of Q_T (total exhaust rate) and P_T (total pressure loss) from Tables 2, 3, or 4. Interpolate to obtain values for number of floors and ϕ other than those given in the tables.
5. For floor areas other than 21 500 ft^2 (2000 m^2), adjust Q_T in proportion to the floor area. No adjustment necessary for P_T.
6. For floor heights other than 12 ft (3.6 m), adjust Q_T and P_T in proportion to the floor height.
7. For A_d/A_f other than 0.001, adjust value of $P_T - \delta P_{f,1}$ in inverse proportion to $(A_d/A_f)^2$ to obtain a new value of P_T. No adjustment is necessary for Q_T.
8. For A_d/A_s other than 0.5, adjust value of $P_T - (\delta P_{f,1} + \delta P_{d,1})$ in proportion to $(A_d/A_s)^3$. Calculate $\delta P_{d,1}$ using Equation 4. No adjustment is necessary for Q_T.
9. Check the pressure difference across the stair doors of the top floor when this floor is vented, using Equation 7. If $\delta P_{f,N} > 0.30$ in of water (75 Pa), increase the size of shaft and/or damper or change the shaft construction or damper type to decrease the value of ϕ and repeat steps 1 through 9.
10. Select exhaust fan size using the final value of Q_T and P_T plus pressure losses associated with inlet and outlet duct connections to the fan.

An example calculation is given in Appendix A, and an approximate check of the simplified calculation procedure involving comparison of the calculated and measured values from a 34-story office building is given in Appendix B.

SUMMARY

A simplified design procedure has been developed to aid in designing smoke exhaust systems for high-rise buildings. It involves 1) selecting the size of damper and exhaust shaft, based on floor area, and 2) selecting a fan with the required capacity from tables of total exhaust rate and pressure loss, based on the required venting rate, total number of floors, and leakage parameter of the smoke shaft.

The values in the tables are based on first floor venting without stack action, due either to low gas temperature in the exhaust shaft or to small indoor-to-outdoor temperature difference. This was considered to be the worst operating condition for a smoke exhaust system. Because the venting rate of the top floor is higher than that of the first floor, pressure differentials across the enclosure during venting of the top floor were checked for possible interferance with the operation of stair doors.

Step-by-step design and sample calculations are given. Measured values for total exhaust rate and pressure loss from a 34-story office building and those calculated using the simplified method are in good agreement.

NOMENCLATURE

A_s = cross-sectional area of smoke shaft [m^2]
A_d = area of damper [m^2]
D = hydraulic diameter [m]
f = friction factor (0.025)
g = acceleration due to gravity [m/s^2]
g_c = dimensional constant $[1 \frac{kg}{N} \cdot \frac{m}{s^2}]$
H = height of floor [m]
P = static pressure [Pa]
δP = pressure difference [Pa]
Q = flow rate [m^3/s]
α = flow coefficient (0.6)
γ = thermal draft coefficient
ρ = air density [kg/m^3]
ϕ_s = leakage area of shaft wall per floor $/A_d$
ϕ_d = leakage area of damper per floor $/A_d$

Subscripts

d = damper
f = floor
F = fire floor
i = floor location
ℓ = leakage flow in shaft wall
N = top floor
o = outside
s = smoke exhaust shaft
T = total

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APPENDIX A

Example calculation

Dimensions of floor: (100 × 160 × 10 ft) (30 × 50 × 3.3 m)
Total number of floors: 30
Smoke exhaust shaft: plastered masonry wall
Smoke vent: curtain fire damper
Building with central HVAC system, average tightness of floor enclosure A_d/A_f = 0.0008, A_d/A_s = 0.55

1. Floor area A_f = 100 × 160 = 16 000 ft^2 (1500 m^2)
   Damper area A_d = 0.0008 × A_f = 12.8 ft^2 (1.2 m^2)
   Size of smoke shaft A_s = 12.8/0.55 = 23.3 ft^2 (2.2 m^2)

2. The value of six air changes per hour is selected for the venting rate of the first floor.

3. ϕ = 0.035 (from Table 1, ϕ_d= 0.025 for curtain fire damper and ϕ_s = 0.005/0.5 = 0.01 for plastered masonry wall).

4. From Table 3, for a 30-story building:

   Total pressure loss: P_T = 0.63 in of water (158 Pa) for ϕ = 0.03
   P_T = 0.76 in of water (189 Pa) for ϕ = 0.04
   Total exhaust air rate: Q_T = 56 500 cfm (26.7 m^3/s) for ϕ = 0.03
   Q_T = 68 600 cfm (32.4 m^3/s) for ϕ = 0.04

   Interpolating for leakage parameter of 0.035,

   P_T = 0.63 + (0.76 − 0.63) × 0.5 = 0.69 in of water (172 Pa)
   Q_T = 56 500 + (68 600 − 56 500) × 0.5 = 62 500 cfm (29.5 m^3/s)

5. As the total exhaust air rate of 62 500 cfm (29.5 m^3/s) is for floor area of 21 500 ft^2 (2000 m^2), adjust the value in proportion to floor area of 16 000 ft^2 (1486 m^2).
   $$Q_T = 62\ 500 \times \frac{16\ 000}{21\ 500} = 46\ 500 \text{ cfm } (21.9\ m^3/s)$$

6. Q_T and P_T calculated thus far are for floor height of 12 ft (3.6 m). Adjust values to conform to floor height of 10 ft:

   P_T = 10/12 × 0.69 = 0.57 in of water (142 Pa)
   Q_T = 10/12 × 46 500 = 38 750 cfm (16.3 m^3/s)

7. As A_d/A_f = 0.0008, adjust $P_T - \delta P_{f,i}$ in inverse proportion to $(A_d/A_f)^2$, where $\delta P_{f,i}$ = 0.10 in of water (25 Pa)
   $$\frac{P_T - 0.10}{0.57 - 0.10} = \left(\frac{0.0010}{0.0008}\right)^2$$
   P_T = 0.83 in of water (206 Pa)

8. As A_d/A_s = 0.55, adjust $P_T - (\delta P_{f,1} + \delta P_{d,1})$ in proportion to $(A_d/A_s)^3$

   Calculate $\delta P_{d,1}$ using Equation 4:
   $$\delta P_{d,1} = P_{f,F} - P_{s,F} = \frac{\rho_{f,F}}{2g_c}\left[\frac{Q_d}{\alpha A}\right]^2$$
   $$Q_d = \frac{\text{Venting rate (ach)} \times \text{floor volume}}{60}$$
   $$= \frac{6 \times 160\ 000}{60} = 16\ 000 \text{ cfm } (7.55\ m^3/s)$$

$$\delta P_{d,1} = \frac{0.075}{2 \times 32.2 \times 3600} \left(\frac{16\ 000}{0.6 \times 12.8}\right)^2$$

$= 1.403\ lb/ft^2$

$= 0.27$ in of water (67 Pa)

$\delta P_{f,1} = 0.10$ in of water (25 Pa). (design pressure difference across the floor enclosure of first floor)

$$\frac{P_T - (0.10 + 0.27)}{0.83 - (0.10 + 0.27)} = \left(\frac{0.060}{0.55}\right)^3$$

$P_T = 0.96$ in of water (239 Pa)

9. Calculate pressure difference across top floor enclosure ($\delta P_{f,N}$) when this floor is vented, using Equation 7:

$$\delta P_{f,N} = P_T \left[\frac{\delta P_{f,1}/\delta P_{d,1}}{1 + \delta P_{f,1}/\delta P_{d,1}}\right]$$

$$= 0.96 \left[\frac{0.10/0.27}{1 + 0.10/0.27}\right]$$

$= 0.26$ in of water (64 Pa).

As this is less than 0.30 in of water, there should be no problem of stair door operation due to excessive pressure. With $A_d/A_s = 0.60$, the value of $\delta P_{f,N} > 0.30$ in of water.

10. Select exhaust fan size with $Q_T = 38\ 750$ cfm (16.3 m^3/s) and $P_T = 0.96$ in of water (239 Pa) plus pressure losses associated with inlet and outlet duct connections to the fan (use Q_T).

APPENDIX B

Approximate check of calculation procedure by comparison with measured values in a 34-story building

Test Building: Data obtained from Tamura (1982):

Outside temperature: 44 F (7°C)
Floor area: 24 000 ft^2 (2230 m^2)
Floor height: 12 ft (3.6 m)
Smoke shaft: sheet metal, multiblade dampers
Damper area: 17.8 ft^2 (1.65 m^2)
Shaft area: 33.7 ft^2 (3.12 m^2)
$A_d/A_f = 0.0007$, $A_d/A_s = 0.52$

Measurements with 5th floor vented:

Venting rate = 3.7 ach
δP across 5th floor enclosure = 0.16 in of water (40 Pa)
Measurements at 31st floor:

$Q_T = 36\ 300$ cfm (17.1 m^3/s) or 7.45 ach

$P_T = 0.52$ in of water (129 Pa)

Using simplified calculation procedure:

Measured data show that $Q_T/Q_d = 7.45/3.7 = 2$. Table 2 shows that for a building of 30 stories this ratio is obtained with $\phi = 0.02$, i.e., 32 200/16 900 = 1.9. It is, therefore, probable that for the smoke shaft of the test building ϕ was about 0.02.

Q_T = 32 200 cfm (15.2 m^3/s) from Table 2. Adjusting for the difference in floor areas according to step 5,

$$Q_T = 32\ 200 \times \frac{24\ 000}{21\ 500} = 36\ 000 \text{ cfm } (17.0 \text{ m}^3/\text{s}).$$

P_T = 0.30 in of water (76 Pa) from Table 2. Adjusting for the difference in A_d/A_f values according to step 7,

$$\frac{P_T - 0.10}{0.30 - 0.10} = \left(\frac{0.0010}{0.0007}\right)^2$$

P_T = 0.51 in of water (126 Pa).

The above calculations were based on a value of $\phi = 0.02$, which represents a relatively airtight construction. The smoke exhaust shaft of the building is constructed of sheet metal and the dampers designed to serve as smoke dampers are probably tighter than the fire dampers listed in Table 1; the actual value of ϕ is probably in the range of 0.02 to 0.03. The calculated values agree reasonably well with the measured values.

<u>NOTE</u>: Adjustment of P_T for pressure differential due to stack effect and also inlet and outlet pressure losses due to duct connections to the fan (not measured) are not included. The two effects would have opposite effects on P_T. Adjustments of Q_T and P_T for venting of the 5th instead of the 1st floor and the effect of the fan characteristic are not included.

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TABLE 1*

Leakage Area of Exhaust Shaft (ϕ)

(a) Exhaust shaft wall

Type of construction	$\phi_s (\frac{A_d}{A_s})$
Monolithic concrete	0.005
Masonry wall unplastered	0.015
Masonry wall plastered	0.005
Gypsum wallboard on steel studs (assumed)	0.010

(b) Dampered opening in exhaust shaft

Type of fire damper	ϕ_d
Curtain fire damper	0.025
Single-blade fire damper	0.035
Multiblade fire damper	0.045
Leakage rated dampers (see UL 555S)	

*Tamura and Shaw 1973. <u>Note</u>: A_s = cross-sectional area of venting shaft; A_d = area of fire floor damper; ϕ_s = leakage area in shaft wall per story/A_d; ϕ_d = leakage area of damper per story/A_d.

TABLE 2

Required Exhaust Rate and Pressure Loss for Fan Selection[1] - Venting Rate of 4 ach

Leakage parameter		Number of floors									
		4	7	10	15	20	25	30	50	70	100
0	Q_T(2)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)	16900 (8.0)
	P_T(3)	0.23 (57)	0.23 (57)	0.23 (57)	0.23 (58)	0.23 (58)	0.24 (59)	0.24 (60)	0.24 (62)	0.26 (64)	0.27 (67)
0.01	Q_T	17800 (8.4)	18400 (8.7)	19300 (9.1)	20500 (9.7)	21800 (10.3)	23000 (10.9)	24400 (11.5)	29900 (14.1)	36000 (17.0)	46200 (21.8)
	P_T	0.23 (57)	0.23 (58)	0.24 (59)	0.24 (60)	0.25 (62)	0.26 (64)	0.27 (66)	0.31 (77)	0.37 (92)	0.50 (125)
0.02	Q_T	18400 (8.7)	19900 (9.4)	21400 (10.1)	24200 (11.4)	26700 (12.6)	29400 (13.9)	32200 (15.2)	44500 (21.0)	59000 (27.9)	
	P_T	0.23 (58)	0.24 (59)	0.24 (61)	0.25 (64)	0.27 (67)	0.29 (71)	0.30 (76)	0.41 (103)	0.60 (149)	
0.03	Q_T	19300 (9.1)	21400 (10.1)	23700 (11.2)	27700 (13.1)	31800 (15.0)	36200 (17.1)	40700 (19.2)	61400 (29.0)		
	P_T	0.23 (58)	0.24 (60)	0.25 (63)	0.27 (67)	0.29 (73)	0.32 (80)	0.36 (89)	0.58 (144)		
0.04	Q_T	19900 (9.4)	22900 (10.8)	26000 (12.3)	31600 (14.9)	37300 (17.6)	43200 (20.4)	49800 (23.5)	81600 (38.5)		
	P_T	0.23 (59)	0.25 (61)	0.26 (65)	0.29 (71)	0.32 (80)	0.37 (92)	0.42 (106)	0.84 (208)		
0.05	Q_T	20700 (9.8)	24600 (11.6)	28400 (13.4)	35400 (16.7)	42800 (20.2)	50800 (24.0)	59500 (28.1)			
	P_T	0.24 (59)	0.25 (63)	0.27 (67)	0.31 (76)	0.36 (89)	0.42 (106)	0.51 (128)			

Note 1 Floor area = 10 700 - 65 000 ft^2 (1000 - 6000 m^2); Floor height = 12 ft (3.6 m); Damper/floor area = 0.001; Damper/shaft area = 0.50.

2 Q_T = Total exhaust air rate, cfm per 21 500 ft^2 of floor area (m^3/s per 2000 m^2 of floor area).

3 P_T = Total pressure loss, in of water (Pa). Entrance and exit losses of the fan must be added to the values of P_T for fan selection.

TABLE 3

Required Exhaust Rate and Pressure Loss for Fan Selection[1] - Venting Rate of 6 ach

Leakage parameter		Number of floors									
		4	7	10	15	20	25	30	50	70	100
0	Q_T(2)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)	25400 (12.0)
	P_T(3)	0.39 (96)	0.39 (97)	0.39 (98)	0.40 (99)	0.40 (100)	0.41 (102)	0.41 (103)	0.43 (108)	0.45 (113)	0.48 (120)
0.01	Q_T	26500 (12.5)	27300 (12.9)	28400 (13.4)	30000 (14.2)	31800 (15.0)	33500 (15.8)	35200 (16.6)	42600 (20.1)	50600 (23.9)	64400 (30.4)
	P_T	0.39 (97)	0.40 (99)	0.40 (101)	0.42 (104)	0.43 (108)	0.45 (111)	0.46 (116)	0.55 (137)	0.67 (166)	0.92 (230)
0.02	Q_T	27300 (12.9)	29200 (13.8)	31300 (14.8)	34700 (16.4)	38100 (18.0)	41700 (19.7)	45500 (21.5)	61800 (29.2)	81500 (38.5)	
	P_T	0.39 (98)	0.40 (101)	0.42 (104)	0.44 (110)	0.47 (117)	0.50 (125)	0.54 (134)	0.74 (185)	1.09 (272)	
0.03	Q_T	28400 (13.4)	31300 (14.8)	34300 (16.2)	39600 (18.7)	44900 (21.2)	50600 (23.9)	56500 (26.7)	84500 (39.9)		
	P_T	0.40 (99)	0.41 (103)	0.43 (108)	0.47 (117)	0.51 (128)	0.57 (141)	0.63 (158)	1.05 (262)		
0.04	Q_T	29200 (13.8)	33200 (15.7)	37500 (17.7)	44500 (21.0)	52100 (24.6)	60200 (28.4)	68600 (32.4)	111500 (52.6)		
	P_T	0.40 (100)	0.42 (105)	0.45 (112)	0.50 (125)	0.57 (141)	0.65 (162)	0.76 (189)	1.52 (380)		
0.05	Q_T	30300 (14.3)	35400 (16.7)	40500 (19.1)	49600 (23.4)	59500 (28.1)	70100 (33.1)	82000 (38.7)			
	P_T	0.41 (101)	0.43 (108)	0.47 (116)	0.54 (134)	0.63 (157)	0.76 (189)	0.92 (230)			

Note 1 Floor area = 10 700 - 65 000 ft^2 (1000 - 6000 m^2); Floor height = 12 ft (3.6 m); Damper/floor area = 0.001; Damper/shaft area = 0.50.

2 Q_T = Total exhaust air rate, cfm per 21 500 ft^2 of floor area (m^3/s per 2000 m^2 of floor area).

3 P_T = Total pressure loss, in of water (Pa). Entrance and exit losses of the fan must be added to the values of P_T for fan selection.

TABLE 4

Required Exhaust Rate and Pressure Loss for Fan Selection[1] - Venting Rate of 8 ach

Leakage parameter		Number of floors									
		4	7	10	15	20	25	30	50	70	100
0	Q_T(2)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)	33900 (16.0)
	P_T(3)	0.61 (152)	0.61 (153)	0.62 (154)	0.63 (157)	0.64 (159)	0.65 (161)	0.65 (163)	0.69 (172)	0.73 (181)	0.78 (194)
0.01	Q_T	35200 (16.6)	36400 (17.2)	37500 (17.7)	39600 (18.7)	41700 (19.7)	44000 (20.8)	46200 (21.8)	55500 (26.2)	65700 (31.0)	83200 (39.3)
	P_T	0.61) (153)	0.63 (156)	0.64 (159)	0.66 (165)	0.69 (171)	0.71 (178)	0.74 (185)	0.88 (220)	1.08 (269)	1.51 (377)
0.02	Q_T	36200 (17.1)	38800 (18.3)	41300 (19.5)	45500 (21.5)	50000 (23.6)	54400 (25.7)	59300 (28.0)	80000 (37.8)	105800 (49.6)	
	P_T	0.62 (155)	0.64 (160)	0.66 (165)	0.70 (175)	0.75 (186)	0.80 (199)	0.86 (213)	1.20 (300)	1.78 (443)	
0.03	Q_T	37500 (17.7)	41300 (19.5)	45100 (21.3)	51700 (24.4)	58500 (27.6)	65700 (31.0)	73300 (34.6)	108900 (51.4)		
	P_T	0.63 (156)	0.65 (163)	0.69 (171)	0.75 (186)	0.82 (204)	0.91 (227)	1.02 (254)	1.71 (425)		
0.04	Q_T	38800 (18.3)	43800 (20.7)	49000 (23.1)	57800 (27.3)	67400 (31.8)	77500 (36.6)	88500 (41.8)	143000 (67.5)		
	P_T	0.63 (158)	0.67 (167)	0.71 (177)	0.80 (199)	0.91 (226)	1.05 (261)	1.22 (305)	2.48 (618)		
0.05	Q_T	40000 (18.9)	46400 (21.9)	52900 (25.0)	64400 (30.4)	76900 (36.3)	90500 (42.7)	105300 (42.7)			
	P_T	0.64 (160)	0.69 (171)	0.74 (185)	0.86 (214)	1.01 (253)	1.22 (304)	1.49 (372)			

Note 1 Floor area = 10 700 - 65 000 ft^2 (1000 - 6000 m^2); Floor height = 12 ft (3.6 m); Damper/floor area = 0.001; Damper/shaft area = 0.50.

2 Q_T = Total exhaust air rate, cfm per 21 500 ft^2 of floor area (m^3/s per 2000 m^2 of floor area).

3 P_T = Total pressure loss, in of water (Pa). Entrance and exit losses of the fan must be added to the values of P_T for fan selection.

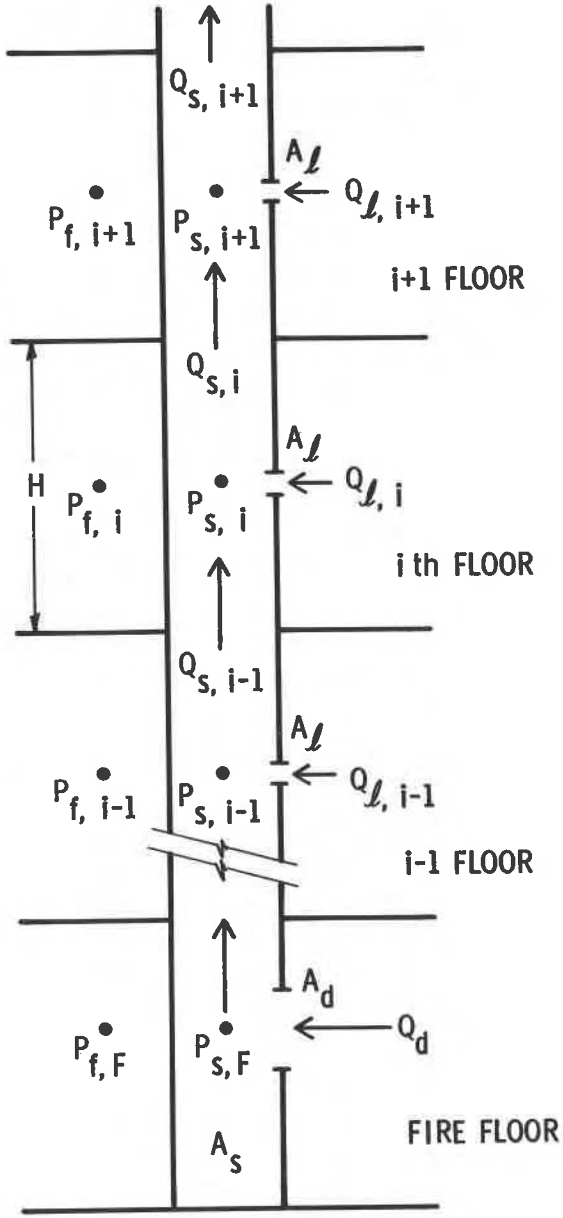

Figure 1. Pressures and flow rates of smoke exhaust shaft

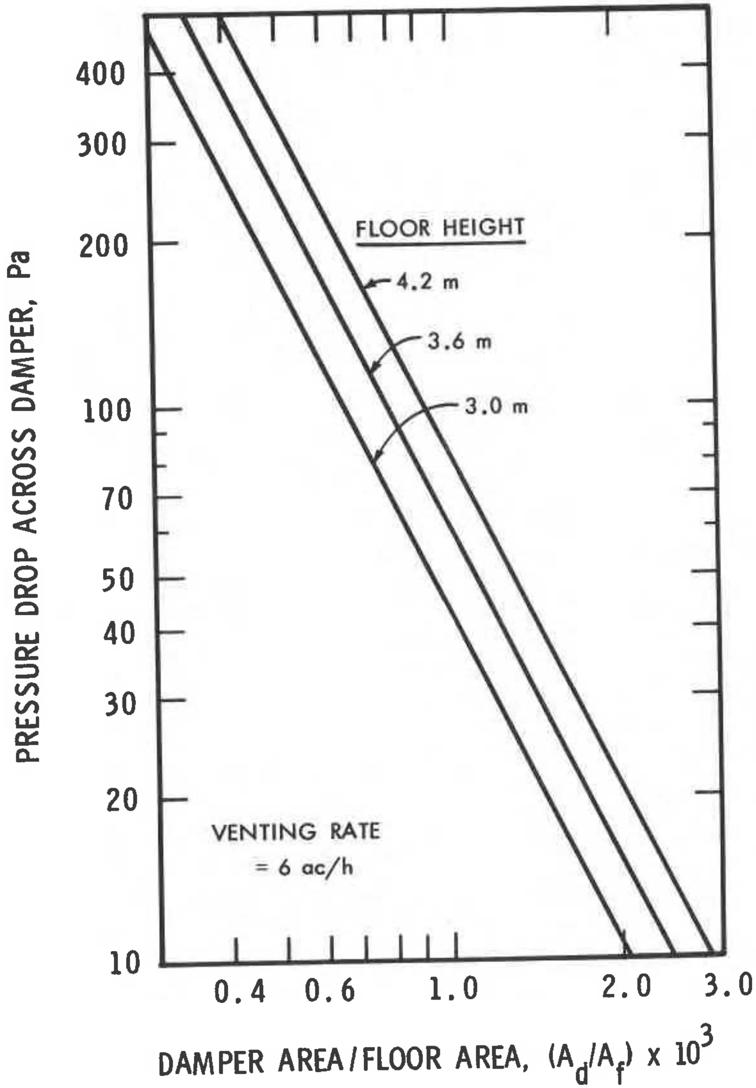

Figure 2. Relation between vent size and pressure drop across vent

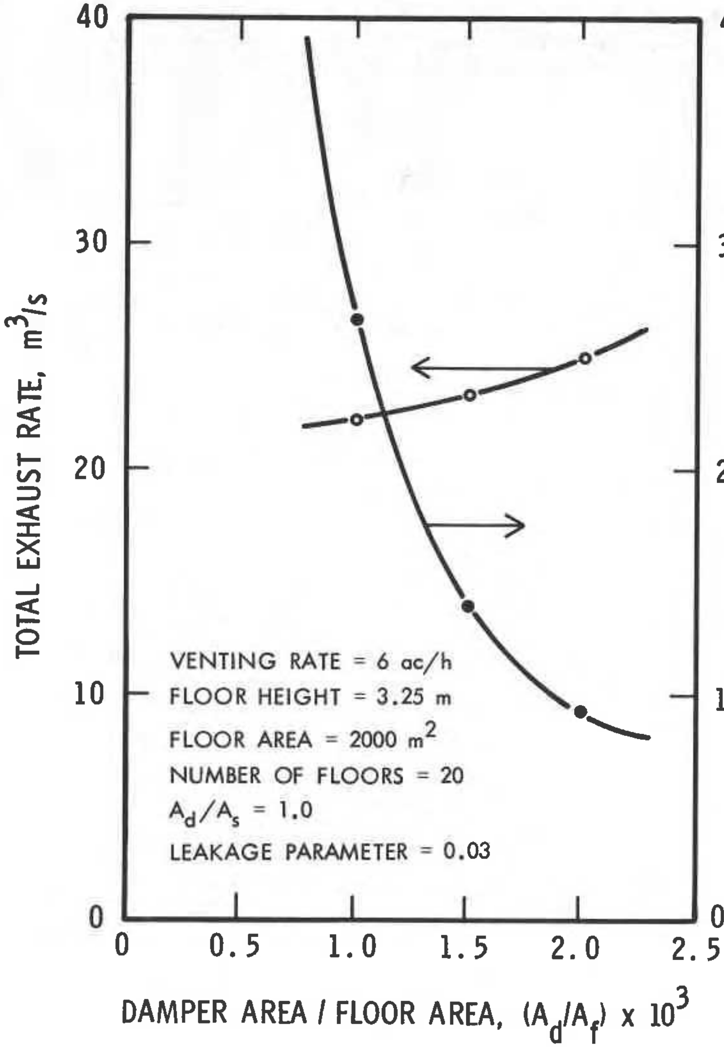

Figure 3. Relation between vent area and total exhaust rate and pressure loss

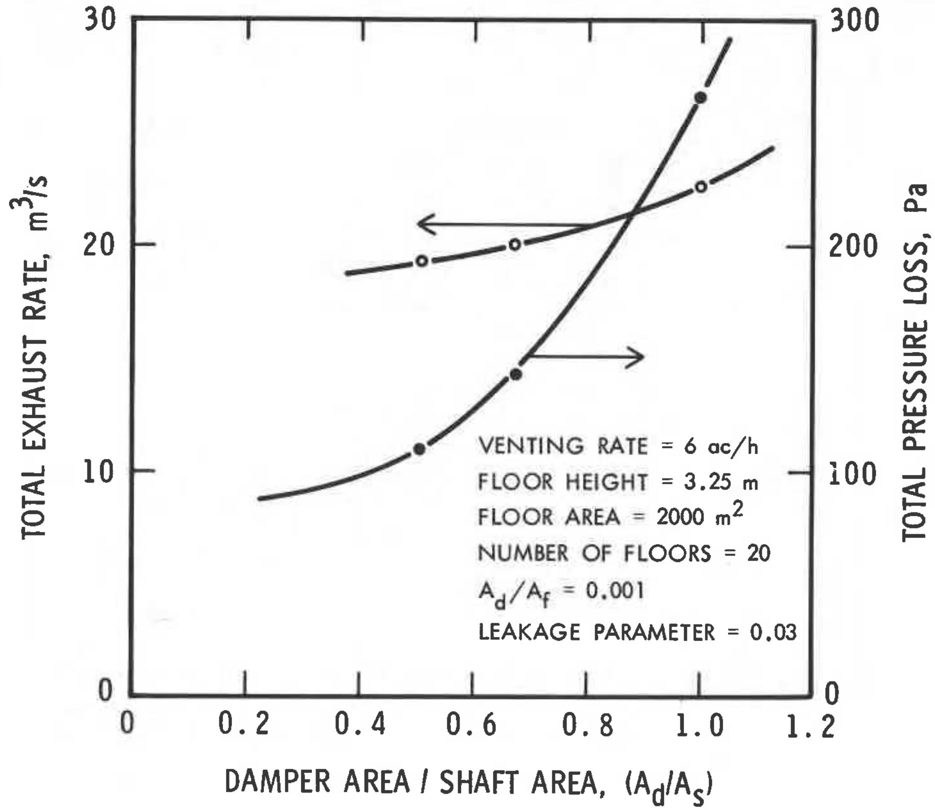

Figure 4. Relation between shaft area and total exhaust rate and pressure loss

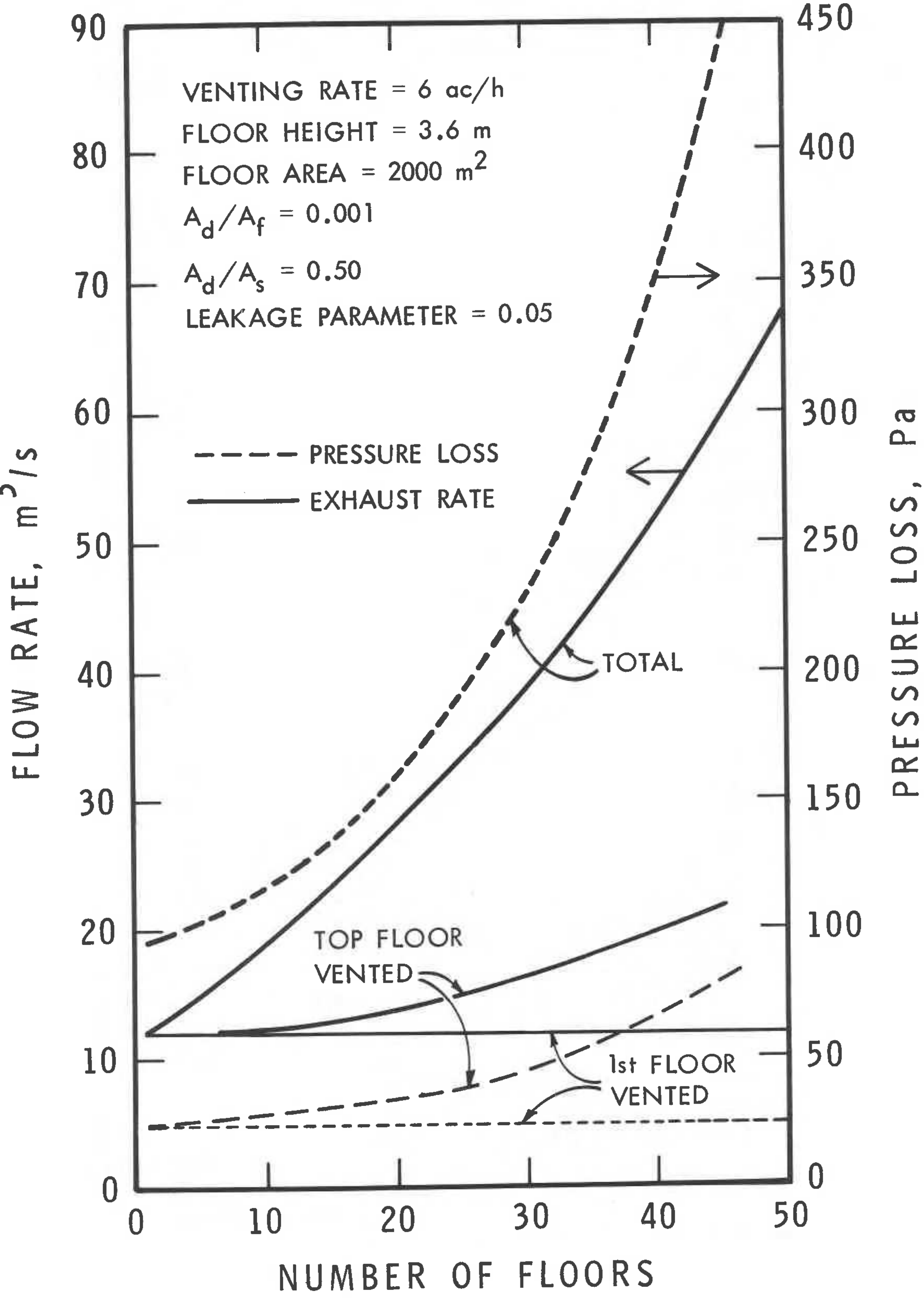

Figure 5. Relation between number of floors and exhaust rate and pressure loss

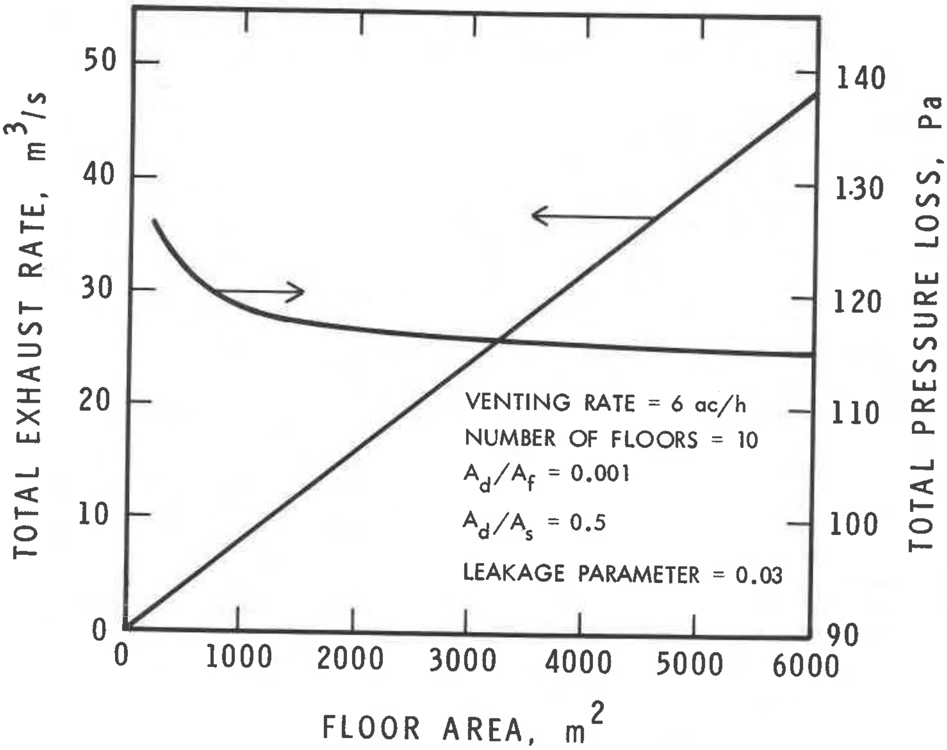

Figure 6. Relation between floor area and total exhaust rate and pressure loss

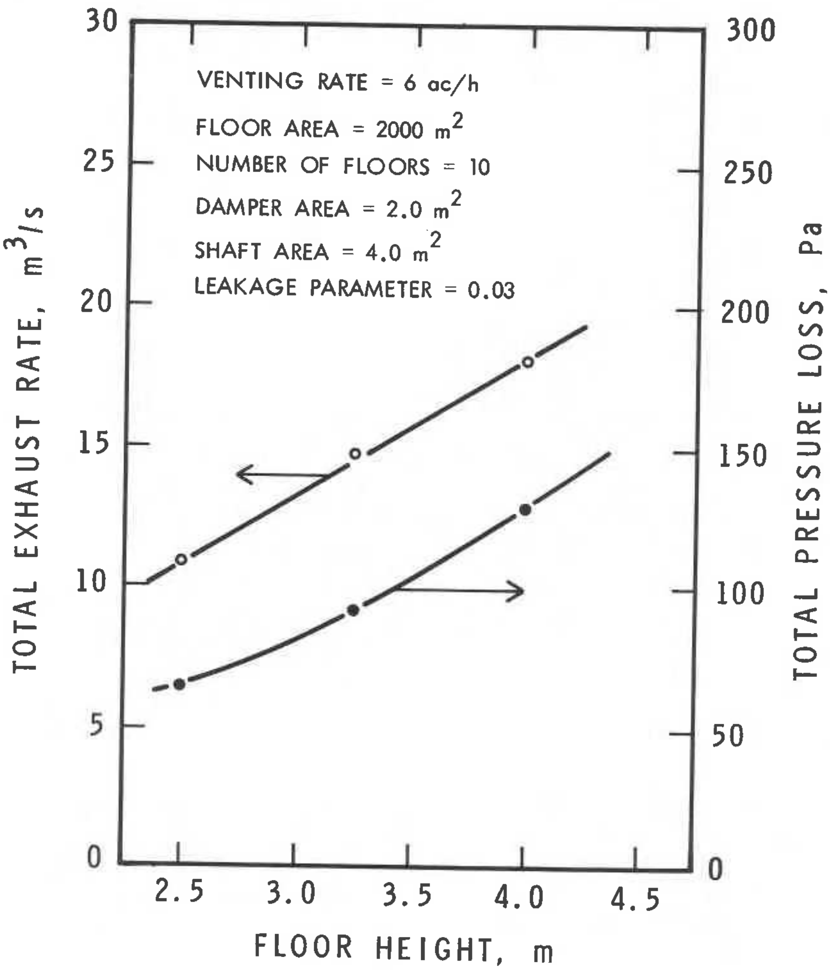

Figure 7. Relation between floor height and total exhaust rate and pressure loss

Discussion

R.N. LACEY, Lincoling Scott Australia Pty Ltd., Melbourne: The paper suggests that four, six, or eight air changes per hour are appropriate for smoke removal for various system types in office buildings and that these rates are based on measurements. Were the measurements with real fires or with test smoke?

TAMURA: The recommended venting rates were based on field measurements to determine the airtightness of a typical floor enclosure of several commercial office-type buildings. From these measurements the required venting rates were determined to produce a negative pressure of 25 Pa (0.10 in of water) on the fire floor to overcome fire pressures so that smoke migration into adjacent floors and vertical shafts is prevented.

LACEY: What adjustments are required for sprinkler control and how do they affect sprinkler controlled fires?

TAMURA: It is expected that there is little effect on sprinklered fires at the recommended venting rates as the induced air movement in the fire region is likely to be minimal at these rates.