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Natural Venting To Control Smoke Movement In Buildings Via Vertical Shafts

by
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CONDUITS VERTICAUX POUR LE CONTROLE DU TRANSPORT DE LA FUMEE DANS LE EDIFICES PAR VENTILATION NATURELLE

SOMMAIRE

Le mouvement de l'air causé par le tirage peut être un moyen important par lequel la fumee se propage d'étage en étage. Avec un feu à un étage inférieur, la fumée se propage de l'étage du feu aux étages supérieurs principalement par les conduits verticaux. Cette communication examine le contrôle de la pression dans les conduits par ventilation naturelle afin d'empêcher la fumée de pénétrer dans un conduit, ou si elle pénètre, de pourvoir les moyens de l'évacuer à l'extérieur.

La ventilation par le haut augmente la contamination du conduit par la fumée; la ventilation par le bas encourage le transport de la fumée des étages contaminés vers le conduit. Les facteurs affectant la grandeur optimale des évents pour la ventilation du haut et du bas des conduits sont étudiés. La ventilation par le haut peut aider l'évacuation de la fumée causée par un incendie dans un conduit. La grandeur d'évent requise, cependant, est plus grande que celle qui est requise dans le cas d'un incendie à un étage inférieur.

No. 2162

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A. G. WILSON

Natural Venting to Control Smoke Movement in Buildings Via Vertical Shafts

Smoke, as a result of fire, is a hazard to life not only to occupants on the fire-floor but also to others far removed from the source of fire. Studies of smoke movement in buildings[1,2,3] have shown that with a fire in a lower story, smoke under the influence of stack action can spread quickly into upper stories via vertical shafts. Many stories may become untenable in a short time and smoke in elevator and stair shafts can seriously interfere with evacuation and impede fire fighting. As the time required for evacuation increases with building height, life hazard caused by smoke is greater for taller buildings.[4]

To prevent movement of smoke from the fire-floor upwards, it is necessary to control the air flow pattern across openings in the walls of vertical shafts, so that smoke is either prevented from entering a shaft or if it does is exhausted to outside. This can be achieved through control of shaft pressures, either by mechanical supply or exhaust or natural venting. This paper deals with the natural venting method of smoke control, and examines the factors that affect natural venting of vertical shafts and vent size requirements. The study was based on a mathematical model similar to one used in a previous study of smoke movement in buildings.[1] The results of field measurements on natural venting of shafts are also reported.

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MATHEMATICAL MODEL

The basic components of the mathematical model are illustrated in Fig. 1. Major separations are exterior walls, walls of vertical shafts, and floors. To represent various shafts in a building, 2 vertical shafts are included in the model with provision for varying the size of openings to outside at the top and bottom. Leakage areas in the major separations are lumped and represented by orifice areas A_w, A_{s1}, A_{s2}, and A_f.

The value of outside absolute pressure P_{O1} (Fig. 1) is taken as normal atmospheric pressure. In the absence of wind effects, outside air pressures at other levels depend only on the density of outside air. Inside pressures at various levels, at mid-height of stories, P_f, are interrelated by the weight of the column of inside air between levels and the pressure drop across the floors. Inside pressures at various levels in the shaft, P_s, are interrelated only by the weight of the column of shaft air, assuming there is no friction pressure drop in the vertical shaft.

The problem is to determine the values of inside pressures with which a mass flow balance can be obtained for each story and for the vertical shaft. A computer program was formulated using an iterative technique to solve for all unknown inside pressures. It was designed to permit variation in the number of stories, in the size of various equivalent orifice areas, and in the values of outside and inside densities.

The equivalent leakage areas were based on air

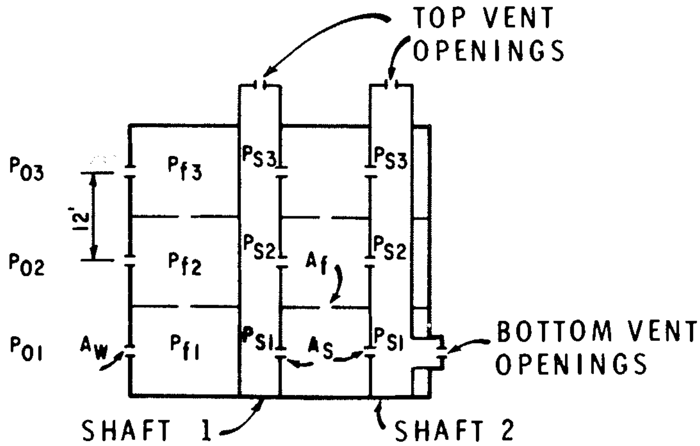

Fig. 1 Mathematical model.

leakage measurements in 4 tall office buildings,[5] and are as follows:

$A_w : A_s : A_f = 2.5 : 5.0 : 3.75$ sq ft
where A_s is the sum of the leakage areas in the walls of all vertical shafts.

These leakage areas are for each story and, for most of the calculations, are assumed to be the same for all stories.

The performance of exterior vents in vertical shafts depend on the distribution of pressure differences across major separations caused by stack action which in turn depends on the relative resistances or ratios of leakage areas of the major separations. The ratios of leakage areas for the model building are:

$$A_w : A_s : A_f = 1.0 : 2.0 : 1.5$$

These ratios are assumed to be typical for buildings of varying height and plan dimensions and were used in most of the computer calculations.

STACK ACTION AND TOP VENTING OF VERTICAL SHAFTS

Fig. 2 shows the pressure difference pattern across the major separations of a 20-story model building caused by stack action with an outside temperature of 0 F. The equivalent orifice leakage areas assumed for the major separations are $A_w : A_s : A_f = 2.5 : 5.0 : 3.75$ sq ft. The value of A_s is the sum of the leakage areas of vertical shaft 1, $A_{s1} = 4.5$ sq ft, and vertical shaft 2, $A_{s2} = 0.5$ sq ft. Both top and bottom vent openings of shafts 1 and 2 are closed. Because the changes in absolute pressure with height (both inside and outside the building) are much greater than the resultant pressure differences across major separations, it is difficult to indicate the values of these differences on an absolute pressure plot. Fig. 2 was constructed, therefore, with the outside pressure line drawn to an arbitrary, but convenient, slope. The inside pressure lines were then referenced to it, using the computed pressure differences with the pressure difference scale shown on the figure.

Fig. 3 shows the resultant air flow pattern caused by stack action as indicated by the pressure difference pattern given in Fig. 2. Air flows into the building through the outside wall below the level of the neutral pressure plane, up through floors and vertical shafts and out through the exterior wall above the level of the neutral pressure plane. The total infiltration rate into the building is 1470 lb/min with 1279 lb/min into shaft 1 and 142 lb/min into shaft 2, with the remainder through openings in the floors. Because of the series flow resistance represented by floor openings, the air flow rate up through floors is small and most of the upward flow of air occurs in the vertical shafts.

If smoke is assumed to follow the air flow pattern shown in Fig. 3, smoke migrates (through the vertical shafts) from any fire-floor below the neutral

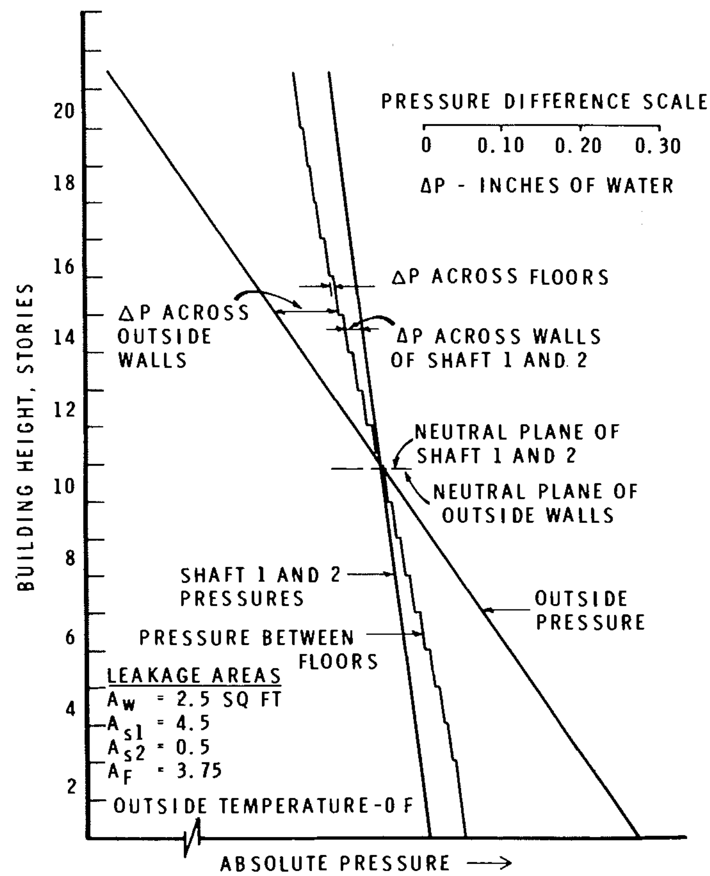

Fig. 2 Pressure pattern caused by stack action.

plane into stories above. By providing an opening at the top of the shaft, smoke in the shaft is vented to outside, thus reducing smoke contamination of upper stories. This method of overcoming smoke transfer through vertical shafts can be considered for shafts that are not intended for occupancy or evacuation.

Opening the vent at the top of the vertical shaft will raise the level of the neutral pressure plane of the shaft so that the number of stories from which air flows *into* the shaft is increased and correspondingly the number of stories into which air flows *from* the shaft is reduced. For a given building configuration, the extent of increase in the height of the neutral pressure plane depends on the vent size and location. The optimum vent size is that which raises the level of the neutral pressure plane to the level of the top story so that air from all stories below the top one flows into the vertical shaft. At the top story, the pressure difference across the wall of the vertical shaft is 0 and hence there is no air flow into or out of the shaft at this level.

For the 20-story model building, the optimum vent size for shaft 1 (leakage area/story of 4.5 sq ft) was computed to be 92 sq ft with the vent opening located one story height above mid-level of the top occupied story. Fig. 4 shows the relative values of absolute pressures with height with the top vents closed and also with the top vent of shaft 1 open

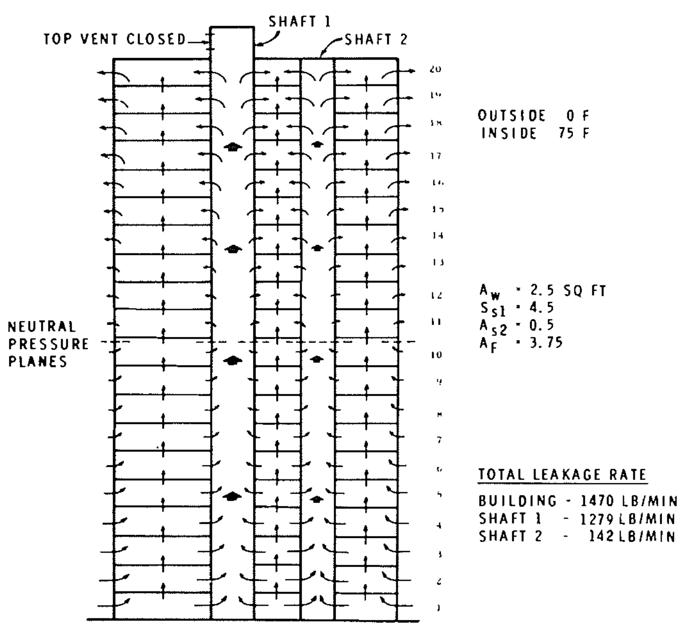

Fig. 3 Air flow pattern caused by stack action with top vent of shaft 1 closed.

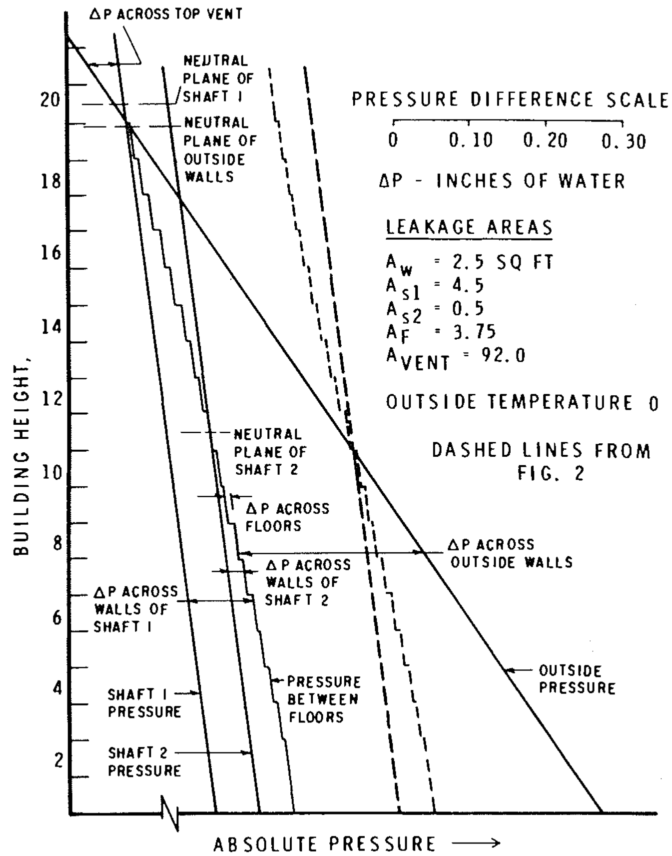

Fig. 4 Pressure pattern caused by stack action with top venting of shaft 1.

to outside. With the top vent of shaft 1 open, pressures in shaft 1 are reduced as anticipated, resulting in a shift in the pressure line to the left. At the same time, the pressures between floors and in shaft 2 are substantially reduced because of the relatively large area of openings connecting shaft 1 and the space between floors in this example. The neutral pressure plane of shaft 1 with the top open is located at the 20th story with air flow into shaft 1 from floors below the neutral pressure plane. The location of the neutral pressure plane of shaft 2 is approximately the same as before. The neutral pressure plane of the building is raised from the 11th to to the 19th story which almost doubles the pressure difference across the outside wall at the 1st story level.

Fig. 5 shows the resultant air flow pattern obtained from Fig. 4. With a fire in a lower floor, smoke in shaft 1 is exhausted to outside without contaminating the upper stories. Smoke contamination of upper stories can still occur via vertical shaft 2 although the amount is reduced. With the top vent of shaft 1 open, the total infiltration rate into the building is increased from 1470 lb/min to

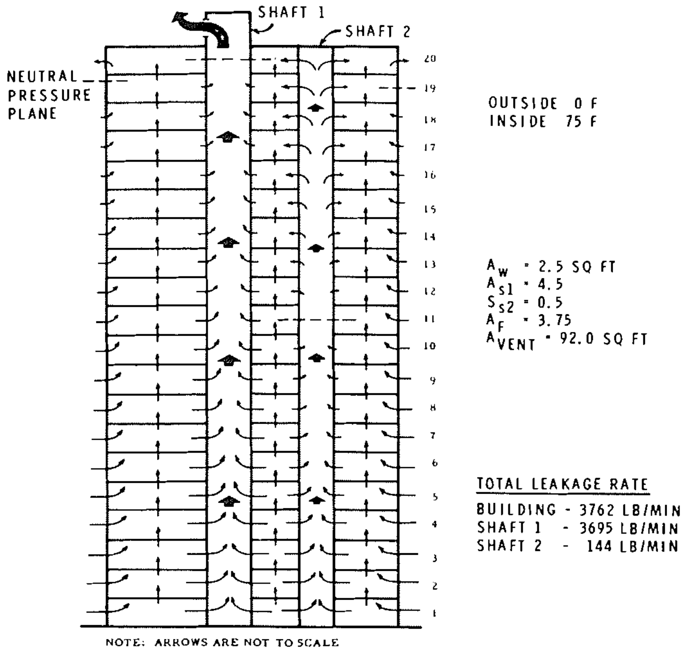

Fig. 5 Air flow pattern caused by stack action with top venting of shaft 1.

3762 lb/min. The vertical flow rate in shaft 1 is 3695 lb/min. and in shaft 2 is 144 lb/min.

In this example, vertical shafts representing 90% of total shaft leakage area/story were vented to outside. This resulted in heavy venting of the building to the outside, a reduction of pressures between floors and in the shafts and a corresponding reduction in the pressure difference across the top vent. If the vented shafts represented a smaller percentage of the total shaft leakage area, the reduction in the pressure difference across the top vent would be less and, therefore, less vent area would be required.

Fig. 6 gives the calculated optimum vent sizes for buildings with ratios of leakage areas of $A_w : A_s : A_f = 1.0 : 2.0 : 1.5$. The vents are assumed to be located 1 story height above mid-level of the top occupied story. The required vent size for a given building height is expressed as a ratio of vent size to shaft leakage area/story. Vent area requirements are a function of the ratio of leakage area/story of vented shafts relative to all shafts; curves are given for different percentage values of this ratio.

As shown in Fig. 6, the required vent size increases with building height and also increases with an increase in the leakage areas of the vented shafts. For a given shaft, the required vent size increases as the number of shafts to be vented is increased. When the leakage area of an exterior wall is less than that indicated in Fig. 6, required vent sizes are smaller than those shown in the figure as the flow rate through the exterior wall and hence through the vertical shaft is decreased; conversely, when the leakage area is greater, the required vent sizes are greater than those indicated in Fig. 6. Increasing the height of the vent above the top story or permitting the neutral pressure plane of the shaft to be located a few stories below the top one (thus accepting some smoke contamination of upper floors) would significantly reduce the required vent size. If the vents were located at the same level as the top story, the pressure difference across them would be reduced by the stack effect associated with the height of 1 story (see Fig. 4) and the optimum vent size would be correspondingly greater.

Venting of elevator shafts in the event of fire is often specified in building codes. Fig.7 shows the optimum vent size for elevator shafts as a function of building height when the leakage areas of the vented elevator shafts represent 80% of the total shaft leakage area. The required vent areas were calculated from Fig. 6 and expressed as a percentage of hoistway cross-sectional area. The total equivalent leakage area/story/car was assumed to be 1.0 sq ft[1] and the hoistway area/car was

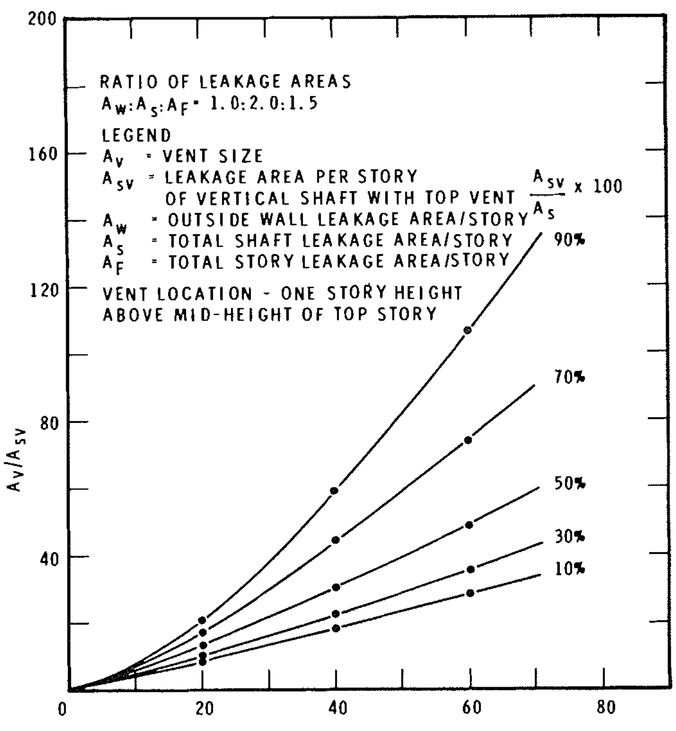

Fig. 6 Optimum size of top vent for vertical shafts.

assumed to be 64 sq ft. If 50% of the shaft cross-sectional area is assumed to be the practical maximum vent area, the corresponding maximum building height is 30 stories. The vent area specified in some building standards[6,7] is 3½% of the hoistway area which on the above basis is adequate for a building height of less than 10 stories.

Pressure measurements were conducted on a 38-story building at an outside air temperature of 28 F to determine the influence of shaft venting. This building contains a shaft, enclosing 9 elevators, with 2 top vents; the total vent area is equal to 20 sq ft or 3.0% of the hoistway area. If the leakage area into the vertical shaft is assumed to constitute 80% of the total vertical shaft area, the required vent size from Fig. 7 is approximately 80% of the hoistway area. The vent for this elevator shaft appears to be greatly undersized for the prevention of smoke transfer to upper floors.

Pressure measurements indicated that the neutral pressure level of the elevator shaft is normally located at the 14th story. When the smoke vents were opened, with the air handling system on, the neutral pressure level of the elevator shaft was

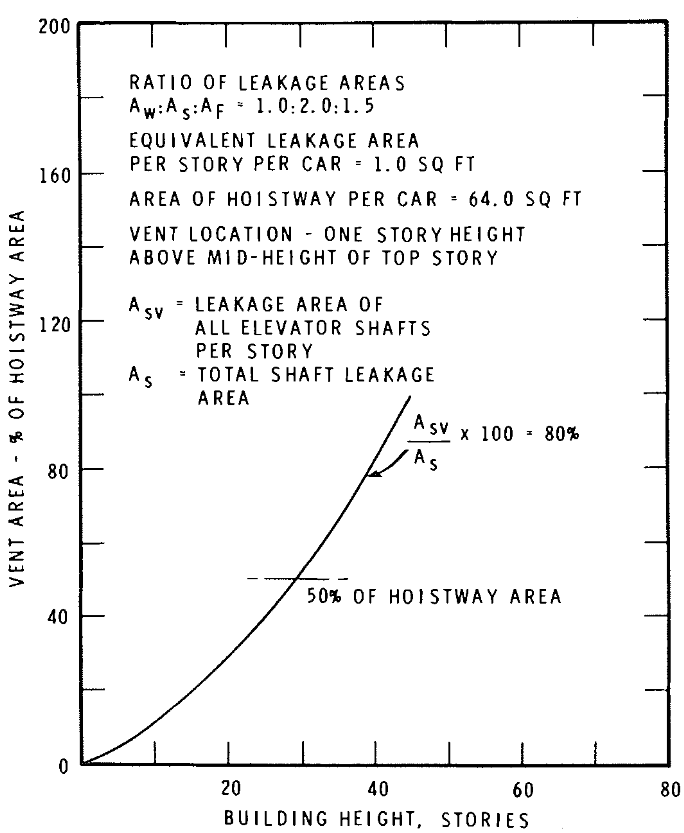

Fig. Optimum size of vent for elevator shaft.

raised from the 14th to the 22nd story. With the air handling system off, the neutral pressure level was raised to the 26th story. These measurements indicate that with the air handling system on, the existing vents are only partially effective and in the event of fire, smoke contamination of stories above the 22nd can occur via the elevator shaft. With the air handling system off, air ducts act as additional vertical shafts and increase the total shaft leakage area. The ratio of leakage of the vented shaft to total shaft leakage area is therefore decreased and, as indicated in Fig. 6, the effectiveness of the vent is increased. This was confirmed by the increase in the level of the neutral plane with the air handling system off.

So far, vent size requirements for vertical shafts have been discussed in relation to the venting of smoke entering the shaft from a fire-floor as a result of stack action caused by a difference in inside and outside temperature. Vent size requirements were also computed for the case of fire in a vertical shaft. With equal inside and outside air temperatures, an elevated shaft air temperature induces air flow into the shaft at lower stories and air flow out at upper stories; a similar air flow pattern is induced across the outside wall.[1] In the remaining shafts the air flow pattern is reversed with inflow at the top and outflow at the bottom. A fire in a shaft produces, therefore, a potential for smoke contamination throughout the building.

Assuming a vent location the height of one story above mid-level of the top story, the vent size required to raise the neutral pressure level of a heated shaft to the top story can be approximated by the following equation:

$$A_v = \left(\frac{\rho_f}{\rho_s}\right)^{\frac{1}{2}} A_s \sum_{i=1}^{n-1} (i)^{\frac{1}{2}} \qquad (1)$$

where A_v = required vent size, sq ft
ρ_s = density of shaft air, lb/ft^3
ρ_f = density of air in floors, lb/ft^3
A_s = leakage area in shaft/story, sq ft
n = total number of stories

Eq (1) is derived from a mass balance for the heated shaft without accounting for the effect of leakage openings in the outside walls and in the walls of the remaining shafts. Consideration of the air flow resistance of these components results in a vent size greater than that indicated by Eq (1). Vent sizes determined from Eq (1) for a shaft at an elevated temperature are generally much greater than those given in Fig. 7. For example, the size of vent required to vent smoke entering an elevator shaft from a fire-floor in a 20-story building is 18 sq ft according to Fig. 7; whereas the size of vent required to vent smoke originating in an elevator shaft at a temperature of 500 F is 103 sq ft. This is much greater than the hoistway area of 64 sq ft. If 50% of the hoistway area is assumed to be the maximum practical vent size, venting of the elevator shaft to prevent smoke contamination of adjacent interior spaces is limited to a building height of approximately 10 stories. For tall buildings, vent sizes determined from Eq (1) are prohibitive; if smaller vent sizes are used, smoke contamination of the building can be expected. The prevention of fires in vertical shafts is therefore particularly important.

STACK ACTION AND BOTTOM VENTING OF VERTICAL SHAFTS

When the air temperature outside a building is below that inside, venting of vertical shafts at the top decreases shaft pressures relative to pressures between floors. This decreases the outflow of smoke from the shaft into the adjacent spaces but increases the flow of smoke from the fire-floor into the shaft. A shaft vented at the top cannot, therefore, be used for evacuation. Locating the vent at the bottom of the shaft, however, causes shaft pressures to increase relative to those in adjacent spaces, and thus decreases the flow of smoke from these spaces into the shaft. With reference to Fig. 2 the shaft pressure is shifted to the right and with adequate vent sizing the neutral pressure plane is lowered to the 1st story. This results in an outflow of air from the vertical shaft into all stories with the exception of the 1st, where outside air enters the vertical shaft through the bottom vent.

The size of vent required to equalize the pressure in the shaft and adjacent space in the 1st story with vents located at the 1st story level is somewhat greater than that given in Fig. 6 for top vents located 1 story height above the neutral pressure plane of the shaft. Furthermore, with bottom venting, inflow of outside air causes a lowering of the shaft air temperature and a distortion of the air pressure profile in the shaft. This may adversely affect the vertical distribution of air pressure differences across the shaft wall under some conditions.

Bottom venting of stair shafts can be readily achieved by opening a stairwell door leading directly to outside at a lower level. A single door represents a vent area of about 20 sq ft. The leakage area/story for a stairwell shaft will depend upon the tightness of the door and wall construction. Measurements on 2 buildings[1] gave a total leakage area/story of about 0.3 sq ft (with doors closed). On the basis of Fig. 6 and these areas, an outside door would provide adequate venting of stairwells for most buildings.

Measurements were conducted on a 10-story building with a heated stairwell adjacent to the exterior wall. To measure air temperature in the stairwell, thermocouples were installed at the 1st, 3rd, 5th, 7th, and 9th story levels. To measure pressure differences across the stairwell doors, pressure taps were inserted under the 2nd, 3rd, 4th, 5th, 7th, 9th, and 10th stairwell doors. Table I gives the air temperatures in the stairwell shaft and the pressure differences across the stairwell doors, with the exit door to outside on the ground story both open and closed. The temperature and pressure difference readings with the exit door open given in Table I were taken ½ hour after the exit door was opened, when a quasi-steady state thermal condition was reached.

With the exit door closed, the shaft air temperature was 73 F and the neutral plane was located at the 8th story level; air flowed into the stairwell from the stories below this level and out of the shaft above this level. With the exit door open and all other stairwell doors closed, the shaft air temperature at the 1st story level decreased to 40 F, the reduction in temperature decreasing with height. Pressure measurements across the stairwell doors indicated that the pressure in the shaft was higher than the pressure in the floors resulting in an outflow of air from the shaft into all stories.

When the 2nd floor stairwell door was opened, along with the exit door, the shaft air temperature at the 1st story level was 40 F as before but the temperature drop at other levels in the shaft was much less. Pressure differences across the various inside stairwell doors were reduced, but the direction of air flow was still from shaft to adjacent spaces at all levels. With only the exit and 9th-floor stairwell doors open, there was a greater air

TABLE I

EFFECT OF BOTTOM VENTING OF STAIRWELL SHAFT OF A TEN STORY BUILDING

	EXIT DOOR CLOSED		EXIT DOOR OPENED	
FLOOR	AIR TEMP. F	ΔP STAIRWELL DOOR IN. OF WATER	AIR TEMP. F	ΔP STAIRWELL DOOR IN. OF WATER
10		−0.025		−0.050
9	73	−0.025	72	−0.050
8				
7	73	0.015	69	−0.020
6				
5	73	0.020	64	−0.015
4				
3	73	0.040	56	−0.020
2		0.045		−0.020
1	71		40	−0.020

Notes: (a) + air inflow into stairwell shaft.
− air outflow from stairwell shaft.
(b) outside temperature, 22 F.

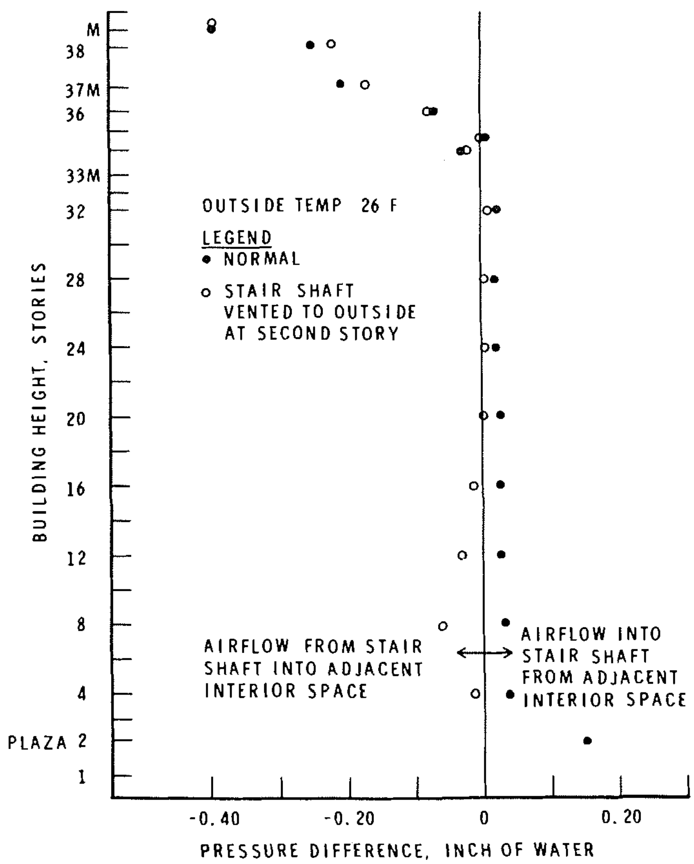

Fig. 8. Venting of stairwell shaft at the second floor of 38-story building.

flow rate through the shaft and a corresponding greater drop in the shaft air temperature at all levels. The flow direction across the stairwell doors at lower levels fluctuated indicating some air infiltration into the shaft from these stories.

The effect of venting a stairwell at the bottom was also investigated on a 38-story building. One stairwell in this building is offset at the 2nd story by a short corridor having a door to an outside plaza. Doors separated this corridor from the stairwell above and below.

Pressure differences across several stairwell doors were measured with all stairwell doors closed, and also with the stairwell serving the upper stories connected to outside by opening the appropriate doors in the corridor. Air temperatures in the shaft were not measured. Outside air temperature was 26 F. The results of the pressure measurements are given in Fig. 8. With all stairwell doors and the outside door to the plaza closed, the direction of air flow was into the stairwell from the 2nd to the 33rd story and out of the shaft above this story. Opening the bottom of the stairwell to outside caused an increase in the shaft pressure and an air flow out of the shaft from the 2nd to the 20th story levels. Air flow into the shaft occurred, however, from the 20th to the 33rd story, although the rate of air inflow was decreased as indicated by the reduction in pressure differences.

Additional studies of bottom venting was made on a 2-car elevator shaft in a 17-story building. Outside air temperature was 28 F. Pressure differences across elevator doors and shaft air temperatures were measured in several stories. The elevator cars were positioned at the basement level. Initially, the 2 elevator doors on the ground story were open, but covered with plywood sheets. Pressure measurements indicated that the neutral pressure plane of the elevator shaft was located at the 9th story level. Measurements were also made with the outside entrance doors open and one of the ground story elevator door openings uncovered to give an opening of 15 sq ft. In another study of air tightness of shafts, a total leakage area/story/car of approximately 1 sq ft was obtained. On the basis of Fig. 6, the elevator door opening would approximate the optimum vent size, assuming a ratio of vented shaft to total shaft leakage area/story of 0.4. Although the elevator shaft temperature was reduced to 55 F at the 1st story level, with lesser reduction in shaft temperature at upper levels, pressure measurements across elevator doors indicated that air flow occurred from the shaft to adjacent spaces from the 2nd story up. These measurements demonstrate the possibility of bottom venting elevator shafts to inhibit their contamination by smoke in the event of fire.

TOP AND BOTTOM VENTING OF SHAFTS

With outside air temperature below that inside, increasing the number of shafts that are top-vented increases the amount of air or smoke exhausted to outside, lowers the pressures in the shafts and adjacent interior spaces, and decreases the pressure difference across the vent openings. The vent size required for a given shaft is, therefore, increased as more shafts are top-vented. Similarly, increasing the number of shafts that are bottom-vented increases the pressures in shafts and adjacent spaces and decreases the pressure difference across the vent openings so that the size of vent required for a given shaft increases as more shafts are bottom-vented. Venting some shafts at the top and others at the bottom reduces the influence of venting on pressures in shafts and adjacent spaces and thus reduces vent-size requirements for optimum venting. This is demonstrated by the results of computations for the 20-story model building in which 2 elevator shafts were assumed, each having a leakage area of 2 sq ft/story. With one elevator shaft top vented and the other bottom vented, the required vent sizes are 19 sq ft and 21 sq ft respectively. If both shafts are either top or bottom vented the required vent sizes are 45 sq ft and 64 sq ft each respectively.

EFFECT OF LARGE OPENING IN EXTERIOR ENCLOSURE

In the foregoing discussion of natural venting of vertical shafts it was assumed that the exterior enclosure had normal air leakage characteristics uniformally distributed as represented by the model building of Fig. 1. In the event of a fire major openings to the exterior might however occur on the fire-floor, for example as a result of breaking of windows. With low outside temperatures and fire in a lower story this would cause an increase in the pressure on the fire-floor relative to pressures in the vented shafts. With vents at the top of the shaft the effect would be similar to increasing the average shaft leakage area/story and somewhat greater vent sizes than shown in Fig. 6 would be required or some smoke transfer into the top story would occur. With vents at the first story level the vent area requirements to prevent smoke transfer into the shaft would be substantially increased, and the building height for which optimum vent sizes were practicable would be correspondingly decreased. In either case, however, venting would have the effect of reducing smoke contamination.

SUMMARY

In the event of fire, air movement caused by stack action can be an important means by which smoke spreads from story to story, particularly with low outside temperatures. With a fire in a lower story, smoke from the fire-floor spreads to upper stories mainly through vertical shafts in the building. The control of smoke movement, therefore, involves the control of air movement across the walls of the vertical shafts.

The distribution of pressure differences across the walls of vertical shafts can be altered by natural venting to outside at the top or bottom. Top venting increases the number of stories from which air flows into the shaft and decreases the number of stories into which air flows from the shaft. Bottom venting has the opposite effect. In this paper the optimum vent size is defined as the minimum required to induce air flow into the shaft at all levels with top venting, and air flow out of the shaft at all levels with bottom venting.

Optimum vent size is essentially independent of the inside-outside temperature difference. It increases, however, with the height of the building and the effective area through which leakage can take place between the shaft and the rest of the building. If venting is restricted to either the top or bottom locations, the optimum vent size increases as the number of vented shafts increases. Top venting some shafts and bottom venting others reduces the optimum vent sizes for both. Top venting increases smoke contamination of the shaft and cannot, therefore, be used for shafts in which smoke contamination must be restricted, such as stairwells. Bottom venting inhibits the flow of smoke into the shaft from adjacent contaminated spaces. The flow of air into the shaft from outside, however, tends to lower the shaft air temperature which adversely affects the performance of the vent. A large opening from outside into a fire-floor on a lower level increases the optimum vent size. These factors and the practical restrictions on vent sizes limit the conditions under which venting can be fully effective as a smoke control measure.

Top venting can assist in the evacuation of smoke originating from a fire in the shaft. The vent size required, however, to prevent flow of air and smoke from a shaft at elevated temperature to adjacent interior spaces is much greater than that required for shafts at building temperature. Because of the difficulty of preventing smoke contamination of building from fires in shafts, special precautions are required to minimize the possibility of their occurrence.

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DISCUSSION

R. E. BARRETT, (Battelle Memorial Institute, Columbus, Ohio): The authors have continued their usual high standard of work in analyzing the phenomena of venting vertical shafts to control smoke movement in tall buildings. However, I would like to point out two practical problems associated with the application of this technique.

If some shafts are vented at the top to exhaust smoke while other shafts are vented at the bottom due to occupants exiting, we have a satisfactory condition during cold weather conditions. However, as was pointed out in an earlier paper by Mr. Locklin and myself,[1] a reversal of the normal stack effect (and most air flows) occurs when the outside

(1) R. E. Barrett, and D. W. Locklin, Computer Analysis of Stack Effect in High-Rise Buildings, ASHRAE TRANSACTIONS, Vol. 74, Part II (1968), pp. 155–169.

air is significantly warmer than the air within a building. Although this condition may not occur frequently in Canada, it is a common summertime occurance in the United States. During this summertime condition, smoke would exhaust through the bottom-vented shaft and the top-vented shaft would remain clear. However, occupants may not appreciate that this reversal occurs and might accidently enter a smoke filled shaft thinking it is safe.

The second problem relates to pressure differences at the bottom of the bottom-vented shaft for the winter condition. As you suggest in your paper, we would not want to vent this shaft continually because of heat loss. Therefore, I assume that this shaft would be vented by occupants opening the exit door as they leave the building. As this door would be a fire exit, it would have to open outward. However, based on a few preliminary measurements reported in our earlier paper, a force of about 33 lbs would be required to open a door against the 0.45 in.-of-water pressure difference at the first floor (Fig. 4, pressure difference between Shaft 2 and outside, with Shaft 1 vented at top). This is not excessive as a normal adult can exert a force of 40 to 45 lbs when opening doors. However, considering that the pressure difference increases proportionally with building height, the force required to open the door at the bottom of a 30-story or taller building under these conditions would be excessive. An accompanying problem would include preventing the door from slamming in the face of the occupants. However, practical problems related to door opening could be solved.

MR. WILSON: I appreciate your comments. There are a great many practical problems such as those that you have mentioned. The object of the paper was not to promote the idea of attempting to control smoke in buildings by this means alone. This is a technique that is sometimes called up in building codes. The object was to rationalize the approach if it was going to be used.

If one can define the objectives clearly and if one can develop an understanding of the mechanisms and can develop an adequate knowledge of the air leakage characteristics of the various components of the building, a great many options arise in the design of smoke control systems. This is only one small part of it.

W. MURPHY, (Seattle, Wash.): I would like to compliment you on your presentation. I heard your first presentation in San Francisco. And I will have to apologize, I anticipated the publication of your paper in trying to apply the technique of analyzing smoke shaft probelms to my 50 story high rise buildings. We have yet an unsolved smoke shaft problem.

I took readings and correlated them along the lines that you presented. And interestingly enough they pointed out a most drastic problem in that I couldn't rationalize any of my readings as opposed to your theoretical concept. And in trying to determine why I was so divergent, we discovered we had improper placement of smoke stops on all the mechanical floors and this explained 75,000 cfm.

We corrected this however, but I noticed one thing in your model at least with one shaft continuous from top to bottom. Your neutral plane remains pretty much constant for all shafts. I analyzed 6 different shafts, some of which terminated at intermediate floors, and I came up with 6 different neutral planes. Would you anticipate that this phenomena would occur in a completely integrated building?

MR. WILSON: The model, as you point out, is oversimplified for many buildings, particularly those that have shafts that terminate at various levels. For these one has to recognize that the model and the data are not pertinent and one must develop an appropriate solution.

MR. MURPHY: One other small question. In stating a bottom vent or top vent, are you stating venting at one place or the other, or both?

MR. WILSON: The data show the vent area requirements for optimum venting at the top. Detailed information on vent sizes for optimum venting at the bottom is not given. The graph and the data are for a vent at one story height above the top floor. If one were venting at the bottom, it would be difficult to locate the vent one story below the ground floor, so that it would probably be located at the ground floor level. For this case, one would require a greater vent size than that shown for top venting. Some information is given in the paper comparing the two situations.

MR. MURPHY: My specific question was whether the shafts you analyzed were vented both at the bottom and at the top, or at one or the other.

MR. WILSON: In this paper, the shafts were vented either at the top or at the bottom. If one is venting shafts only at the top, the more shafts vented, the greater the vent area required to achieve optimum venting in each shaft. The same situation occurs when one attempts to vent all the shafts at the bottom. If one is dealing with smoke control only by venting of shafts, one can minimize the vent shaft requirements by venting some at the top and others at the bottom.