CHANGE OF FIRE COURSE CONDITIONS AT ACTIVATION OF A DEVICE FOR SMOKE AND HEAT REMOVAL AND FIXED EXTINGUISHING DEVICE

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Abstract

This report describes changed conditions of the course of fire at activation of selected fire safety devices, which particularly include devices for smoke and heat removal and fixed extinguishing devices. Particular attention is paid to the fire development stage. In principle, changes are described in the form of simple equations and represented graphically. The study elaborated with the use of the CFAST fire zone model demonstrates how the selected characteristics describing the course of fire are influenced if the specified devices are activated.

Key words
Course of fire, change of conditions, fire safety devices, CFAST.

Introduction

In the past as well as at present, the course of fire has been the subject of interest of professionals engaged in fire safety. A lot of literary sources deal with description of the individual fire stages. In some cases, a simple fire description seems to be insufficient and a more detailed evaluation of the individual fire stages and their parameters gains importance. A characteristic example of using a more detailed description of the fire course is the *fire engineering applications* [1].

The course of fire as well as its stages is influenced by many factors. One of them is also the activation of some fire safety devices. These devices include the devices for smoke and heat removal (DSHR) and fixed extinguishing devices (FED), which have a significant impact on the fire course after activation. Moreover, attention must be paid to the electric fire signalling (EFS) devices.

The devices described are also designated as the so-called *active fire safety devices*, which are generally expected to start up automatically pursuant to selected parameters, perform certain tasks automatically and create conditions to limit fire development, ensure safety of persons and conditions for the intervention of fire brigades, etc. [2], [3]

Course of fire without activation of fire safety devices

As a rule, the course of fire can be described by the *following stages*:

- initial stage,
- fire development stage,
- fully developed fire stage,
- burn-down stage.

In an idealized description of the course of fire, the initial and fire development stages are usually joined under the common designation of the fire development stage.

Figure 1 schematically illustrates the course of fire.

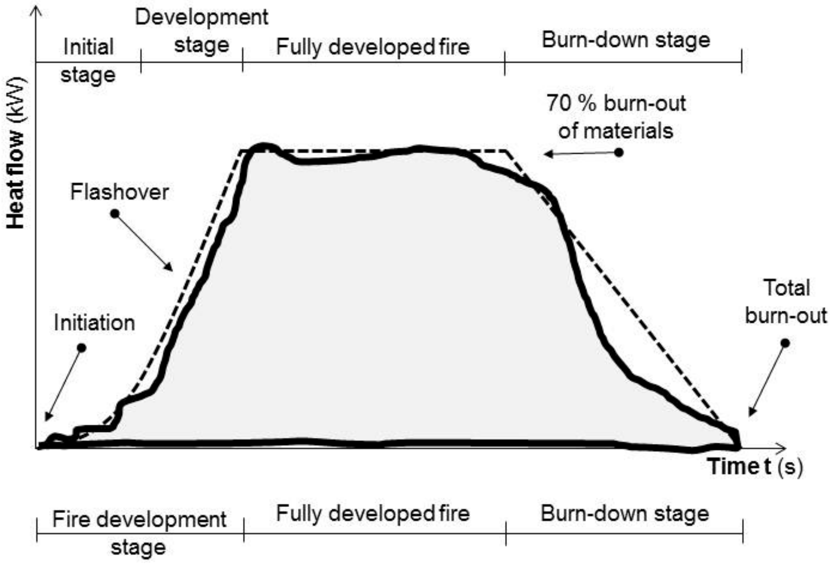

Fig. 1
Course and individual stages of fire [4]

Fire stages after activation of active fire safety devices

The fire stages after activation of EFS, FED or DSHR can be divided into the following three time intervals:

- stage of *free fire development* as the time from fire initiation to the activation of the device $\langle 0 - t_{\text{activation}} \rangle$,
- stage of *developed or uniform fire* as the time from activation of the device to the beginning of fire brigade intervention or burn-out of 70 % of materials [5] $\langle t_{\text{activation}} - t_{intervention} \rangle$,
- stage of *burn-down or cooling down of fire* as the time from the beginning of the fire brigade intervention or burn-out of 70 % of materials to the extinguishment time $\langle t_{intervention} - t_{\text{extinguishment}} \rangle$. [1]

The stage of free development of fire until the time of fire safety device activation at the time interval of $\langle 0 - t_{\text{activation}} \rangle$, can be described, for example, by the "t-quadratic fire"[1] equation [5],[6]:

$$\dot{Q}_{1(\mathrm{t})} = \dot{Q}_0 \left(\frac{t}{t_{\mathrm{g}}}\right)^2 \text{ nebo } \dot{Q}_{1(\mathrm{t})} = \alpha t^2 \qquad (1)$$

where $\dot{Q}_{1(\mathrm{t})}$ heat flow released during the fire development stage (kW)
$\dot{Q}_0$ reference speed of heat release (kW)
t time after initiation of the fire (s)
t_{g} time necessary for achieving the reference speed (s)
α fire development coefficient ($kW.s^{-2}$)

The stage of developed or uniform fire until the beginning of the fire brigade intervention or burn-out of 70 % of materials at the time interval of $\langle t_{\text{activation}} - t_{\text{intervention}} \rangle$ can be described by the following relation:

$$\dot{Q}_{2(t)} = \begin{Bmatrix} \dot{Q}_{max,EFS} \\ \dot{Q}_{max,FED} \\ \dot{Q}_{max,DSHR} \end{Bmatrix} \tag{2}$$

where $\dot{Q}_{2(t)}$ heat flow during the stage of developed or uniformly developing fire (kW)
$\dot{Q}_{max,EFS}$ maximum heat flow at activation of EFS (kW)
$\dot{Q}_{max,FED}$ maximum heat flow at activation of FED (kW)
$\dot{Q}_{max,DSHR}$ maximum heat flow at activation of DSHR (kW)

The burn-down or cool-down stage of fire is described with the individual devices.

Course of fire at activation of electric fire signalling

If EFS is activated, fire information is transmitted to a place with permanently present persons who can then report it to the fire brigade, or directly to the fire brigade. Simultaneously, controlled and auxiliary devices are activated.

The EFS activation results in *reducing* the time until the beginning of the fire brigade intervention, thus also the *time of free fire development* or *time of developed fire*. At the same time, the fire cool-down period may be reduced.

Figure 2 illustrates the influence of EFS activation on the course of fire in closed spaces.

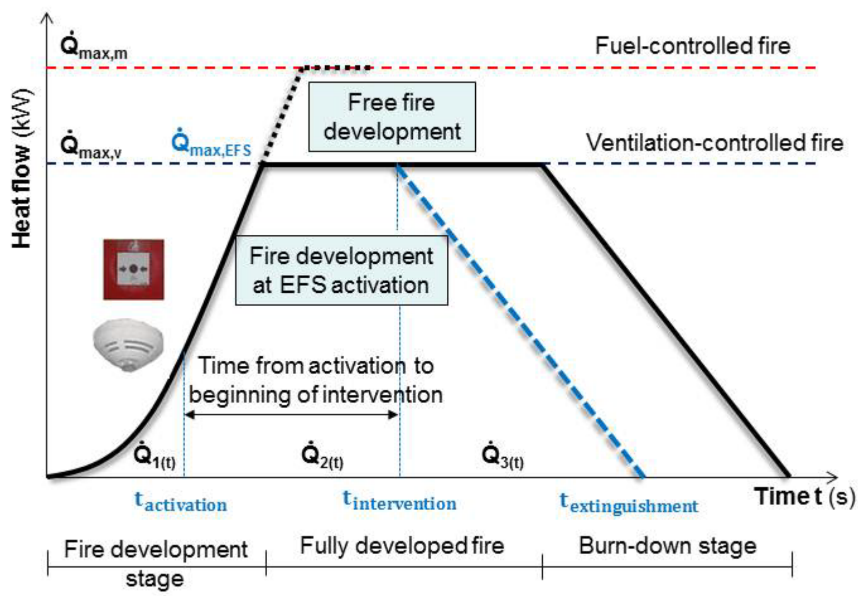

Fig. 2
Influence of EFS activation on the course of fire [2]

The fire cool-down stage until the time of its extinguishment by the fire brigade at the time interval of $\langle t_{intervention} - t_{extinguishment} \rangle$ can be described by the equation [2],[3]:

$$\dot{Q}_{3(t)} = \frac{\dot{Q}_{max,EFS}}{(t_{extinguishment} - t_{intervention})} \cdot (t_{extinguishment} - t) \qquad (3)$$

kde $\dot{Q}_{3(t)}$ heat flow during the burn-down or fire cooling stage (kW)
$\dot{Q}_{max,EFS}$ maximum heat flow at activation of EFS (kW)
$t_{extinguishment}$ time of fire extinguishment (s)
$t_{intervention}$ time of starting extinguishing works by the fire brigade (s)
t time after initiation of the fire (s)

Course of fire at activation of fixed extinguishing equipment

After the FED has been activated, there is usually *a significant reduction in the heat released from the developing fire* and *limitation of its further development*. In some cases, the FED extinguishes the fire, even without subsequent intervention of the fire brigade. Simultaneously, activation of the device is signalled to a place with permanent presence of persons who can then report the fire to the fire brigade.

The FED activation results in significant *limitation of the time of free fire development* and *the time of fire cool-down*. The stage of fully developed fire is not presupposed.

Figure 3 illustrates the influence of FED activation on the course of fire in closed spaces.

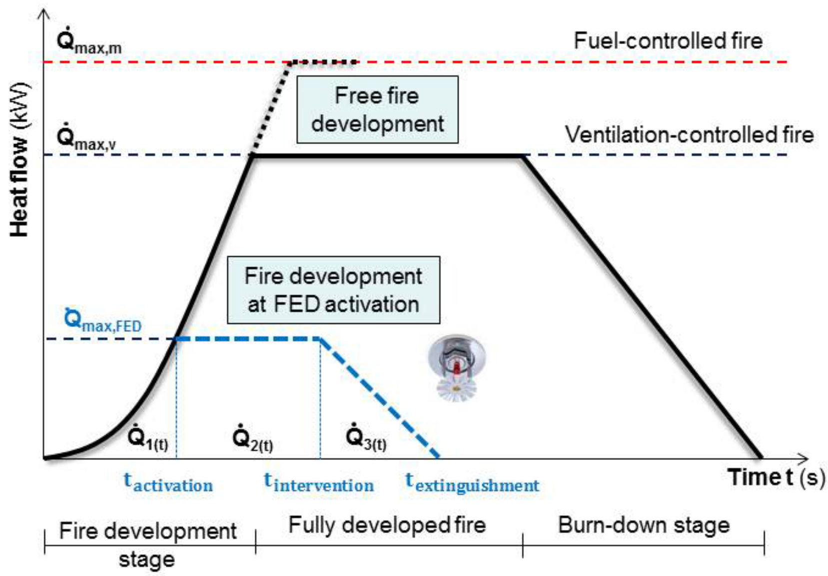

Fig. 3
Influence of FED activation on the course of fire [2]

The stage of fire cool-down until the time of its extinguishment by the fire brigade at the time interval of $\langle t_{intervention} - t_{extinguishment} \rangle$ can be described by the equation [2], [3]:

$$\dot{Q}_{3(t)} = \frac{\dot{Q}_{max,FED}}{(t_{extinguishment} - t_{intervention})} \cdot (t_{extinguishment} - t) \qquad (4)$$

kde
$\dot{Q}_{3(t)}$ heat flow during the burn-down or fire cooling stage (kW)
$\dot{Q}_{max,FED}$ maximum heat flow at activation of FED (kW)
$t_{extinguishment}$ time of fire extinguishment (s)
$t_{intervention}$ time of starting extinguishing works by the fire brigade (s)
t time after initiation of the fire (s)

Course of fire at activation of the device for smoke and heat removal

If the DSHR is activated, *increased gas exchange* occurs in the burning space. Simultaneously, activation of the device is signalled to a place with permanent presence of persons who can then report the fire to the fire brigade.

The increased gas exchange results in the *increased speed of ventilation-controlled burn-down of materials in the stage of fully developed fire*, as a result of which *a higher value of heat flow released may be achieved*. In the stage of free fire development and burn-down, the increased gas exchange in the burning space has generally no impact on the speed of burning down of substances (as a rule, the burn-down speed is controlled by the burning speed of materials, and is not influenced by the increased input of oxidant).

The signalling of DSHR activation results in *reduced time* until the beginning of the fire brigade intervention, and thus also the *time of free development of fire or time of developed fire*.

The influence of DSHR activation on the course of fire in a closed space is illustrated in Figure 4.

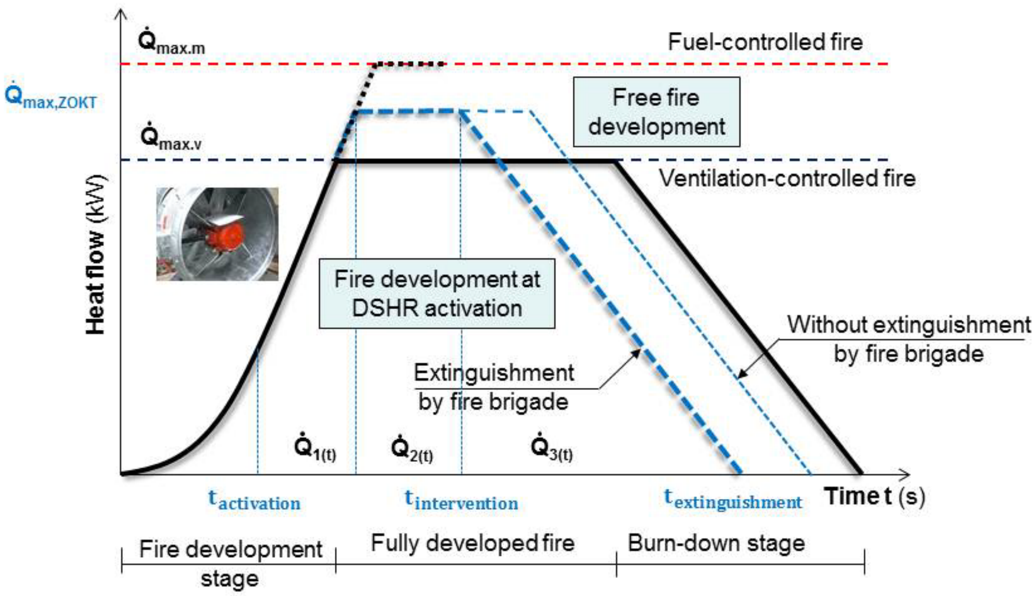

Fig. 4
Influence of DSHR activation on the course of fire [2]

The stage of cooling down of the fire until the time of its extinguishment by the fire brigade at the time interval of $\langle t_{\text{intervention}} - t_{\text{extinguishment}} \rangle$ can be described by the equation [2], [3]:

$$\dot{Q}_{3(\mathrm{t})} = \frac{\dot{Q}_{\mathrm{max,DSHR}}}{(t_{\mathrm{extinguishment}} - t_{\mathrm{intervention}})} \cdot (t_{\mathrm{extinguishment}} - t) \qquad (5)$$

kde

$\dot{Q}_{3(\mathrm{t})}$	heat flow during the burn-down or fire cooling stage (kW)
$\dot{Q}_{\mathrm{max,DSHR}}$	maximum heat flow at activation of DSHR (kW)
$t_{\mathrm{extinguishment}}$	time of fire extinguishment (s)
$t_{\mathrm{intervention}}$	time of starting extinguishing works by the fire brigade (s)
t	time after initiation of the fire (s)

Representation of fire course change at DSHR and FED activation by means of a fire model study

The change in the fire course at activation of DSHR and FED can be demonstrated in the form of the following study. The fire was simulated in a single-storey object with geometrical dimensions of 40/20/7 m. The centre of the fire was situated on the floor in the centre of the object. The fire was simulated in the development stage by the so-called "t-quadratic fire" characterized by the fire development parameter t_g (time for achievement of the reference speed[2]) of 300 s and maximum heat release speed RHR_f of 500 $\mathrm{kW.m^{-2}}$.

The fire development was evaluated in three variants:

- without activation of DSHR and FED,
- at activation of DSHR,
- at FED activation.

The comparison included mass quantity of the smoke, the smoke layer descent, temperature of the upper layer of gases and temperature of the lower layer of gases in the space. The solid line represents the course of fire uninfluenced by fire safety devices, the dashed line that at activation of DSHR, and the dotted line that at activation of FED (influence of the devices has been evaluated separately).

According to the principles [7], DSHR was designed as a natural one. The influence of FED was simulated by a single sprinkler head of standard parameters[3], located at the ceiling height above the centre of fire. The CFAST[4] [8] zone model of fire was used for the study.

Results of the study are illustrated in Figures 5 and 6.

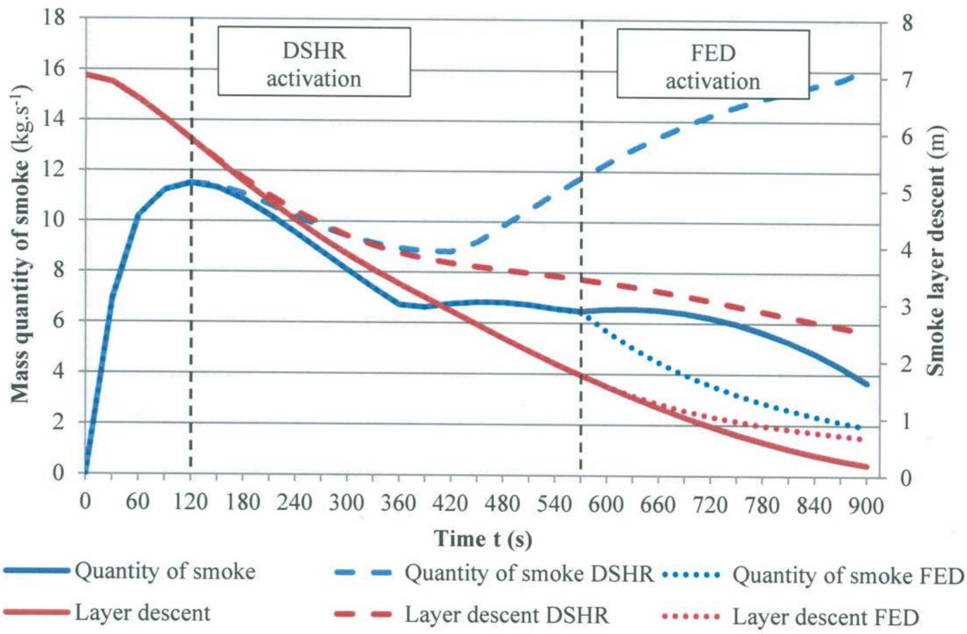

Fig. 5
Mass quantity of smoke and descent of the smoke layer with/out the influence of DSHR and FED

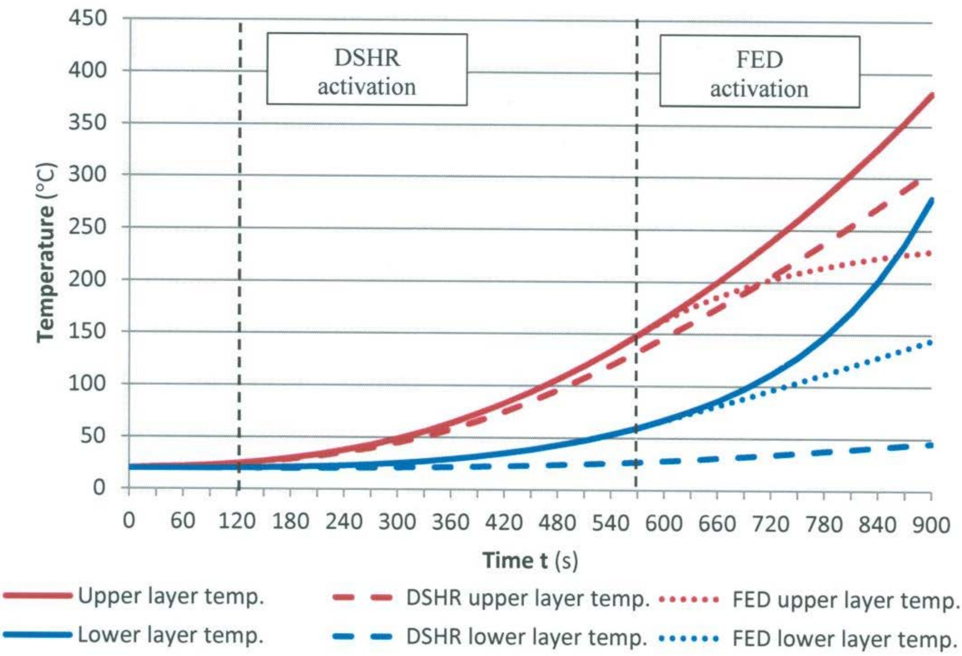

Fig. 6
Temperature of upper and lower layer of gases with/out the influence of DSHR and FED

Discussion of results

The fire courses illustrated in Figures 1 to 4 must be regarded as informative only. A wide variety of modification will occur in real situations. Similarly, the equations describing the individual fire stages must be perceived with certain reservation in this context. In principle, however, the given figures and equations describe the individual stages of fire at activation of fire safety devices quite concisely.

The results of the presented studies show the change of all monitored parameters at activation of DSHR or FED.

The mass quantity of arising smoke is positively influenced by FED. During its activation, the mass quantity of produced smoke is reduced. Conversely, during DSHR activation, the quantity of produced smoke increases. The smoke, however, is exhausted outside the burning space; the negative significance of this phenomenon is disputable.

The DSHR has a significant positive influence on the descent of the smoke layer in the space. For the purpose of smoke removal, higher height of the smokeless space has been kept. FED also slows down the smoke layer descent. However, the influence is not fundamental in the time interval monitored.

Temperatures of the upper and lower gas layers are significantly influenced by the activation of DSHR as well as FED. At the end of the interval monitored, the upper gas layer temperature is influenced by FED more than by DSHR, which is caused by the significant reduction of the heat released during FED activation.

It must be stated that the *results* presented correspond to the initial presumptions of the study and calculation principles of the fire model used, and *cannot be applied to all situations generally*. Quite *apparently, however, they present the connection between the change of conditions in the space*, where the fire develops, *and the activity of the specified fire safety devices.*

Conclusion

To determine more detailed characteristics of the fire course and its individual stages, it is necessary to take into account the activation of the electric fire signalling devices, smoke and heat removal devices and fixed extinguishing devices. As a rule, attention will be paid to the time of activation of the described devices and change of characteristics in connection with their activation. In most cases, the changes will have a crucial influence on the course of fire.

Acknowledgements
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Legend of symbols

Unit	Dimension	Description
RHR_{f}	$kW.m^{-2}$	maximum heat release speed
$\dot{Q}_{\mathrm{max,EFS}}$	kW	maximum heat flow at activation of EFS
$\dot{Q}_{\mathrm{max,m}}$	kW	maximum heat flow at fuel-controlled fire

$\dot{Q}_{max,FED}$	kW	maximum heat flow at activation of FED
$\dot{Q}_{max,v}$	kW	maximum heat flow at ventilation-controlled fire
$\dot{Q}_{max,DSHR}$	kW	maximum heat flow at activation of DSHR
$\dot{Q}_0$	kW	reference speed of heat release (1000 kW)
$\dot{Q}_{1(t)}$	kW	heat flow released during the fire development stage
$\dot{Q}_{2(t)}$	kW	heat flow during the stage of developed or uniformly developing fire
$\dot{Q}_{3(t)}$	kW	heat flow during the burn-down or fire cooling stage
t	s	time after initiation of the fire
$t_{activation}$	s	time of activation of the device
t_g	s	time necessary for achieving the reference speed
$t_{extinguishment}$	s	time of fire extinguishment
$t_{intervention}$	s	time of starting extinguishing works by the fire brigade
α	$kW.s^{-2}$	fire development coefficient

NOTES:

[1] The fire development can be characterized by a simplified curve, where the heat release speed is proportionate to the square of time.
[2] Time of achieving the fire output of 1 MW.
[3] The reaction speed index RTI 100 $(m.s)^{1/2}$,water supply intensity 7.10^{-5} $m.s^{-1}$, activation temperature 68 °C.
[4] CFAST (Consolidated Model of Fire and Smoke Transport) v. 6.2.0.291 is a zone fire model which was developed by the National Institute of Standards and Technology (NIST).

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