Extended abstract

Context

Modern architecture often includes the presence of an atrium inside the building. It creates a vertical space that, in the event of fire, allows the spread of hot smoke between different floors. To limit the risk of this effect, a smoke ventilation system (SHEVS) can be placed on top of the atrium.

This installation, which can be natural (vents) or mechanical (motorized), must be sized to meet design criteria such as the height of the smoke layer base or its temperature.

In both cases (natural or mechanical SHEVS), the mass flow rate of the smoke entering the smoke layer in the atrium needs to be calculated. To achieve this, the air entrainment within the smoke plume that occurs along the path of the smoke flow, from the fire room until the base of the smoke layer in the reservoir must be evaluated.

This evaluation can either be performed using a numerical modeling (CFD), or an empirical method of calculation. This study focuses on the second approach.

Literature review and comparison between existing empirical methods

The study began with a literature review which aimed to compare the existing empirical methods to quantify the air entrainment into smoke spill plumes. 10 empirical methods developed between the early 80's and 2011 were compared.

There is on the one hand a complex method (BRE-method developed by the Building Research Establishment) which involves a large amount of parameters and calculation steps, and on the other hand a series of 9 simplified methods which involves between 4 and 6 parameters and allows a 1- or 2-steps calculation process. All the reviewed methods assume that the smoke flow leaving the fire room doesn't contain unburned gases from the pyrolysis.

The comparison highlighted the following points:

- None of the existing simplified methods covers the full scope of the BRE-method. There are always restrictions with regard to the type of spill plume (free/adhered; entrainment/no entrainment into the ends of the spill plume).
- There is no satisfactory matching between the results of the BRE-method and those of the existing simplified methods. The results generally differ from 20 to 40%, considering in each case the best matching simplified method.

Consequently, none of the existing simplified methods could serve as an acceptable alternative to the BRE-method.

Analysis of the BRE-method

The analysis of the calculation flow of the BRE-method was conducted in order to identify its input parameters and some 'useful' intermediate parameters that are necessary for design issues (sizing of the channelling screens, thermal requirements for facade).

A global sensitivity analysis has been performed with respect to all the input parameters. It has shown that 9 of the 10 identified input parameters have a significant effect on the result of the calculation of the mass flow rate in the spill plume.

The performed analyzes led to the development of a simplified BRE-method which is based on a 2-steps calculation process:

STEP 1: the calculation of the mass flow rate under the balcony (m_B);

STEP 2: the calculation of the mass flow rate in the spill plume (m_X) which can be decomposed as follows:

- STEP 2.1: the calculation of the air entrainment along the width of the spill plume ($m_{X,width}$);
- STEP 2.2: the calculation of the air entrainment within the ends of the spill plume ($m_{X,ends}$).

Search for a simplified BRE-method

Formally, only STEP 2 is considered since the calculation process of STEP 1 included in the BRE-method is simple enough.

Basic analysis of the graphs of m_X as a function of X (height of rise in the atrium) clearly shows that:

- $m_{X,width}$ is a linear function of X and can be expressed as: $m_{X,width} = K_1 X + K_2 + K_{mB} m_B$
- $m_{X,ends}$ is a quadratic function of X that passes through the origin and can be expressed as: $m_{X,ends} = K_3 X^2 + K_4 X$

A detailed sensitivity analysis has given the value of K_1, K_2, K_{mB}, K_3 and K_4 as a function of the parameters m_B, Q_C and W_B.

Finally the value of $m_{X,width}$ and $m_{X,ends}$ can be expressed by the following.

- For free plumes:

$$m_{X,width} = 0{,}205\ {Q_C}^{1/3}\ {W_B}^{2/3}\ X + 1{,}65\ m_B + 0{,}0033\ Q_C$$

$$m_{X,ends} = 0{,}03\ \left(\frac{Q_C}{W_B}\right)^{1/3} X^2 + \frac{0{,}4\ m_B\ {Q_C}^{2/15}}{W_B}\ X$$

- For adhered plums:

$$m_{X,width} = 0{,}078\ {Q_C}^{1/3}\ {W_B}^{2/3}\ X + 1{,}50\ m_B + 0{,}0033\ Q_C$$

$$m_{X,ends} = 0{,}006\ \left(\frac{Q_C}{W_B}\right)^{1/3} X^2 + \frac{0{,}19\ m_B\ {Q_C}^{2/15}}{W_B}\ X$$

where:

$m_{X,ends}$	= air entrainment that occurs into the ends of the spill plume, between the spill edge and the height X in the atrium [kg/s]
$m_{X,width}$	= mass flow rate at a height X in the atrium, where no air entrainment occurs into the ends of the spill plume [kg/s]
Q_C	= convective part of the heat release rate [kW]
W_B	= width of the smoke flow at the spill edge [m]
X	= current height where the mass flow rate m_X is considered [m]
m_B	= mass flow rate of smoke under the balcony [kg/s]

The proposed equations give a good agreement with the original BRE-method:

- the largest observed relative difference is less than 8%;
- the average relative difference for free plumes is less than 1%;
- the average relative difference for adhered plumes is less than 2%.

Conclusions

Wherever the BRE-method is considered as an acceptable design standard, the proposal for a simplified BRE-method developed in this study is a satisfactory alternative.

This simplification has two main advantages: it reduces the risk of miscalculation and allows quick check by the authorities.