EVALUATION OF LOCAL FIRES IN ENERGY SYSTEMS IN THE CONTEXT OF NATIONAL STANDARDS OF THE CZECH AND SLOVAK REPUBLICS

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ABSTRACT

Equipment for the production and distribution of electricity often represents complicated components which are exposed to damage caused by various influences. One of possible negative influences are also fires. The extent of damage caused by fires depends also on the extent of these fires as the effort is to solve fires in their stage of development that is usually described as a local fire. Partial characterization of local fire, known as fire plume, was the subject of extensive theoretical analysis and experimental research. Methods for the direct application of theories on fire plumes are, however, in the territory of the Czech and Slovak Republics considerably limited due to the lack of interaction with national standards. The article describes derived interrelationships between researches and experiments realized abroad and by national standards in the territory of both republics. Derived procedures allow significantly easier application of methods for assessing local fires, including the characteristics of fire plumes. A wider application of methods for evaluating local fires leads to an increase in the security of energy equipment in the territory of the Czech and Slovak Republics. Principles are generally applicable also in other countries.

Keywords: energetic equipment, local fire, fire plume, national standard, solution finding method.

1 INTRODUCTION

Currently, the dynamic development of equipment for the production and distribution of electricity occurs in the Czech and Slovak Republics. One reason is the need for ecologically produced electricity, when the plants producing electrical energy using solar, water or wind energy are encountered more and more often. Construction of the facilities in the Czech Republic is supported through subsidy titles by the Ministry of Environment [1].

There are annually about 20,000 fires in the Czech Republic. Fires of buildings for electricity production amount to less than 1% of the total number of fires according to the Statistics [2]. The percentage of fires of power plants also corresponds to the data of the Slovak Republic.

Although it is not a substantial number of fires, the consequences are serious. It is not only material damage, which annually amount to several million euros, it primarily concerns business interruption of series of coherent operations that are dependent on electricity supplies.

Causes of fires of current installations for the electricity production and the conditions for their effective solutions are reviewed by experts such as Wang et al. [3] or Backstrom et al. [4]. Also, the safety of possible feedstock for power plants is given considerable attention according to Mráčková and Chromek [5].

From the viewpoint of safe operation of power plants, it is necessary to pay attention to the prevention of fire, and in the event that a fire occurs, limit its consequences. Limiting the consequences of fire means to tackle the fire already in the development stage, which is in ČSN EN 1991-1-2 [6], characterized by the so-called "local fire".

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2 FIRE DEVELOPMENT AND ITS PARAMETERS

According to DiNenno [7] and Balog and Kvarčák [8], fire development is usually characterized by the description of so-called idealized fire, which divides fire into four basic phases; i.e. initial phase, development phase, fully developed phase and burning-out phase.

Based on the concept of the Fire and Rescue Brigade of the Czech Republic [9], the fire phases can be characterized by so called “parameters of fire”. Here belongs the fire perimeter, fire line, linear speed of fire spreading, burn off rate, the height of a flame, temperature of fire, gas exchange intensity, heat emission intensity and the level of smoke.

ČSN EN 1991-1-2 [6] puts released heat flow Q, maximum rate of heat release off 1 m^2 of fuel controlled fire RHR_f and the density of the characteristic fire load per a floor area unit $q_{f,k}$. The above-mentioned values also have vital importance in the characteristic parameter description of a “fire plume”.

Although the above-mentioned fire parameters change in real situations depending on time, according to DiNenno [7], Kučera et al. [10] and Kučera et al. [11], during the evaluation they are used as variables (for instance $Q = f(t)$), or by simplifying assumptions, as constants (for instance. $Q \approx const.$).

3 FOREIGN AND NATIONAL CONNECTIONS OF THE DESCRIPTION OF FIRE DYNAMICS IN THE FIRE PLUME EVALUATION

Fire safety of buildings in the Czech Republic and Slovakia is dealt with by standard procedures mainly (the code of practice for fire safety in buildings), which are represented particularly by ČSN 73 0802 [12], ČSN 73 0804 [13] and STN 92 0201-1 [14].

According to Kučera et al., the code of practice for fire safety in buildings is based on the philosophy of designing a building in a fully developed fire scenario. Some of the European and international standards deal with the fire development phase in detail. As an example, we can state ČSN EN 1991-1-2 [6] or a set of standards ISO 1673x Fire engineering. The above-mentioned and other European and international technical regulations describe, within a local fire, also some principles of fire plume evaluation. One of more significant documents in this respect is, for instance, ISO 16734 Fire safety engineering – Requirements governing algebraic equations – fire plumes [15].

A fire plume is a column of smoke that is created above the center of fire. According to DiNenno [7], Hosser [16], Karlsson and Quintiere [17] and Peacock et al. [18], a fire plume is divided into three basic parts; i.e. the zone of the flame, the transition zone and the smoke zone. The basic characteristics of a fire plume are geometry, temperature, velocity and the amount of smoke. One of the more significant input sections to describe a fire plume is the “dynamics of fire”.

Abroad, the dynamics of fire in relation to fire plumes can be described especially by the following equations [7], [16]–[17]:

$$\mathrm{Q} = \begin{cases} \alpha t^2 \\ 1000\left(\frac{t}{t_g}\right)^2, \\ \mathrm{A} \cdot m_i \Delta H_{\mathrm{eff}} \end{cases} \tag{1}$$

$$RHR_f = \begin{cases} \frac{Q}{A} \\ \frac{1000 \cdot q_{f,k}}{t}, \end{cases} \tag{2}$$

$$q_{f,k} = \frac{\sum_{i=1}^{n} M_i \cdot \Delta H_{eff}}{\sum_{i=1}^{n} S_i}, \tag{3}$$

where

Q	heat flow (kW)
α	fire development coefficient (kW.s^{-2})
t	the time of fire development (s)
t_g	the time needed to reach the reference rate (s)
A	the area of fire (m^2)
m_i	the mass rate of a substance burning off an area unit per time unit (kg.m^{-2}.s^{-1})
ΔH_{eff}	effective heating value (kJ.kg^{-1})
RHR_f	maximum rate of heat release off 1 m^2 of fuel controlled fire (kW.m^2)
$q_{f,k}$	the density of characteristic fire load per a floor area unit (MJ.m^{-2})
S_i	the ith area of inflammable material occurrence (m^2)

Among the most significant parameters of fire in terms of local fire description in national standards of the Czech Republic and Slovakia rank the fire load p, average fire load $\bar{p}$, coefficient expressing the burning-off rate in terms of characteristics of inflammable substances a, the mass rate of a substance burning off an area unit per time m_i [12]–[14].

The following equations have been derived to describe the fire dynamics in relation to fire plumes for the Czech Republic and Slovakia:

$$\mathrm{Q} = \begin{cases} \alpha t^2;\ non-industr.\ build.\ \alpha = \frac{a^2 \cdot p}{2560}, industr.\ build. \alpha = \frac{\bar{p}}{2560} \\ \frac{p \cdot a^2 \cdot t^2}{2560};\ non-industrial\ buildings, where\ t_g = \frac{1600}{a \cdot p^{1/2}} \\ \frac{\bar{p} \cdot t^2}{2560};\ industrial\ buildings, where\ t_g = \frac{1600}{\bar{p}^{1/2}} \end{cases}, \quad (4)$$

$$RHR_f = \begin{cases} \frac{1000 \cdot p \cdot a \cdot H_d}{t}; non-industrial\ buildings \\ \frac{1000 \cdot \bar{p} \cdot H_d}{t}; industrial\ buildings \\ \frac{\sum_{i=1}^{n} 1000 \cdot m_i \cdot H_i \cdot S_i}{\sum_{i=1}^{n} S_i} \end{cases}, \quad (5)$$

$$q_{f,k} = \begin{cases} p \cdot a \cdot H_d;\ non-industrial\ buildings \\ \bar{p} \cdot H_d;\ industrial\ buildings \end{cases}, \quad (6)$$

where

a	coefficient specifying the burning-off rate in terms of the characteristics of inflammable substances (-)
p	fire load (kg.m^{-2})
$\bar{p}$	average fire load (kg.m^{-2})
H_d	standard heat value of wood (MJ.kg^{-1})
M_i	mass of the ith type of material (kg).

In some cases, for national standards of the Czech Republic and Slovakia, eqns (1)–(3) are applicable.

4 THE COMPARISON OF FOREIGN AND NATIONAL METHODS, DESCRIBING THE DYNAMICS OF FIRE IN RELATION TO FIRE PLUME

The comparison of foreign and nationally derived methods (equations), describing the dynamics of fire in relation to fire plume has been conducted at 10 selected plants (see Figs 1–3).

The comparison of results of foreign and derived, national methods intended to determine the time needed to reach the reference rate t_g is shown in Fig. 1.

The comparison of results of foreign and derived, national methods to determine the heat flow Q is shown in the Fig. 2.

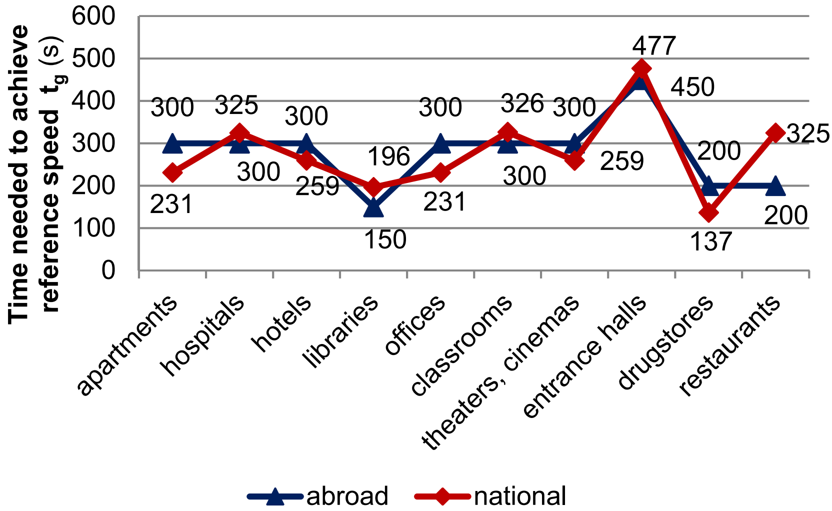

Figure 1: The comparison of results of foreign and national methods to determine the time needed to reach the reference rate t_g.

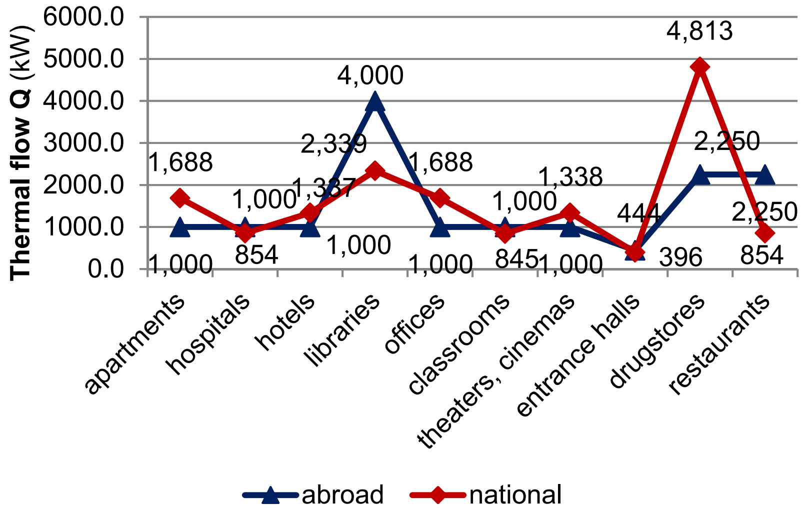

Figure 2: The comparison of results of foreign and national methods for the released heat flow Q.

The comparison of results of foreign and derived, national methods to determine the density of characteristic fire load per the floor area unit $q_{f,k}$ is showed in Fig. 3.

5 DISCUSSION

The most important values for the assessment of fire development phase include the time required to reach the reference rate t_g and the coefficient of fire development α. Using the above values, further parameters describing the dynamics of a fire can be set that had been described in previous sections of the article, i.e. the released heat flow Q, the maximum heat release rate of 1 m^2 of the fire controlled by fuel RHR_f and the density of characteristic fire load per unit of floor area $q_{f,k}$.

The relation between the time required to reach the reference rate t_g and the Code of fire safety standards for buildings in the Czech Republic is currently described by the equation [12]:

$$t_g = \frac{k}{\alpha \cdot p^{1/2}}, \tag{7}$$

where k is the constant for determining the time required to achieve the reference rate within the national standard (s.kg$^{1/2}$.m^{-1}).

The constant k is in the national standard of the Czech Republic expressed by a value of 2000 s.kg$^{1/2}$.m^{-1} [12]. The Slovak Republic has no similar relation imposed by their national standard.

The constant correctness was verified on selected plants. While maintaining the structure of the eqn (7), the "appropriate constant k" was found by means of the subsequent removal of outliers by the method of internal walls using quartiles, as a mean value of the resulting data set. As the resulting mean value, median, the value of 1600 s.kg$^{1/2}$.m^{-1} (rounded to hundreds) was determined. The determined mean value was used to derive other national equations (see Section 3 of the paper).

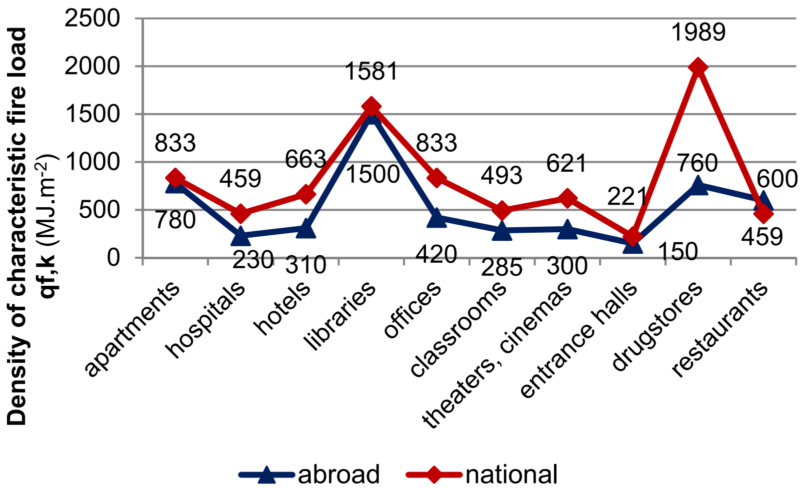

Figure 3: The comparison of results of foreign and national methods to determine the density of characteristic fire load per the floor area unit $q_{f,k}$.

It should be noted to the constant derived for determining the time required to achieve the reference rate within the national standard k that the number of plants having been compared was limited (15 plants) and the comparison would benefit from a wider variety of plants. The limited scope of plants is caused by lack of foreign published values of the time needed to reach the reference rate t_g. A more detailed description of the derivation of the "appropriate constant k" is not subject of the article.

The results of the comparison between foreign and national derived equations forming a link to the Code of fire safety standards for buildings are shown in Figs 1, 2 and 3.

The results of the derived equations to achieve the time required to reach the reference rate t_g (see Fig. 1) did not indicate any essential differences between the methods, and the outputs can be considered relevant.

The results of the derived equations for the released heat flow Q (see Fig. 2) show significant differences for libraries and drugstores. Also, deviations for restaurants are significant.

The results of the derived equations for characteristic fire load densities per unit of floor area $q_{f,k}$ (see Fig. 3) show a substantial deviation for drugstores.

The cause of deviations between foreign and national derived equations consists in differences in the description of the fire dynamics for individual spaces that are characterized in the code of fire safety standards for buildings [12]–[14] and foreign sources [7], [16]–[17]. The values describing the fire dynamics were created by different authors at different times, with diverging assumptions, and probably often according to different procedures. The results of the compared methods indicate that instead of the standardized calorific value of materials (H_i, H_d) it would be more appropriate to use the effective calorific value ΔH_{eff}. A more detailed analysis of the "correctness" of the values presented in the above sources, foreign or national, is not further the subject of the article.

The derived national equations for describing the dynamics of fire in relation to the evaluation of fire plume can be considered relevant. The application range of the equations is much wider, they do not only determine characteristics of fire plume, but can also be used for the evaluation of other parameters of a local fire. The derived equations provide an adequate basis for assessing the stage of fire development in energy facilities.

6 CONCLUSION

In the article, equations for describing the dynamics of fire in the evaluation of local fire, especially fire plume, were presented. The derived equations create relations among foreign methods and national methods for the Czech and Slovak Republics in the evaluation of fire safety for buildings and technological equipment.

The derived equations will facilitate the assessment of parameters of local fire in the two republics. Finally, they will lead to a more effective evaluation of local fire of power equipment, thereby increasing its security.

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