ON THE MINIMUM SMOKE EXTRACTION RATE FOR BASEMENT REQUIRED IN THE LOCAL FIRE CODES

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ABSTRACT

Smoke control systems are required in basements in Hong Kong under certain conditions. The differences in the smoke extraction rate listed in the two versions of fire service installation codes are discussed. Empirical equations on the smoke production rate appeared in the literature are used to explain the physics behind the codes. A design graph on the number of air changes per hour and the resulted clear height is recommended for local use.

1. INTRODUCTION

In the local codes of practice for fire service installation [1,2], smoke control systems are required in basements under some conditions. However, the two smoke extraction rates for basement listed in D4 of the 1994 version [1] and the 1998 version of the code [2] are different:

- D4, 1994: The minimum extraction rate shall be equivalent to not less than eight air changes per hour of the total compartment volume.
- D4, 1998: The minimum extraction rate shall be equivalent to not less than eight air changes per hour of the total compartment volume. The design volume shall be considered to be 7,000 cubic metres for any compartment of 7,000 cubic metres or less.

Before having the new version [2], there were some arguments on designing smoke control systems based on the old version of the code [1] for spaces with smaller volumes. The flow rate when expressed in volume per unit time would be very small if eight air changes per hour was taken as the design parameter. However, in the new version of the code, the volumetric extraction rate might be very large. Whether this is good or not has to be studied. Explanation on the physics behind the code is attempted in this article for clarifying the situation.

2. PHYSICAL PRINCIPLES

The equation developed at the Fire Research Station, UK [3-6], is commonly used to estimate the smoke production rate M’ (in kgs^{-1}) of a fire of perimeter P (in m) for a certain clear height y (in m):

$$M' = 0.188\, P\, y^{3/2} \qquad (1)$$

The above equation was verified by Hinkley [5] to give good estimation of smoke production rates by comparing with experimental data.

A common design fire is of size 3 m by 3 m, perimeter P 12 m and heat release rate 5 MW. This gives a heat release rate per unit area of 0.56 MWm^{-2}.

The sizing of a smoke control system is commonly performed by taking the extraction rate M_e' to be greater than the smoke production rate M’. Value of the extraction rate can be expressed as the number of air changes per hour N_e in terms of the basement volume V_s, by taking the density of normal, unheated air as 1.2 kgm^{-3} [7] for simplicity as:

$$N_e = (M_e' \times 3600) / V_s \times 1.2 \qquad (2)$$

Combining equations (1) and (2) for $M_e' > M'$, without adjusting M_e' by including the unburnt fuel and combustion product emitted by the fire, which might take about 3% [8] of air entrained, gives:

$$N_e > \frac{564P}{V_s} y^{3/2} \qquad (3)$$

3. DESIGN ALTERNATIVES

Putting those values of $N_e = 8$ and $V_s = 7{,}000\ m^3$ as specified in the codes [1,2] into equation (3) gives:

$$\frac{564\,Py^{3/2}}{7{,}000} < 8 \qquad (4)$$

or $$Py^{3/2} < 99 \qquad (5)$$

It is obvious that higher the clear height, smaller the fire perimeter P that the smoke management system can control if operating at the same extraction rate. For example:

- For y = 1 m, maximum P of the fire that the smoke management system operating with 8 ACH can control is 99 m. This is equivalent to a square fire of side about 25 m.
- For y = 1.5 m, maximum P is 54 m, or equivalent to a square fire of side about 13 m.

However, those figures are trivial. A general plot of N_e against y for V_s of 7,000 m^3 and 3,500 m^3, and a fire with perimeter P of 12 m, based on equation (3) is shown in Fig. 1.

For a basement of space volume 7,000 m^3, installing a smoke extraction system operating at 8 ACH will keep y at 4.09 m. The clear height will be 2.58 m at 8 ACH for a space volume of 3,500 m^3, since y varies as $V_s^{2/3}$ as given by equation (3). This implies smaller the space volume, lower is the clear height for the same extraction rate. This is very dangerous as a space with smaller volume but lower clear height means that a larger portion of space would be filled with smoke.

Based on equation (3), N_e is plotted against V_s for clear heights y at 1.0 m, 1.5 m and 2.0 m in Fig. 2.

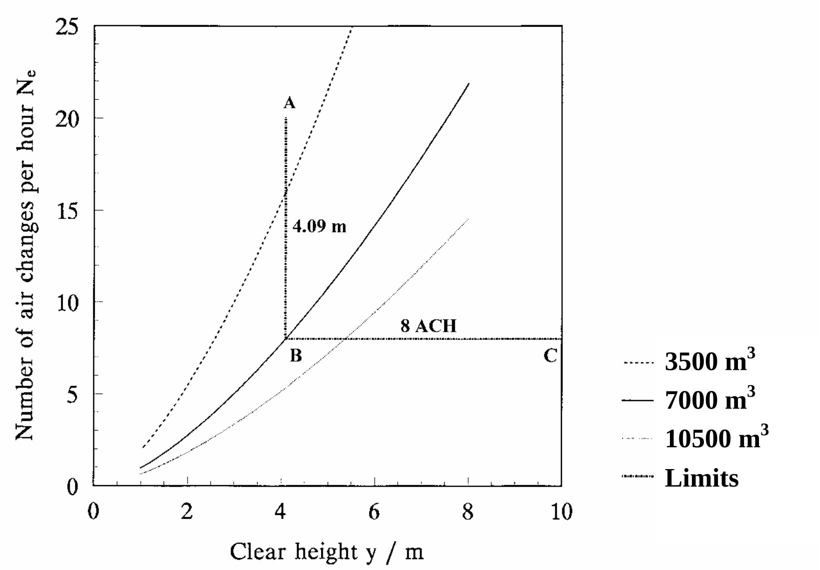

Fig. 1: Extraction rates at different clear heights

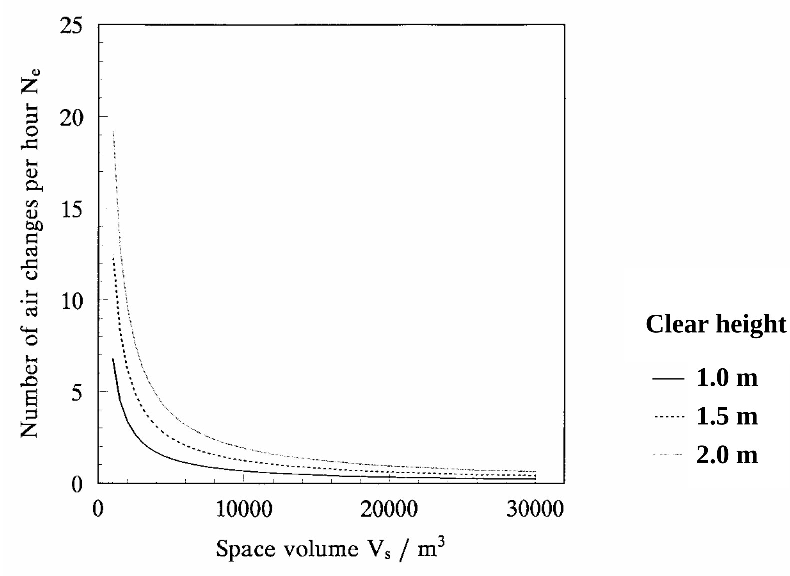

Fig. 2: Extraction rates at different space volumes

For keeping the clear heights at 1.0 m, 1.5 m and 2.0 m, the smoke extraction rate N_e required for a space volume of 7,000 m^3 would be 0.97 ACH, 1.78 ACH and 2.73 ACH respectively. All the values are much less than 8 ACH!

4. INTERPRETATION

An interpretation of the code [2] can be:

For an underground space of volume V_s less than 7,000 m^3, the volume V_s is taken as 7,000 m^3 to calculate the mass flow rate of the smoke extraction fan.

Mathematically, for $V_s \leq 7{,}000\ m^3$:

$$N_e = \frac{M_e' \times 3{,}600}{7{,}000 \times 1.2} \qquad (6)$$

This will give:

$$N_e \geq 8 \qquad (7)$$

Putting in equation (1) for $M_e' \sim M'$ gives:

$$\frac{1.2 \times 7{,}000}{3{,}600} N_e \sim 0.188\, P y^{3/2}$$

or

$$y^{3/2} = \frac{12.4}{P} N_e \qquad (8)$$

This can be further simplified for a fire of perimeter P of 12 m to give:

$$y^{3/2} = 1.033\ N_e \qquad (9)$$

Since $N_e \geq 8$, the clear height y can be kept higher than 4.09 m. This will give a sufficiently high clear height.

For a space with volume less than 7,000 m^3, say 3,500 m^3, the value of N_e of 8 ACH would give a mass flow rate M_e' of 9.33 kgs^{-1}. But the design space volume V_s is taken as 7,000 m^3 for calculating the mass flow rate, i.e. 18.66 kgs^{-1} while using equation (6). This value of N_e would be double the required value of 8 ACH. Therefore, instead of having 8 air changes per hour, N_e would be 16 air changes per hour. For 8 ACH in a space of 3,500 m^3, the clear height can be kept at above 2.58 m. But with 16 ACH, the clear height can be 4.09 m.

5. RECOMMENDATION

For the above studies, the limits of the design extraction rates and the resulted clear heights can be specified by drawing two straight lines AB and BC in Fig. 1:

- Line AB is for clear height of 4.09 m and line BC for N_e of 8 ACH. For space volumes less than 7,000 m^3, minimum N_e follows line AB in order to keep the clear height at or above 4.09 m.
- For space volumes greater than 7,000 m^3, 8 ACH should be used and the resultant clear height follows line BC.

Note that for basements with ceiling heights less than 4.09 m, providing 8 ACH of extraction rate, should give a space free of smoke for a fire of P 12 m.

6. CONCLUSION

Extraction rates for smoke control system in basement appeared in the two versions of fire service installation codes are discussed. Attempts are made to explain the physics behind through the common smoke production equation. A design graph plotting the extraction rate in terms of the number of air changes per hour against the clear height is recommended for local use.

However, heat transfer was not considered in the above arguments. Therefore, care must be taken in this aspect. Full-scale burning tests [e.g. 9] should be carried out to verify the results.

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