COMMENT ON ESTIMATING HEAT RELEASE RATE FOR A DESIGN FIRE IN SPRINKLER PROTECTED AREA

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ABSTRACT

In implementing fire safety engineering approach in Hong Kong, in fact performance-based design, heat release rate for a design fire has to be estimated. For areas protected by sprinkler, the sprinkler activation time is deduced from a thermal balance equation based on the ceiling jet equation. The heat release rate is then determined from some functions such as the NFPA t^2-fire.

However, activating the sprinkler system might not necessarily control the fire at that instance. The fire would still be burning to give much higher heat release rates. This point will be discussed in this paper. Full-scale burning tests on fires with and without sprinkler are used to illustrate the problem.

1. INTRODUCTION

Local approval of fire safety designs and inspection of buildings upon completion are held responsible by the Buildings Department (BD) and Fire Services Department (FSD). Normally, the building design shall be submitted to the BD for checking against all fire aspects for approval; and the requirements and installation of fire protection system shall be determined by the FSD.

The prescriptive codes are basically on the fire resistance construction (FRC) [1], means of escape (MoE) [2] for occupants, means of access (MoA) [3] for fire fighting, and the fire services installation (FSI) [4]. These codes are demonstrated to work for traditional buildings, such as those of height up to 40 levels. However, they may not be sufficient for providing fire safety in some buildings with special designs. Supertall buildings are obvious examples [5,6] in having total evacuation time longer than half an hour even in using lifts for escape [7].

There are no engineering performance-based fire codes (EPBFC) in Hong Kong yet. "Fire engineering approach FEA" for passive fire safety designs is accepted by the authority (i.e. BD) since 1998 [8]. This is basically performance-based design and useful for buildings with special hazards requiring individual design considerations but not yet included in the prescriptive codes. But doing this without strong scientific fire research for local safety provision is impossible. For projects considered in the past, FEA is basically to demonstrate that the safety of the design is equivalent to the existing codes.

But in most cases, the parts deviated from the prescriptive codes for passive building construction would be assessed. An example is the non-compliance with FRC code for glazing. Therefore, the application of FEA for most projects is to demonstrate the equivalency to prescriptive codes.

Knowledge of fire science and engineering was applied together with practical experience under local conditions [8]. Mathematical fire models, either zone models or field models (application of Computational Fluid Dynamics CFD or Numerical Heat Transfer NHT), had been used to analyze potential fire scenarios. Full-scale burning tests, scale models studies and site measurements on evacuation pattern might be required to demonstrate the safety of the design.

There are not yet standard methods for assessing those designs. A government consultancy project on reviewing the code started a few years ago. However, it took 10 years to develop some guides useful for performance-based designs [9,10] in the U.K. There, most of the buildings are not so complicated, their living style is much well-organized and the consultancy team developing the guides has published numerous papers. It might not be feasible for Hong Kong to work out such EPBFC within a few years. There are so many complicated buildings and the living style is very different. In-depth research is necessary for working out something meaningful.

2. HEAT RELEASE RATE

The heat release rate of a design fire has to be estimated in applying Fire Engineering Approach for projects having difficulties to comply with the prescriptive codes. There had been lots of arguments on the heat release rate of a design fire. A low value of 0.5 MW was used in a terminal! The heat release rate has to be assessed in order to answer a common question on hazard assessment [11]:

How big is a fire?

The heat release rate [12] will give the most important information on how much heat will be released in burning the combustibles. Once the heat release rate is known, the resulted fire environment such as smoke temperature, smoke layer thickness, smoke flow rate, radiation heat flux, possibility to flashover, and the effects on adjacent combustibles and construction elements in the office, and hence the building as a whole, can all be estimated with empirical expressions or fire models.

On estimating the probable heat release rate for a design fire in a sprinkler protected area, a common practice is to apply an empirical equation [13] for the maximum ceiling jet temperature rise ΔT_{max} at ceiling height H (in m) due to a fire of convective heat release rate $\dot{Q}_c$ (in kW):

$$\Delta T_{max} = \frac{16.9\dot{Q}_c^{3/2}}{H^{5/3}} \qquad (1)$$

Results will be combined with a thermal balance equation on relating the activation temperature of the thermal sensing element of the sprinkler heads with a certain Response Time Index (RTI). The activation time t_a will be calculated based on RTI from a heat balance equation. Upon activation of sprinkler, the heat release rate is assumed to be kept at a constant value.

For example, a t^2-fire [14] with a heat release rate $\dot{Q}(t)$ (in kW) at time t (in s) given by the equation through a constant t_g:

$$\dot{Q}(t) = 1000\left(\frac{t}{t_g}\right)^2 \qquad (2)$$

where t_g is 75 s, 150 s, 300 s and 600 s respectively for ultra-fast, fast, medium and slow t^2-fire.

The heat release rates $\dot{Q}_{des}$ of the design fire were estimated in many projects by:

$$\dot{Q}_{des} = 1000\left(\frac{t_a}{t_g}\right)^2 \qquad (3)$$

3. EXTINGUISHMENT, SUPPRESSION AND CONTROL

However, activating the sprinkler does not mean the fire can be controlled at that certain value immediately. The three terms on control, suppression and extinguishment have to be understood by following NFPA 13 [15] and NFPA 750 [16]:

- Fire control in NFPA 13 [15] means limiting the size of a fire by distribution of water so as to decrease the heat release rate and pre-wet adjacent combustibles, while controlling ceiling gas temperatures to avoid structural damage.
- Fire extinguishment in NFPA 750 [16] means the complete suppression of a fire until there are no burning combustibles.
- Fire suppression in NFPA 13 [15] means sharply reducing the heat release rate of a fire and preventing its regrowth by means of direct and sufficient application of water through the fire plume to the burning fuel surface.

All these can be illustrated by Fig. 1 on plotting the heat release rate against time.

It is obvious that it would take time to control the heat release rate at a certain value. The value can be much higher than that estimated from equation (3), depending on the scenario concerned. Note that the ‘design fire scenario’ [17] is one of the primary uncertainties in fire safety engineering. A design fire depends on the geometry and use of the building; the combustibles used and stored; and most importantly, the ventilation provision. It cannot be decided without understanding the above. Recent result indicated [18] that very low combustible content can give very high heat release rate, though the fire might only last for a shorter time.

The objective of putting in sprinkler is to control the heat release rate at a certain value at steady state. If the volumetric flow rate of the sprinkler is V_f', the maximum possible heat $\dot{Q}_{spr}$ removed by the sprinkler water spray is given in terms of water density ρ_w and latent heat of vapourization L_w as:

$$\dot{Q}_{spr} = V_f \rho_w L_w \qquad (4)$$

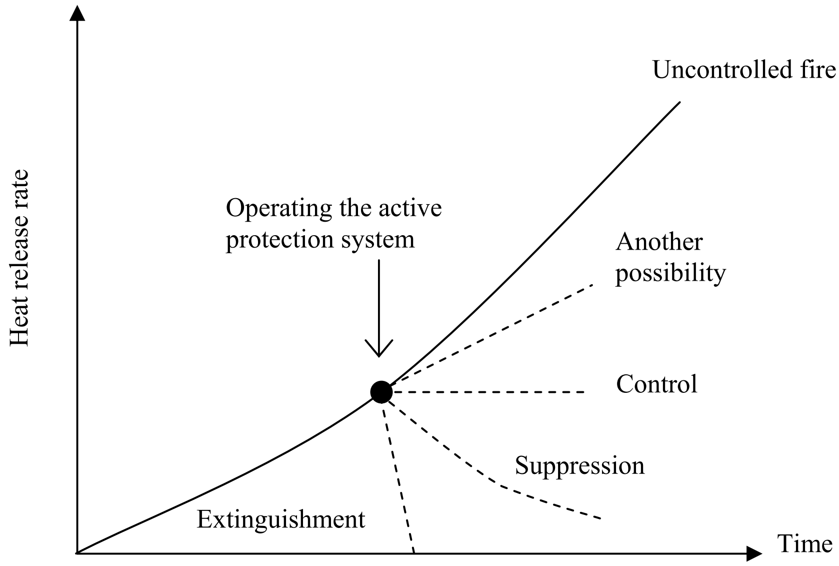


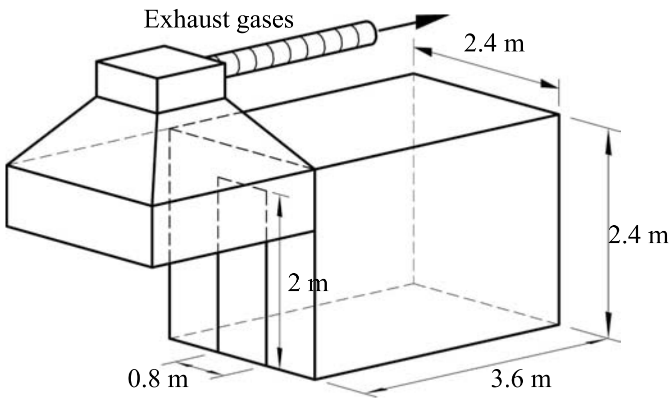
Fig. 1: Action of an active protection system

4. FULL-SCALE BURNING TESTS

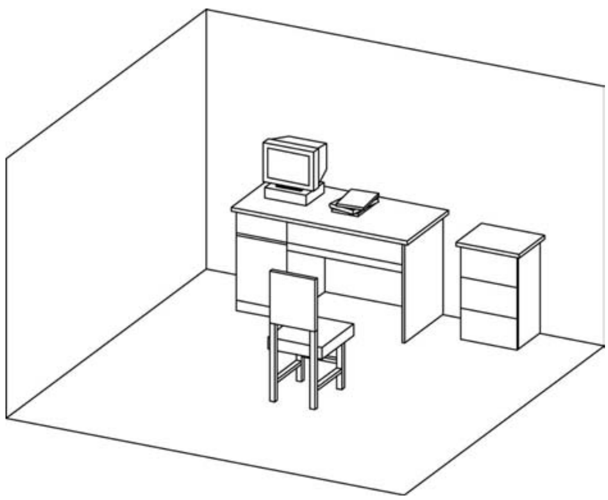
To assess how sprinkler would control a fire, full-scale burning tests were carried out. Office fire scenarios with and without operation of sprinkler were considered. A full-scale burning facility known as the Chinese Assembly Calorimeter [19] was developed by the author with strong support from the Harbin Engineering University. This facility is located at the remote area Lanxi at about 150 km from Harbin, Heilongjiang, China. Flashover office fires were studied in the summer of 2004.

The office scenario considered is shown in Fig. 2. There were a chair, a desk with paper and books on top, a computer box and a cupboard were placed in a burn room. This setup was burnt under an accidental fire to give flashover for determining the heat release rate. Tests were then repeated by operating a sprinkler system at pressure 0.52 bar and flow rate 60 litres/min.

The resultant heat release rate curves for the scenario with and without sprinkler are shown in Fig. 3. It is observed that operating the sprinkler could control the fire for this scenario. But the heat release rate did not stay at the value once the sprinkler was activated. There is a jump of 500 kW, about 50% of the value at sprinkler activation. Note that this scenario gave a small fire of peak heat release rate less than 1.8 MW, only burning for about half an hour.



(a) Room calorimeter



(b) Office fire scenario

Fig. 2: Office fire test

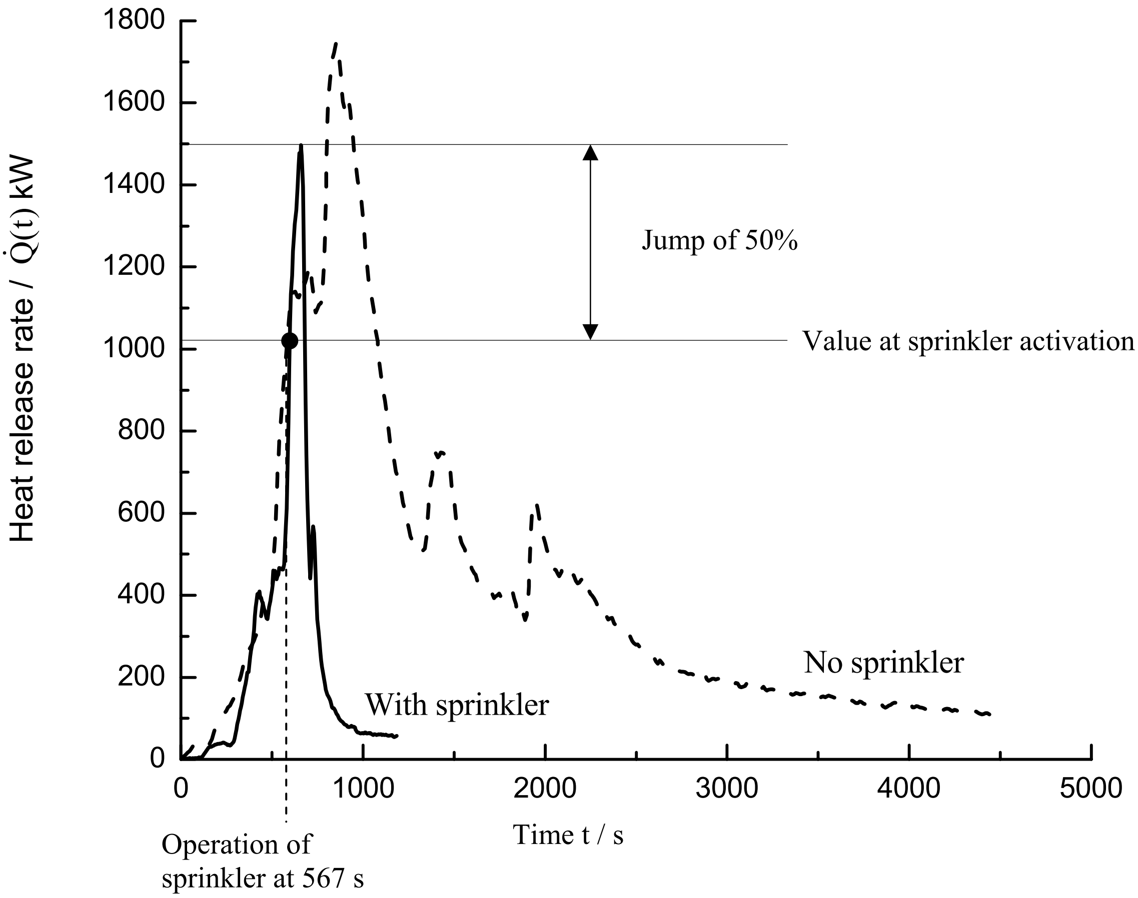


Fig. 3: Heat release rate

5. CONCLUSION

It is observed that even under a small office fire as in the above test, the heat release rate cannot be controlled at the value once the sprinkler system is activated. The heat release rate can be over 50% higher than the value at the time of discharging water. Therefore, in estimating the heat release rate with a t^2-fire, the time to give 'cut-off' value should be extended to be longer than the activation time. In this way, higher heat release rate is resulted, depending on the scenario. Full-scale burning tests are required to confirm the result as the probable heat release rate depends on the scenario. Sprinkler can control fire at a value, but how much is unknown. It is no good to copy something from the literature for a scenario that does not quite match with the actual design. Performing an actual fire test is necessary to demonstrate safety.

Data on heat release rate available in the literature are very limited [14], even fewer on products used and manufactured in the Far East [19]. There are no reliable data on local products for determining a design fire. Different values were used by the designers for different purposes in the past in designing fire protection systems for terminal halls; shopping malls; atria; and train compartments. Very low values of 0.3 MW to 0.5 MW were estimated in some designs [20]. The same value was accepted in one project, but rejected in another similar project. This is due to the lack of a database for local products.

Heat release rates of burning combustibles in typical building arrangements should be measured experimentally in a full-scale burning facility with and without discharging the fire suppressing agent [21]. The results can then be applied for scenario analysis in performance-based design.

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