A method of determining the size of vents (to prevent smoke blocking passages in burning building)

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A METHOD OF DETERMINING THE SIZE OF VENTS (TO PREVENT SMOKE BLOCKING PASSAGES IN BURNING BUILDING)

BY

SHIZUO YOKOI

FROM
BUILDING ENG. (95): 46 - 52, 1959

TRANSLATED BY

K. SHIMIZU

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PREFACE

Fire research has been a matter of prime concern to the Division of Building Research ever since its formation. The Division is now privileged to have liaison with fire research workers in all other countries in which this special branch of building research is being pursued. This facilitates the exchange of information regarding advances in building research typified by the publication of this translation.

The subject of venting, that is of providing openings to release the heat and smoke of building fires by natural convection, is attracting the interest of fire research workers in many countries. This paper by Mr. S. Yokoi of the Building Research Institute of Japan which is here translated deals with the area and height of vents required in order to secure that smoke never flows out through the doors or other openings of the space containing the fire but only through the vent. The cases of a theatre, an underground cinema, and a warehouse are investigated.

More detail of the work here described is given in Mr. Yokoi's paper, in English, entitled "A Study of Dimensions of Smoke Vent and Fire Resistive Construction" published in the Report of the Japanese Building Research Institute No. 29 (March 1959). A copy of this paper is in the library of the Division of Building Research and is available for consultation by those interested.

Ottawa
April 1960

R.F. Legget
Director

NATIONAL RESEARCH COUNCIL OF CANADA

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A METHOD OF DETERMINING THE SIZE OF VENTS

[To Prevent Smoke Blocking Passages in Burning Building]

1. Introduction

The number of fires in cinemas and theatres is increasing. Since a large number of human lives are involved in such cases, fire prevention measures must be considered in a more serious light than in ordinary houses. It is needless to stress the importance of suitable electrical wiring or of care against inflammable material so that a fire will not be started. However, it is also necessary to see that the fire once started be confined to that part of the building where it originated. As one means, the improvement of sprinklers may be considered. In many cases these will be useful. However if a ceiling is high, as in the case of a stage in a theatre, or if there is no suitable place for them because of other installations, trouble is encountered. In such a case, if they are installed too high, they will not start until the fire has spread considerably; then they will all start at once causing reduction in water pressure and making the system ineffective.

It is also necessary to equip a building with means which will facilitate the work of the firefighters and enable them to prevent the fire from spreading. The reason for this is that in general these buildings lack openings other than an entrance and exit and the fire smoulders with an insufficient supply of oxygen; the interior becomes filled with smoke, thereby making it difficult for fire-fighters to enter the building. Even if they can enter the building, it is difficult to locate the centre of the fire. If a vent is provided in the ceiling, firefighting activities are facilitated and it is easier to prevent the fire from spreading even though the force of the fire is intensified because of the draft. However, if the vent is too small, it is not very effective, and if it is too large, the appearance of the building is impaired. Up to now, a suitable size of the cross-sectional area of the vent was not known.

The present article deals with the method of calculating the necessary cross-sectional area and keeping the size as small as possible.

2. Fundamental Considerations

Consider a model shown in Fig. 1, a simple fire-proof structure with a single opening and a single vent, and assume that there is a fire. If smoke and heated air gush out of the opening, it becomes difficult for firefighters to enter the room and the fire will spread. It is necessary to prevent the smoke and the heated air from gushing out of the opening by providing a vent in the ceiling. For this purpose, the position of the neutral zone, in which the difference between pressures outside and inside the room becomes zero, must be located not lower than the upper edge of the opening. It will now be shown that conditions must be satisfied in order to ensure that the neutral zone will coincide with the head of the opening.

3. Analysis

The symbols used are defined below:

h........ the distance between the upper edge of the wall opening and the upper edge of the vent. If the vent does not take the form of a chimney, this will be the distance between the upper edge of the opening and the ceiling

H........ the vertical length of the wall opening

S'....... the area of the wall opening

S''....... the cross-sectional area of the vent in the ceiling

S_0....... the floor area of the room

If the neutral zone is located at the upper edge of the opening, the average speed of the outside air flowing into the room, v'_m, neglecting the effect of the compression at the opening, is

$$v'_m = \frac{2}{3}\sqrt{2gH\left(\frac{\rho_0 - \rho_1}{\rho_0}\right)} \qquad (1)$$

where ρ_o, ρ_1 are the densities of outside and inside gas, respectively. Since the vent is inside the horizontal level, the outgoing speed is constant everywhere in the cross-sectional surface except near the edges, and can be expressed as

$$v'' = \sqrt{2gH\left(\frac{\rho_o - \rho_1}{\rho_o}\right)}. \tag{2}$$

Let L be the amount of air necessary to burn 1 kg of wood and G the volume of air at the prevailing temperature produced as the result of combustion of 1 kg of wood. Further, assume that the discharge coefficient for both incoming and outgoing flows is 0.7 at the opening as well as at the vent. Then, on account of the continuity of fluid, the ratio between the amount of gas expelled from the vent to the amount of the incoming air at the opening in the wall must be equal to the ratio between the amount of gas produced by combustion and the amount of air necessary for combustion; thus, the following expression is valid:

$$\frac{G}{L} = \frac{0.7S''v''}{0.7S'v'_m} = \frac{3S''}{2S'}\sqrt{\frac{\rho_o}{\rho_1}}\sqrt{\frac{h}{H}}. \tag{3}$$

Let G_o be the value of G converted to standard conditions; α, the coefficient of cubical expansion of the gas; and t, the temperature of the gas. Then

$$G = G_o(1 + \alpha t),\ \rho_o = \rho_1(1 + \alpha t),$$

and (3) becomes

$$\frac{G_o}{L}\sqrt{1 + \alpha t} = \frac{3S''}{2S'}\sqrt{\frac{h}{H}}. \tag{4}$$

Let the rate of complete combustion and the rate of excess air be x and n*, respectively, then,

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* The quantities x and n are defined and L and G_o are derived from them in a paper by K. Kawagoe "Fire Behaviour in Rooms". Report of the Building Research Inst., Japan, No. 27, Sept. 1958.

$$G_o = 3.976n - 0.406x + 1.127(m^3/kg)\cdot$$

If it is assumed that n = 1, and x = 0.4 (on account of insufficient supply of air this was made smaller than 0.7, which has been used up to this point)*, $G_o = 4.941\ m^3/kg$. If we let $L = 3.975\ m^3/kg$ and $\alpha = 1/273.2$, expression (4) becomes:

$$S'' = 0.050132\sqrt{t + 273.2} \cdot S'/\sqrt{\frac{h}{H}} .$$

Dividing both sides by S_o to calculate the size of the cross-sectional area of the vent for the area of the floor, S_o, we obtain:

$$\frac{S''}{S_o} = 0.050132\sqrt{t + 273.2}\ \frac{S'}{S_o}\ /\sqrt{\frac{h}{H}}. \qquad (5)$$

The temperature of the room, t, is difficult to estimate. If the supply of air is sufficient, the temperature will reach 700 - 1000°C. If the supply is poor, it may not go too far above 300°C. Therefore, the equation for various room temperatures will be:

$$\left.\begin{array}{lll} \text{Room Temp.} & 300°C: & \frac{S''}{S_o} = 1.20\ \frac{S'}{S_o}\ /\sqrt{\frac{h}{H}} \\ \text{" \quad "} & 500°C: & \frac{S''}{S_o} = 1.39\ \frac{S'}{S_o}\ /\sqrt{\frac{h}{H}} \\ \text{" \quad "} & 700°C: & \frac{S''}{S_o} = 1.56\ \frac{S'}{S_o}\ /\sqrt{\frac{h}{H}} \\ & 1000°C: & \frac{S''}{S_o} = 1.79\ \frac{S'}{S_o}\ /\sqrt{\frac{h}{H}} \end{array}\right\} \qquad (5')$$

Equation (5') shows that for a given ratio $\frac{S'}{S_o}$ of openings to floor area, the size of vent necessary increases as the ratio $\frac{h}{H}$ is reduced.

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* The remark in parenthesis seems to be an aberration as there is no connection between the "rate of complete combustion" (0.4) and the discharge coefficient referred to (0.7)

Generally speaking, when H, the vertical length of a window or other opening in the wall, is large, h of necessity becomes smaller; and other unfavourable conditions, in addition to the large value of H, are introduced. Thus, the design must always be such as to make the vertical length of an opening as small as possible. Further, if the structure is a basement, the vent can be built like a chimney through the ground floor to the roof in order to make h large. However, in such a case, the temperature of the gas in the chimney may not be the same as that of the air in the room; thus, equation (5') may not apply exactly. However, it probably is a close approximation.

In a case in which there are more than two openings of equal size, if the height above the floor is the same, only the value of S', the total area of the opening in (5'), needs to be changed.

The required cross-sectional area of the vent in the ceiling may be calculated from (5'). Fig. 2 shows a graph for the calculation of S''/S_o for a room temperature of 300°C, which seems reasonable to the author. If n is taken as -1 for the abscissae the same value would be taken for the ordinates.

4. The Required Cross-Sectional Area of the Vent in the Ceiling Over the Stage of the Takarazuka Theatre in Tokyo

The results of the analysis above will be applied to the Takarazuka Theatre in Tokyo, where three persons died in the fire of Feb. 1, 1958, to calculate the necessary cross-sectional area of a vent in the ceiling over the stage.

The fire started on the stage. Since all the outside windows had been closed, the stage could be regarded as a room in which there was a fire, and the space for raising and lowering the curtain between the audience and the stage (AB of Fig. 3 and BB of Fig. 4) as the opening. There was a small vent on the roof of the stage, but this was useless. Thus, air flowed from seats to the stage through the lower portion of AB, and the smoke and the flow of heated air gushed towards the audience from the upper portion. As a result, the fire spread to the whole theatre. If the vent at P on the roof had been effective, and the opening at AB had allowed the air to flow solely from the auditorium to the stage, firefighting activities could have been carried out more easily and the fire would not have resulted in such a tragedy.

Let us calculate the cross-sectional area of the vent P necessary to bring the height of the neutral zone to A of Fig. 3. While the fire was confined to the stage, the temperature probably did not rise very high. Therefore, the calculations will be made assuming the temperature of the room to be 300°C.

Floor area of the stage $S_o = 40.5 \times 13.7 - 4.5 = 534.6\ m^2$

Area of the opening $S' = 33 \times 8.7 = 28.71\ m^2$

$H = 8.7 \quad h = 28\ m - 8.7 = 19.3\ m$

Hence, $S'/S_o = 0.54$, $h/H = 2.2$. From Fig. 2, using $n = -1$ for the abscissa and the ordinate, $S''/S_o = 0.44$ corresponding to the above S'/S_o, and h/H is obtained. The area of the vent will have to be as high as 44% of the floor area. The absolute value of S" is 235 m^2. Such a large vent would be impossible in practice.

Now, let us try to limit the cross-sectional area of the vent to 1/10 of the floor area of the stage. Assume that a fire curtain is lowered immediately after the start of the fire between the audience and the stage (AB in Fig. 3 and BB in Fig. 4). It is unnecessary to mention that if it is lowered right to the bottom, the fire can be confined to the stage. However, it is impossible to shut the stage off completely since the actors and others on the stage must be able to escape. The problem to be considered is how far the curtain should be lowered.

Let x be the distance between the lower edge of the curtain and the floor, and assume that the neutral zone is located at that height. Then substituting in (5')

$$S''/S_o = 0.1, \quad S' = 33x, \quad h = 28 - x, \quad H = x$$

$$S_o = 534.6\ m^2,$$

we have $x = 3.5$ m. Even if the temperature on the stage is assumed to be 1000°C rather than 300°C, x is only 2.8 m. This means that the curtain should be lowered to approximately 3 m from the floor, or should be lowered to 66% of AB. At the height of 3 m, men can pass under the curtain, and the plan is feasible from the point of view of evacuation.

5. When There Are Openings of Different Sizes

In the previous section, we dealt with the case in which there was a single opening, or even if there were more than one, all the openings were equal in size and located at the same height. If openings in the wall are several and different in size as in Fig. 5, calculations will have to follow a different line.

First of all the height of the neutral zone must be lower than the height of the upper edge of the highest opening to prevent the heat from the room from escaping through the openings. Therefore the cross-sectional area of the vent will have to be calculated so that the neutral zone coincides with the upper edge of the highest opening.

As in Fig. 5, number the windows 1, 2, 3,.... and associate corresponding suffixes 1, 2.... to those symbols which were defined in Fig. 1, and which are related to a window. Calculating with respect to the i-th window, equation (6) is obtained

$$\frac{S''}{S_o} = 0.050132\sqrt{t + 273.2}\left[\sum_i \frac{S'_i}{S_o}\sqrt{\frac{H_i}{h_1}}\left\{\sqrt{\left(1 + \frac{h_i - h_1}{H_i}\right)^3} - \sqrt{\left(\frac{h_i - h_1}{H_i}\right)^3}\right\}\right] . \tag{6}$$

For the cases where the room temperature is 300°C, 500°C, 700°C, and 1000°C, as in equation (5'), the expression $0.050132\sqrt{t + 273.2}$ in the above equation has to be replaced by the numerical values 1.20, 1.39, 1.56 and 1.79, respectively.

As an example, let us calculate the cross-sectional area of a vent in an underground cinema such as shown in Fig. 6, in which $S_o = 15 \times 7 = 105\ m^2$, the height of the ceiling is 3.5 m, and S'_1 and

S'_2 are two passages forming openings in the wall. $S'_1 = 3.5 \times 1 = 3.5\ m^2$ and $S'_2 = 3 \times 1.5 = 4.5\ m^2$. If the smoke or the heated air from the room are not to gush out of either of S'_1 or S'_2 in the case of a fire, the neutral zone must be located at the upper edge of S'_1, which is the higher of the two openings, i.e., it must be located at the ceiling. Let us suppose that we can use the ground floor, and the vent can be located at 15 m above ground. Then, $h_1 = 15$ m, $h_2 = 15 + (3.5 - 3) = 15.5$ m, $H = 3.5$ m, $H_2 = 3$ m. Assuming the temperature to be 300°C, and substituting these values in (6), we have:

$$\frac{S''}{S_0} = 1.20\left[\frac{3.5}{105}\sqrt{\frac{3.5}{15}} + \frac{4.5}{105}\sqrt{\frac{3}{15}}\left\{\sqrt{\left(1 + \frac{0.5}{3}\right)^3} - \sqrt{\left(\frac{0.5}{3}\right)^3}\right\}\right]$$

$$= 1.20[0.03333 \times 0.4835 + 0.04286 \times 0.4472\{1.2602 - 0.06804\}]$$

$$= 1.20[0.01610 + 0.019167 \times 1.1922]$$

$$= 1.20[0.01610 + 0.02285] = 0.0467.$$

In other words, if a vent of 15 m is provided, its cross-sectional area needs to be approximately 5% of the floor area, i.e., $105 \times 0.047 = 4.9\ m^2$.

Let us see what will happen if the height of the vent is not 15 m, but merely 1 m above ground. As in the previous case:

$$\frac{S''}{S_0} = 1.20\left[\frac{3.5}{105}\sqrt{\frac{3.5}{1}} + \frac{4.5}{105}\sqrt{\frac{3}{1}}\left\{\sqrt{\left(1 + \frac{0.5}{3}\right)^3} - \sqrt{\left(\frac{0.5}{3}\right)^3}\right\}\right]$$

$$= 1.20[0.03333 \times 1.8708 + 0.04286 \times 1.73205 \times 1.1922] =$$

$$1.20[0.06235 + 0.08850] = 0.181.$$

In other words, when the height of the vent is limited to 1 m, its cross-sectional area must be 18% of the floor area; in the present case it is $105 \times 0.181 = 19\ m^2$, an area 3.9 times as large is required compared to the previous case.

Next, let us suppose that, although the height of the vent is 1 m, S'_1 and S'_2 are made lower so that the upper edges of both are located 2 m above the floor. In this case, the height of the neutral zone needs to be 2 m above the floor; further, since the height of the upper edges are equal, the method of Section 3 applies, i.e., assuming that the temperature is 300°C, in (5') $S' = S'_1 + S'_2 = 3 + 2 = 5\ m^2$, $h = 1 + (3.5 - 2) = 2.5$ m, $H = 2$ m, we have

$$\frac{S''}{S_0} = 1.20 \times \frac{5}{105} \div \sqrt{\frac{2.5}{2}} = 1.20 \times 0.4762 \div 1.118 = 0.0511.$$

It will be observed that the required area is only 5% of the floor area and approximates the value when the vent is 15 m above ground.

Finally, we will calculate the vent area required in the case in which the height of the vent is 15 m above ground, and the upper edges of S'_1 and S'_2 are both 2 m above the floor. In this case (5') can be applied also. Since $S' = 5\ m^2$, $H = 2$ m, $h = 15 + (3.5 - 2) = 16.5$ m,

$$\frac{S''}{S_0} = 1.20 \times \frac{5}{105} \div \sqrt{\frac{16.5}{2}} = 1.20 \times 0.04762 \div 2.872 = 0.0199.$$

The required cross-sectional area of the vent becomes still smaller - 2% of the floor area - and is merely $1.5\ m^2 \times 0.0199 = 2\ m^2$. The above considerations indicate that in order to reduce the cross-sectional area of the vent (1) the upper edge of the opening must be low and (2) the vent can be built in the form of a chimney.

6. When the Upper Edge of the Opening is Less than 2 m Above the Floor

One means of making the cross-sectional area of the vent smaller is to lower the upper edge of the wall opening as was explained earlier. However, to make it lower than the height of a man makes it inconvenient to use as a passage way. It is also inconvenient in case of a fire for firefighters to carry on their activities in the room. Therefore, 2 m would be the lower limit for the upper edge of the wall opening in a building such as a theatre where many people will have to be accommodated. However, in a building such as a warehouse, which people do not frequent too often, the upper edge of the opening could conceivably be less than 2 m. In such a case, the height of the neutral zone cannot be lower than 2 m above the floor on account of the firefighting activities. Therefore in such a case there would have to be a little modification in the method of calculation.

(a) <u>When there is one opening</u>

Let us consider the case when the upper edge of the opening is less than 2 m above the floor as in Fig. 7, and let us find the conditions necessary to locate the neutral zone at 2 m above the floor. Let h(m) and h_1(m) be the distances, respectively, from the neutral zone to the upper edge of the vent and from the upper edge of the opening to the upper edge of the vent. Other symbols have the same meanings as defined in Section 3. Equation (7) gives the required area, S", of the vent:

$$\frac{S''}{S_0} = 0.050132\sqrt{t + 273.2}\,\frac{S'}{S_0}\sqrt{\frac{H}{h}}\left\{\sqrt{\left(1 + \frac{h_1 - h}{H}\right)^3} - \sqrt{\left(\frac{h_1 - h}{H}\right)^3}\right. . \quad (7)$$

When the room temperatures are 300°C, 500°C, 700°C, or 1000°C, the value 1.20, 1.39, 1.56 or 1.79 is substituted in the place of $0.050132\sqrt{t + 273.2}$ as in the case of equation (5'). Even if there were more than two openings, as long as the size and the height from the floor are the same, equation (7) can be used with S' the total area.

<u>Example 1</u>. Let us calculate the cross-sectional area of the vent for $S'/S_0 = 0.05$, the height of the vent = 0 m (same as the ceiling), the height of the ceiling = 3 m, the upper edge of opening above the floor = 1.5 m, the vertical length of the opening H = 1 m, and the height of the neutral zone is 2 m above the floor. (Room temperature is assumed to be 300°C).

Solution: $S'/S_0 = 0.05$, t = 300°C, H = 1 m, h = 3 - 2 = 1 m, h_1 = 3 - 1.5 = 1.5 m. These are substituted in equation (7), and we have

$$\frac{S''}{S_0} = 1.20 \times 0.05 \times \sqrt{\frac{1}{1}}\left\{\sqrt{(1 + 0.5)^3} - \sqrt{0.5^3}\right\}$$

$$= 0.6\{1.8371 - 0.3536)\} = 0.089,$$

i.e., the proportion of the vent to the floor area is approximately 9%.

Example 2. Conditions as in example 1; the value of S''/S_o is to be calculated for the case in which the upper edge of the opening is located 1 m above the floor.

Solution: $S'/S_o = 0.05$, $t = 300°C$, $H = 1$ m, $h = 3 - 2 = 1$ m, $h_1 = 3 - 1 = 2$ m. Hence,

$$\frac{S''}{S_o} = 1.20 \times 0.05 \times \sqrt{\frac{1}{1}}\left\{ \sqrt{(1 + 1)^3} - \sqrt{1^3} \right\}$$

$$= 0.06 \times (2.8284 - 1) = 0.1097.$$

Thus, the proportion of the vent to the floor area becomes 11%. In this case, unlike the preceding cases, the lowering of the upper edge of the opening resulted in an increase in the cross-sectional area of the vent. The reason is that in Fig. 7 when the upper edge of the opening is lowered, the value of h_1 increases, and consequently the right side of equation (7) increases.

Example 3. Conditions are the same as in example 2; the value of S''/S_o when the vent protrudes 1 m above the ceiling is calculated.

Solution: $S'/S_o = 0.05$, $t = 300°C$, $H = 1$ m, $h = 3 + 1 - 2 = 2$ m, $h_1 = 4 - 1 = 3$ m. Therefore, we have

$$\frac{S''}{S_o} = 1.20 \times 0.05 \times \sqrt{\frac{1}{2}} \times \left\{ \sqrt{(1 + 1)^3} - \sqrt{1^3} \right\}$$

$$= 0.06 \times \sqrt{\frac{1}{2}} \times 1.8284 = 0.776.$$

The proportion of the vent to the floor area is approximately 8%. Thus, a protuding vent is an effective means to reduce the cross-sectional area.

(b) <u>When there are more than two openings of different sizes</u>

Even though there are more than two openings which are different in size, if the upper edge of one of these openings is located higher than 3 m above the floor, the required cross-sectional area of the vent can be calculated by equation (6). Therefore, in this section, the case in which the upper edges of all the openings are located lower than 2 m above the floor (as in Fig. 8) will be considered, and the cross-sectional area of the vent necessary to place the neutral zone at 2 m above the floor will be calculated. The openings will be numbered 1, 2, 3.... and the quantities associated with an opening will be suffixed with an appropriate number. The meaning of the symbols will be the same as in Section 3. Then, we have:

$$\frac{S''}{S_o} = 0.050132\sqrt{t + 273.2}\left[\sum_i \frac{S'_i}{S_o}\sqrt{\frac{H_i}{h}}\left\{\sqrt{\left(1 + \frac{h_i - h}{H_i}\right)^3} - \sqrt{\left(\frac{h_i - h}{H_i}\right)^3}\right\}\right]. \tag{8}$$

When the room temperatures are 300°C, 500°C, 700°C, or 1000°C, only the substitution of appropriate value of temperature in the above equation, i.e., numerical values of 1.20, 1.39, 156, or 1.79 in place of $0.050132 \times \sqrt{t + 273.2}$ are necessary.

It is necessary for all the openings to be on the same wall.

<u>Example</u>. Calculations will be made of the cross-sectional area of a vent in a warehouse with an entrance of area S'_1 and a window of area S'_2, as in Fig. 9.

Solution: $S_o = 10 \times 5 = 50\ m^2$, $S'_1 = 1 \times 1.5 = 1.5\ m^2$, $S'_2 = 2 \times 0.5 = 1\ m^2$, $H_1 = 1.5$ m, $H_2 = 0.5$ m, $h = 3 - 2 + 1 = 2$ m, $h_1 = 3 + 1 - 1.5 = 2.5$ m, $h_2 = 3 + 1 - 0.5 = 3.5$ m, and assuming the temperature to be 300°C, and substituting these values in (8):

$$\frac{S''}{S_o} = 0.12 \times \left[\frac{1.5}{2} \times \sqrt{\frac{1.5}{2}}\left\{\sqrt{\left(1 + \frac{0.5}{1.5}\right)^3} - \sqrt{\left(\frac{0.5}{1.5}\right)^3}\right\} + \frac{1}{50} \times \sqrt{\frac{0.5}{2}}\left\{\sqrt{\left(1 + \frac{1.5}{0.5}\right)^3} - \sqrt{\left(\frac{1.5}{0.5}\right)^3}\right\}\right]$$

$$= 0.12 \times [0.03 \times 0.866 \times \{1.5396 - 0.1925\} + 0.02 \times 0.50 \times \{8 - 5.1962\}] = 0.12[0.02598 \times 1.3471 + 0.01 \times 2.8038 = 0.12 \times [0.03500 + 0.02804] = 0.0756.$$

Thus, the cross-sectional area of the vent is approximately 8% of the floor area: in absolute value it is $50 \times 0.0756 = 3.78\ m^2$.

7. Conclusions

A method of calculating a cross-sectional area of a smoke vent in the ceiling of buildings such as a cinema or a theatre with few openings to facilitate the entry and the activities of firefighters has been discussed.

(1) The discussion is based on the premise that at the time of the fire the position of the neutral zone, at which the difference in the internal and external pressure is zero, should not be lower than the upper edges of the openings.

(2) Equations were obtained for various sizes and positions of openings. The results were applied to the fire of the Tokyo theatre in Feb. 1958 and other underground theatres to calculate the cross-sectional area of the vent.

(3) The following methods of reducing the size of the vents are suggested:

- (i) building a vent in the form of a chimney taking advantage of the ground floor, or
- (ii) lowering the upper edge of the opening by hanging a partition from the ceiling over the entrance.

(4) In a special case where the upper edges of all the openings are less than 2 m, it is more effective if the upper edges of the openings can be raised as close to 2 m as possible.

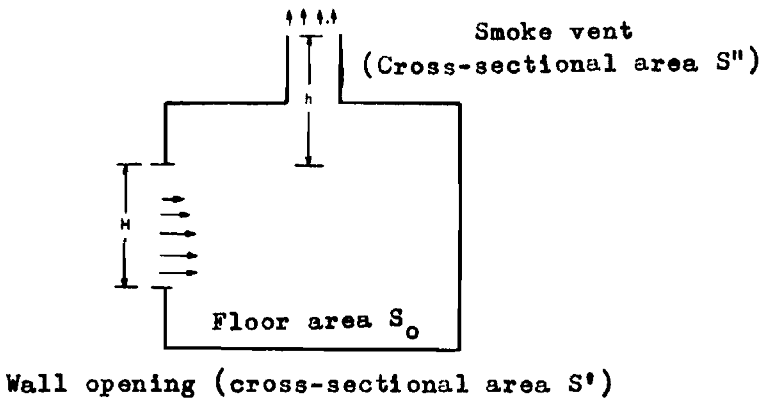


Fig. 1

Model of a fireproof room

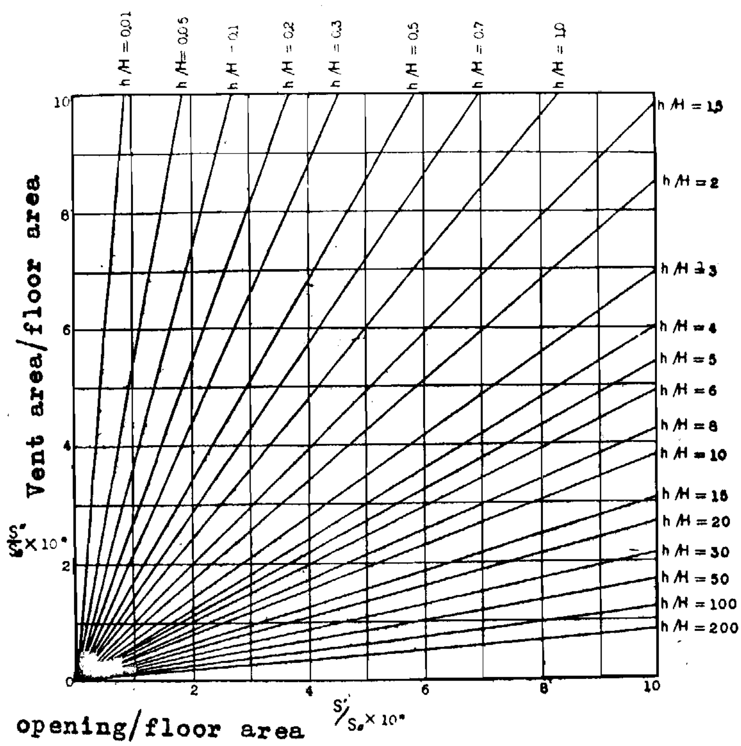


Fig. 2

Required area of vent for a given area of opening

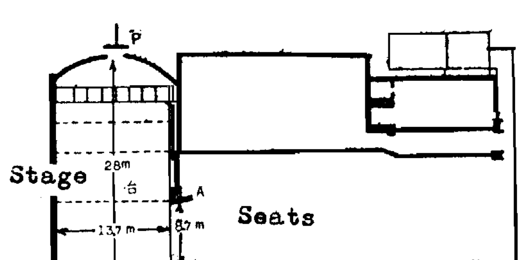


Fig. 3

Vertical section of the Takarazuka Theatre in Tokyo

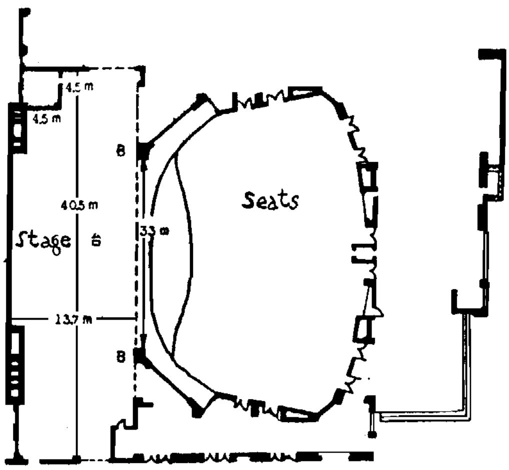


Fig. 4

Plan of the first floor of the Takarazuka Theatre in Tokyo

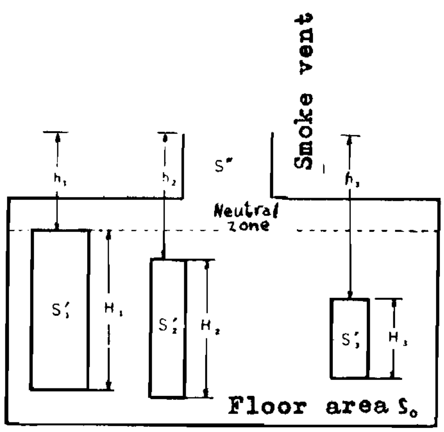


Fig. 5

When there are more than two openings of different sizes

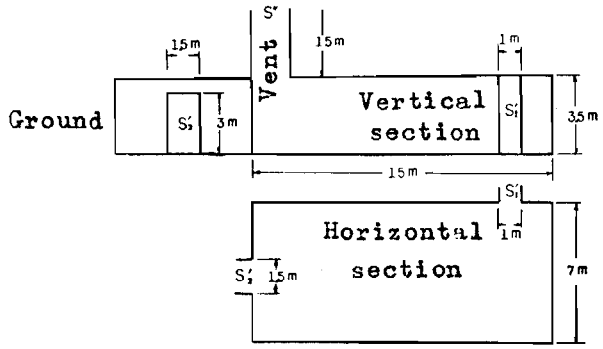


Fig. 6

Example of an underground cinema

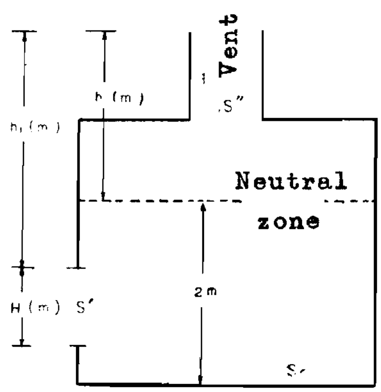


Fig. 7

When the upper edge of an opening is less than 2 m above the floor

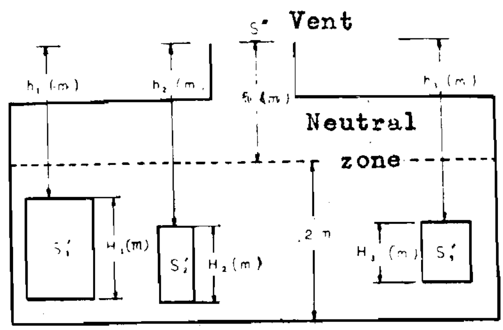


Fig. 8

When there are more than two openings of different sizes

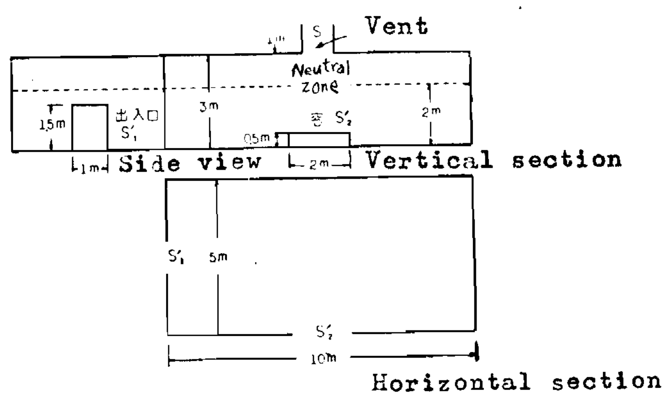
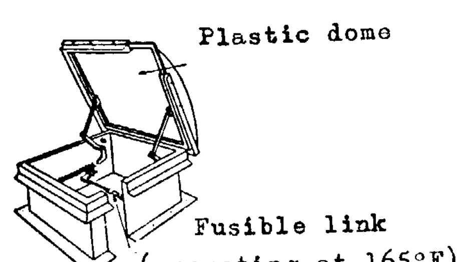


Fig. 9

Example of a warehouse



Example of a smoke vent