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# PROPOSAL OF USING A TIME CONSTANT FOR SPECIFYING ATRIUM SMOKE FILLING IN FIRE CODES

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## ABSTRACT

A time constant including building geometry and design fire characteristics was suggested for specifying smoke filling in atria. From the survey results on 138 local atria, time constants of 73 atria were calculated. The smoke filling times required to fill 80 % of the space volume were evaluated from the NFPA smoke filling equation with a slow $t^2$-fire. The time for the smoke front to reach the ceiling was taken into account. It is further confirmed that time constant is a better parameter than the space volume used in the current fire codes, and is thus recommended to the Authority.

## 1. INTRODUCTION

Atria are built in most of the recent large-scale development projects such as multi-purpose buildings, shopping malls, hotels and office buildings in the Hong Kong Special Administrative Region (HKSAR). Fire safety in those places is very important because of the high occupant loading, large space volume, and the possibility of storing combustible items in shops adjacent to the atrium. Smoke management systems have to be designed carefully [1].

Space volume is an important parameter in the current fire codes [e.g. 2] in deciding whether smoke control systems are required. Critical values are 28,000 $m^3$ for spaces above ground with fire load density less than 1,135 $MJm^{-2}$, and 7,000 $m^3$ for underground spaces. This might not be adequate as the smoke filling time in atria with the same space volume but different geometry would be very different.

The concept of time constants was proposed for specifying the smoke filling time in atria [1]. This is now further reviewed based on a recent detailed field survey on local atria. Further, the time required for the smoke front to travel from the fire to the atrium ceiling is included.

## 2. TIME CONSTANT

For an unsteady NFPA $t^2$-fire [3], the heat release rate Q (in kW) is given in terms of time t (in s) by the following equation:

$$Q = 1000\left[\frac{t}{t_g}\right]^2 \tag{1}$$

Note that time might be required for the fire to develop up to satisfy the above equation.

An empirical equation was reported [3] for the smoke layer interface height y for a hall of floor area A (in $m^2$) and height H (in m):

$$\frac{y}{H} = 0.91\left[t t_g^{-2/5} H^{-4/5}\left(\frac{A}{H^2}\right)^{-3/5}\right]^{-1.45} \tag{2}$$

The equation holds only for:

$$1 \le A/H^2 \le 23 \tag{3}$$

and

$$y/H \ge 0.2 \tag{4}$$

A time constant $\tau_4$ (in s) can be defined [1] by taking the time dependent term (another three constants $\tau_1$, $\tau_2$ and $\tau_3$ were defined with their weakness discussed earlier):

$$\tau_4 = \frac{t_g^{\,2/5}}{0.8722}\left(\frac{A}{H^{2/3}}\right)^{3/5} \tag{5}$$

with $t_g$ of 600 s for a slow $t^2$-fire:

$$\tau_4 = 14.8\left(\frac{A}{H^{2/3}}\right)^{3/5} \tag{6}$$

## 3. SMOKE FILLING

Note that 0.8722 in equation (5) is a dimensional constant giving $\tau_4$ in the unit of seconds. This is related to the time $t_{80}$ required to fill 80% of the atrium with smoke by setting y/H to 0.2 in equation (2):

$$t_{80} = 2.48\ \tau_4 \tag{7}$$

The time $t_{80}$ can be estimated by using equation (7). However, it was pointed out that time $t_s$ would be taken for the smoke front to travel from the fire to the atrium ceiling. An empirical equation was proposed to calculate $t_s$ for a $t^2$-fire before [4]:

$$t_s = 1.81\left(\frac{g}{\rho_\infty C_p T_\infty}\right)^{-0.2} y^{0.8} \tag{8}$$

where g is the acceleration due to gravity, $\rho_\infty$ and $T_\infty$ are the ambient air density and temperature, $C_p$ is the specific heat capacity of air.

The total time $t_{80T}$ for the smoke to fill up 80 % of the atrium space is:

$$t_{80T} = t_{80} + t_s \tag{9}$$

## 4. USE OF THE TIME CONSTANT

A detailed study [5] was carried out from 1995 to 1997 to survey the geometry, section, location, glazing area, thermal environmental control systems and the uses of atria. A total number of 138 atria in 79 buildings were surveyed in the HKSAR. Time constants for those atria are now calculated, but not for all 138 atria due to the condition imposed by equation (3). Further, it is better to set a lower limit on H, so that 0.2 H will give a sufficiently high clear height. For a clear height higher than 1.5 m, the lower limit of H is 7.4 m. In this way, only 69 atria satisfied the above two criteria.

Values of $\tau_4$ and $t_{80T}$ computed are plotted in Fig. 1. The following line with a correlation coefficient of 0.9996 can be fitted:

$$t_{80T} = 2.597\ \tau_4 \tag{10}$$

For atria with smaller time constants, the smoke filling time $t_{80T}$ would be faster. It might not be necessary for an atrium with a large space volume to install a smoke extraction system. Equation (10) is useful in making such a decision if only the smoke filling time is considered. For example, taking $t_{80T}$ to be longer than the egress time $t_{eg}$, say 150 s or 2.5 minutes, atria with time constants smaller than 58 s would require a smoke extraction system.

## 5. CONCLUSION

The concept of using a time constant in specifying the smoke filling time in an atrium was reviewed based on a survey on 138 atria. Only 69 atria satisfied the two criteria given by equation (3) and are of clear height 1.5 m. The volumes of the atria are in fact not too big, and only one has a volume greater than 28,000 $m^3$ where a smoke extraction system is required under the current regulation [3]. On the other hand, the smoke filling time in smaller atria might be short and so smoke control systems are required.

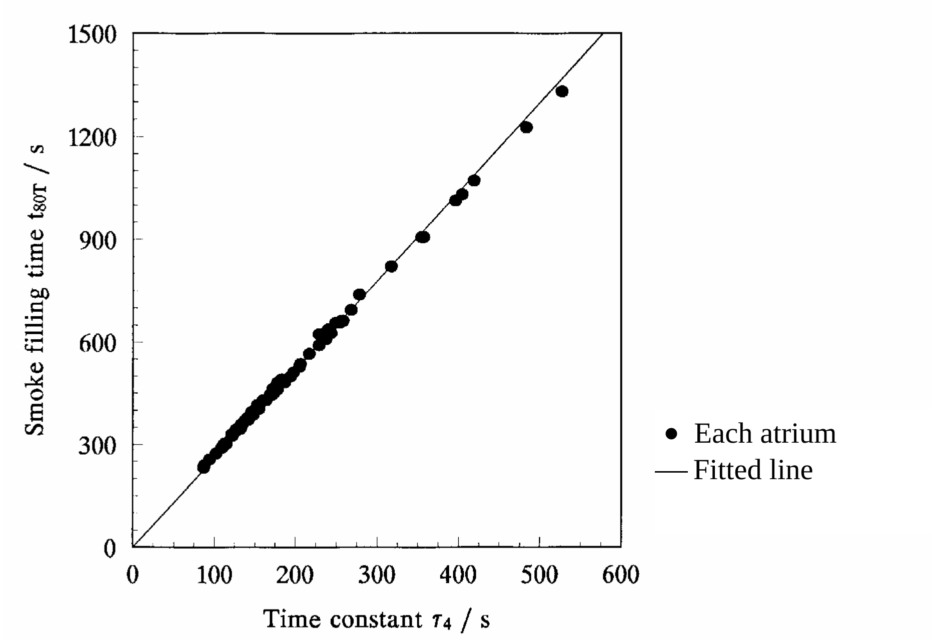


**Fig. 1: Time to fill 80% of atrium with smoke**

There are other factors [6] such as evacuation plan that might determine whether a smoke extraction system is required. For example, designed values of population density depend on the floor area in the local building codes. Atria with large floor area might have higher population density, so the egress time required should be considered carefully. An atrium with small time constants but large floor area might be dangerous because it is likely that the population density is high but the smoke filling time is short. Evacuation will be more difficult and so a good evacuation plan must be worked out.

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