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ESTABLISHING THE DESIGN FIRE PARAMETERS FOR BUILDINGS

BY

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Abstract. For building design, fire safety is the second important key requirement (according to European legislation). The engineering approach of fire safety use, among other things, the concept of fire design, as a model that estimates the severity of a fire developed in the conditions of a specified space; this should capture the reality of the possible danger. The present paper is a review of the procedures to establish an appropriate fire model for a known situation, specifying the parameters values that define the heat flow variation with time, procedures based on the rate of heat release (RHR), depending on the type of the analysed building.

Key words: design fires; fire safety engineering; fire load; rate of heat release; heat release rate.

1. Introduction

This paper defines the characteristic parameters for the design fire curve (which highlights the rate of heat release *versus* time), concept used in fire safety engineering for

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a) the assessment by calculation of structural stability in the event of fire (temperature distribution at the contact area of the burning environment with the structural elements);

b) the analysis of safe human evacuation in case of fire (appreciation of visibility, toxicity and temperature from radiation, due to the spreading of smoke and hot gases).

The main stages of a real fire developed within an enclosure are presented in Fig. 1 (Staffansson, 2010): pre-flashover (which includes ignition and growth) and post-flashover (which includes fully developed fire and decay).

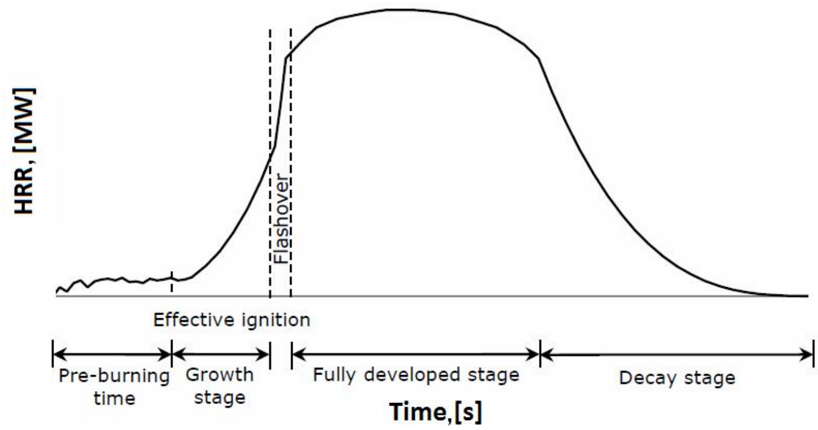

Fig. 1 – Schematic figure of the main stages of fire development within an enclosure.

The ideal fire development is presented in the Fig. 2.

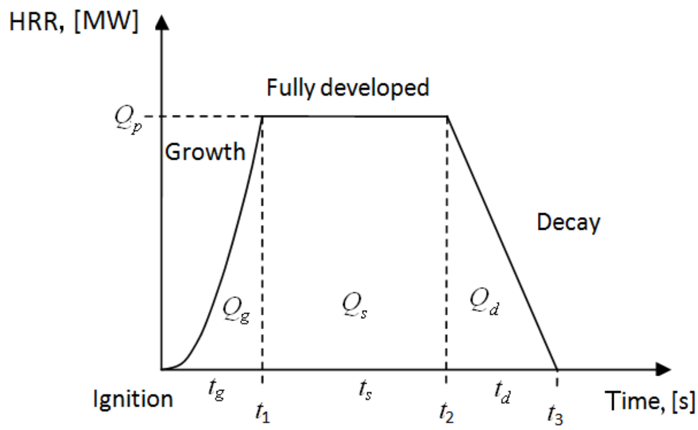

Fig. 2 – Development of an ideal fire model (obtained by simplification) used for calculation.

2. Fire Severity

The total energy stored in the fuel, Q_t, [MJ], and released during combustion as heat flow (power) is (Spearpoint, 2008; Karlsson & Quintiere, 2000)

$$Q_t = m\Delta H_{\text{eff}} , \tag{1}$$

with (Karlsson & Quintiere, 2000)

$$\Delta H_{\text{eff}} = \chi \Delta H_c , \tag{2}$$

where: m is the mass of fuel, [kg]; ΔH_{eff} – effective heat of combustion, [kJ/kg]; χ – combustion efficiency (we assume an efficiency of 80%, χ = 0.8); ΔH_c – complete heat of combustion, [kJ/kg].

Complete heat of combustion for some common materials is presented in Table 1.

Table 1
Complete Heat of Combustion Values of Typical Fuels

Material	ΔH_c, [MJ/kg]	Material	ΔH_c, [MJ/kg]
Methanol	20	Paraffin wax	47
Ethanol	27	Foam rubber	37
Benzine	45	Rubber isoprene	45
Gasoline	44	Silk	19
Fuel oil	40	Wood	18
Cellulose	17	Wool	23
Clothes	19	ABS	36
Cotton	18	Epoxy	34
Grain	17	Polyester	31
Grease	41	Polyethylene	44
Leather	19	Polystyrene	40
Linoleum	20	Polyurethane foam	26
Paper, cardboard	17	Polyvinil chloride	17

The heat flux released at the end of the growth stage of the fire, Q_p, [MW], (peak burn rate), is estimated differently for fuel control fires and ventilation controlled fires.

In the case of fuel controlled fires (specific for large compartments) $Q_{p,f}$, [MW], is based on the physical size of the rate of heat release which can be specified by

a) the type of occupancy/activity, RHR_f, specified in Table 2 (EC1-1-2):

$$Q_{p,f} = \text{RHR}_f A_f , \tag{3}$$

b) the type of combustible materials from the enclosure, HRRPUA (Heat Release Rate Per Unit Area), specified in Table 3 (Spearpoint, 2008)

$$Q_{p,f} = \text{HRRPUA} \cdot A_f\,, \qquad (4)$$

where A_f is the orizontal area of the burning materials.

Table 2
RHR_f *for Different Occupancies*

Occupancy	RHR_f, [MW/m^2]
Dwelling, Hospital (room), Hotel (room), Office, Classroom of a school, Shopping centre, Transport (public space)	2.50
Library, Theatre (cinema)	5.00

Table 3
Rates of Burning for Some Liquid and Solid Fuels

Material	HRRPUA, [MW/m^2]	Material	HRRPUA, [MW/m^2]
Petrol	2.40	100 mm in crib*	1.24
Kerosene	1.68	Furniture	1.80
Heavy fuel oil	1.39	25 mm in crib*	4.20
Ethanol	0.40	Softboard	0.14
Methanol	0.34	Polyethylene	1.36
Flat wood	0.09	Polystyrene	1.40
1 m^3 of wood	0.53		

* Cribs 1.0 m high. Spacing between sticks is two times the stick thickness.

In the case of ventilation controlled fire (specific for small and medium-size compartments) $Q_{p,v}$, [MW], is calculated with the next procedure asfollows:

a) the mass flow rate through the ventilation openings, m_a, [kg/s], can be assumed as (Zehfuss & Hosser, 2007)

$$m_a = 0.52 A_w \sqrt{h_w}\,, \qquad (5)$$

where: A_w is the area of ventilation openings, [m^2]; h_w – averaged height of the ventilation openings, [m];

b) being aware of the stoichiometric ratio (r = 5.2 kg air/kg burning material for wooden fire load respectively furnishings), that is the reguired amount of air for the combustion per kg of burning material, the burning rate, m, [kg/s], can be assumed as (Zehfuss & Hosser, 2007)

$$m = \frac{m_a}{r} = \frac{0.52}{5.2} A_w \sqrt{h_w} = 0.1 A_w \sqrt{h_w}\,, \qquad (6)$$

From eqs. (1), (5) and (6) the peak buring rate $Q_{p,v}$, [MW] for the ventilation controlled fire is stated by (Zehfuss & Hosser, 2007)

$$Q_{p,v} = 0.1 A_w \sqrt{h_w} \Delta H_{\text{eff}} \ . \quad (7)$$

In the particular case of residential and office buildings (where the fuel is mainly wood) $Q_{p,v}$, [MW] can be estimated by

$$Q_{p,v} = 1.44 A_w \sqrt{h_w} \ , \quad (8)$$

3. The Growth State

Following effective ignition, the fire starts to grow. The fire growth rate depends on: the type of combustion process, the type of fuel burning, ventilation conditions and the interactions with the surroundings.

The amount of heat and smoke produced during the fire growth stage *prior* to flashover is very important in fire safety engineering when evaluating the life safety in buildings.

The most popular approache to estimate the growth rate for a particular design fire is the t^2, *t*-squared (EC1-1-2). The t^2 approximation is close enough to make reasonable design decision for common situations. For complex fuel geometries other fire growth rates can be used: cubic, parabolic or exponential functions (Spearpoint, 2008).

The t^2 fire gained popularity when it was included in the european (EC1-1-2) and american (NFPA-72) legislation.

The t^2 approache has three categories for fire growth defined by EC1-1-2 slow, medium and fast and an additional category, ultra fast, defined by NFPA-72. These definitions are simply determined by the time required for the fire to reach 1 MW.

A slow fire is defined as taking 600 s, a medium fire 300 s, a fast fire 150 s and a ultra fast fire has a growth time of 75 s to reach 1 MW.

Time to reach peak burning rate is stated by Spearpoint, (2008)

$$t_1 = k \sqrt{Q_p} \ , \quad (9)$$

Energy released in the growth state is given by Spearpoint, (2008)

$$Q_g = \frac{t_1 Q_p}{3} \ . \quad (10)$$

The energy is calculated as the chart area; 1/3 is a god aproximation for the parabolic variation (Spearpoint, 2008).

Heat release rate are shown in Fig. 3 for the four different growth time given in Tabel 4 (Staffansson, 2010; Spearpoint, 2008; EC1-1-2).

Table 4
Typical Growth Times for Design Fires

Fire growth rate	Grouth time, *k*, [s]	Occupancy/Activity
Slow	600	Densely packed wood products, Art-gallery, Public space for transport means, Storage building with few combustible materials
Medium	300	Solid wooden furniture items with small amounts of plastic, Dwelling, Hospital bedroom, Hotel bedroom, Hotel reception, Office buildings, School classroom, Storage building for cotton or pyester sprung mattresses
Fast	150	High stacked wood pallets, Shopping centre, Library, Theatre, Cinema, Cartons on pallets, Some upholstered furniture, Storage buildings with full mail bags, plastic foam, stacked timber
Ultra fast	75	Upholstered furniture, High stacked plastic materials, Thin wood furniture such as wardrobes, Chemical Plant, Storage buildings with alcoholic liquids or upholstered furniture

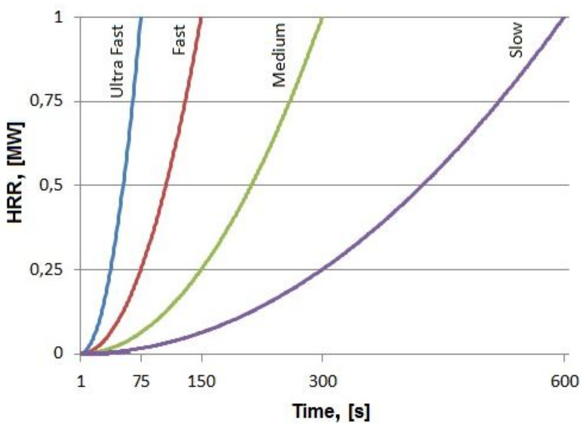

Fig. 3 – Heat release rate for t^2 fires.

Flashover follows the growth period and it is the stage between the growth state and the fully developed fire. Flashover provides the rapid transition from the development phase to the fully developed fire (when all the surfaces of combustibile materials from the enclosure will burn). In many cases, it is estimated that flashover occurs when the upper layer temperature of hot gas reaches 500°C…600°C or when the radiation to the floor of the compartment reaches 15 to 20 kW/m² (case of small enclosures). Following this, the fire may either be ventilaton-controlled or fuel controlled.

However, flashover does not always occur (Zalok, 2013). The factors that affect whether this phenomen occurs are: surface area of the enclosure, the area of enclouser openings, the effective height of encloue openings, heat release rate and thermal properties of compartiment boundaries.

Several mathematic models exist for the prediction of the maximum HRR, [MW], for fashover namely

a) McCaffreym Quintiere and Harkload (1981):

$$Q_{fo} = 0.610(h_k A_T \sqrt{h_w})^{0.5}; \tag{11.a}$$

b) Babrauskas (1980):

$$Q_{fo} = 0.600 A_w \sqrt{h_w}, \;\; Q_{fo} = 0.750 A_w \sqrt{h_w}; \tag{11.b}$$

c) Thomas (1981):

$$Q_{fo} = 0.007.8 A_T + 0.378 A_w \sqrt{h_w}\;, \tag{11.c}$$

where: h_k is the effective heat transfer coefficient, [kW/m.K]; A_T – total compartment surface area, [m^2].

If Q_t is less than Q_{fo} it is unlikely that flashover will occur (Spearpoint, 2008).

The time for flashover can be estimated with the relation:

$$t_{1,fo} = \sqrt{t_g^2 Q_{fo}}\;, \tag{12}$$

If the time $t_{1,fo}$, is less than the time t_1, Q_{fo} has to be taken into account.

The fire load consumed until the time to flashover is

$$Q_{1,fo} = \frac{t_{1,fo}^3}{3t_g^2}\,. \tag{13}$$

4. The Fully Developed State

The fully developed fire is the stage where the peak heat release rate is reached. The peak heat release rate can be limited by the available combustible surfaces or by the available ventilation. In the first case we discuss about a fuel controlled fire and in the second case of a ventilation controlled fire.

It is estimated that 70% of total energy (EC1-1-2) is consumed at the start of the decay state; energy released in the steady state, Q_s, [MW] is

$$Q_s = 0.7 Q_t - Q_g\,. \tag{14}$$

Duration of the steady state is

$$t_s = \frac{Q_s}{Q_p}\,. \tag{15}$$

5. The Decay State

The last stage for the enclosure fire is the decay stage. In this stage, the amount of combustible volatiles decreases because the fuel becomes consumed, which will lead to a decrease of the fire intensity.

The energy released in the decay state, Q_d , [MW], it is assumed to be 30% of the total energy (EC1-1-2)

$$Q_d = 0.3Q_t \,. \tag{16}$$

Duration of the decay state is

$$t_d = \frac{2Q_d}{Q_p} \,. \tag{17}$$

6. Conclusions

The severity of a fire is given by the caloric energy released during the evolution of fire.

The content of this paper can constitute the basis of making a software module for analysing the evaluation of fire resistance of structural elements and/or to assess fire safety evacuation of occupants of a space; this issue will be subject to the following studies.

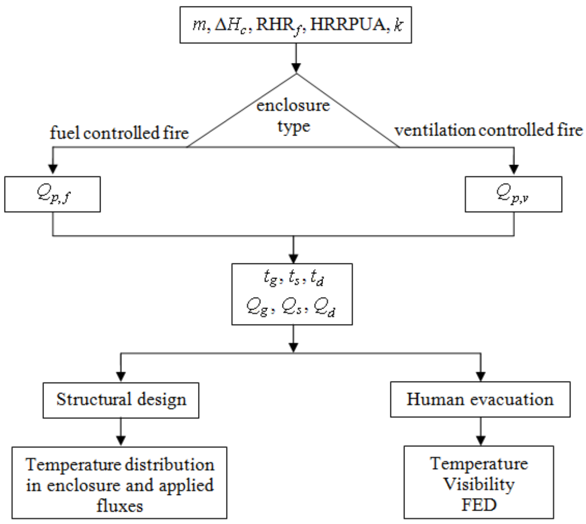

Fig. 4 – The flow chart for establishing the design fire parameters for buildings.

The flow chart for determinating the parameters involved in fire severity is shown in Fig. 4.

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STABILIREA PARAMETRILOR FOCULUI DE CALCUL ÎN CONSTRUCȚII

(Rezumat)

Pentru proiectarea construcțiilor, securitatea la incendiu este a doua cerință esențială importantă (conform legislației europene). Abordarea inginereasca a securității la incendiu utilizează, printre altele, şi conceptul focului pentru proiectare, ca model ce apreciază severitatea unui incendiu dezvoltat în condițiile unui spațiu precizat, acesta trebuind să surprindă, acoperitor, realitatea pericolului posibil a se manifesta.

Prezentul articol încearcă o trecere în revistă a procedurilor cu privire la stabilirea modelului pentru incendiu adecvat unei anumite situații, precizând valorile parametrilor ce definesc variația debitului căldurii degajate în timp, proceduri care se bazează pe debitul căldurii eliberate (RHR) precizat funcție de destinația clădirii analizate.