Transactions of the VSB - Technical university of Ostrava Vol. XII, No. 2, 2017
Safety Engineering Series DOI 10.1515/tvsbses-2017-0011

COMPARATIVE ANALYSIS OF RULES IN FIVE LEADING STANDARDS FOR SMOKE DETECTORS SITING IN THE PRESENCE OF A CEILING IRREGULARITY

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Research article

Abstract: Subdividing elements and different structures on the ceiling like beams or similar, significantly affect the location of the smoke detector, because they change the flow of combustion products. From point of view of fire detection system, designers it is very interesting how to arrange and distribute smoke detectors in applications when beams are formed structure like a “honeycomb” The European norm 54-14 is mandatory, but in practice, a main question appears: “Do we have the explanations detailed enough for all of the situations that could occur related to length, width and depth of honeycomb cells”? The main goal of this paper is to show the differences between the rules and the instructions in five standards: EN 54-14, VDE 0833-2, BS 5839-1, NPB 88, NFPA 72, and to find the best solution for various situations in practice.

Keywords: Ceiling irregularities, standards, smoke detector, simulation.

Introduction

Unlike European standard, German, British, Russian and American ones define different rules. German standard in contrast to the European specifies that the elements subdividing the ceiling height of more than 3 % of the room height are obstacles, and need to be considered. According to this standard, premises which are separated by beams are discussed in relation to the maximum monitoring area of detector. In British standard, ceiling obstructions such as beam should be treated as walls only if their depth is more than 10 % of ceiling height and their voids bigger than 0.8 m. In that case, independent coverage is required. Internal volumes are not considered in this standard, only the width and the height ratio of honeycomb cells. Russian standard recommends putting the point smoke detectors in each segment of the ceiling that is wider than 0.75 m, if the depth of the joists is bigger than 0.4 m. American standard is completely different compared to other standards in case of ceiling beams. Honeycomb form is treated through absolute values of the beam dimensions which are forming this structure. It is obvious that the above mentioned five leading standards, provide various definitions of the rules for sitting point smoke detectors in case of honeycomb structure on ceiling. Consequently, this problem may be investigated in relation to the influence of dimensions of honeycomb cells to stratification, ratio of cells volumes and compartment height, etc.

European standard EN 54 Part 9: *Test fires for fire detectors* describes test fires which are intended to represent fires that can occur in the real world and, on the other hand, represent tests for fire detector performance. The response of the detectors subjected to test fires is the most important factor which determines arrangement and distribution of fire detectors in order to detect fire in an early stage, table 1. Heat release rates can be estimated from the mass loss data once the initial mass and an energy density are known. Tab. 1 is an estimate of the initial mass based upon the description of the test fires in EN 54. (Grosshandler, 1995)

Materials and methods

For this purpose, we made the simulations by means of PiroSym software package for various positions of point smoke detectors. The distance of detectors from the burner is chosen to be on the edge of point smoke detector covering the area according to the European standard, whereas response time of each detector is measured for heat release rates of 500 kW and 100 kW.

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 DOI 10.1515/tvsbses-2017-0011

Tab. 1 Heat release rates of TF1-TF6 (Grosshandler, 1995)

Test fire	Average consumption rate [g/s]	Average heat release rate [kW]	Maximum heat release rate [kW]
TF1	2.70	56	145
TF2	0.11	2.3	3.8
TF3	0.19	3.2	3.6
TF4	1.20	30	84
TF5	3.10	150	214
TF6	4.00	120	125

Ceiling irregularities

Beams, other subdividing elements and different structures on the ceiling, significantly affect the disposition of the detector, because they change the flow of combustion products. The European standard defines that quite precisely, which is depicted in the fig. 1. (EN 54-14:2004)

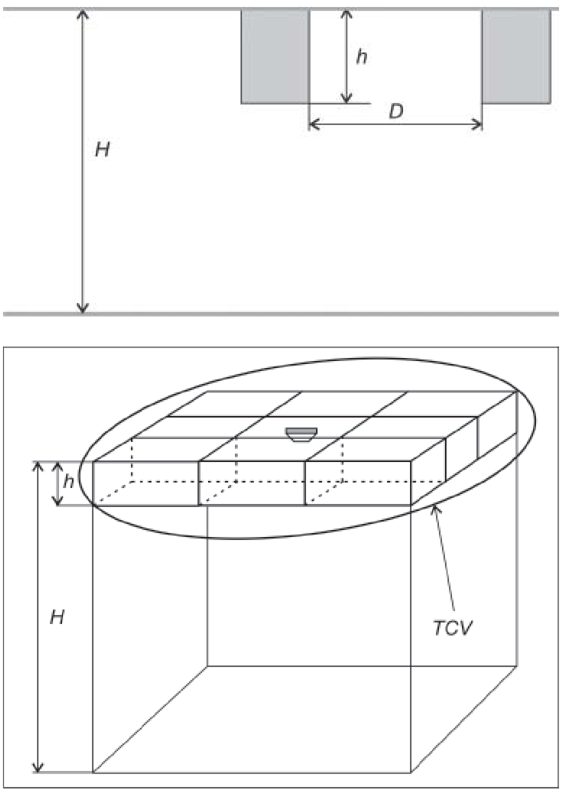

Fig. 1 Ceiling irregularities considered by European standard (EN 54-14:2004)

The ceiling having irregularities with depths less than 5 % of the ceiling height should be treated as flat. Any ceiling irregularity having depth greater than 5 % of the ceiling height should be treated as a wall:

- $D > 0.25 \times (H - h)$ - detector in every cell,
- $D < 0.25 \times (H - h)$ - detector in every second cell,
- $D < 0.13 \times (H - h)$ - detector in every third cell.

If the ceiling arrangement is such as to form a "honeycomb" then a single point-type detector may cover a group of cells. The internal volume of the cells (denoted *TCV*) covered by single detector should not exceed $TCV = 12\ \text{m}^2 \times (H - h)$ in case of smoke detector.

German standard (DIN VDE 0833-2:2009) also considers the arrangement of point-type smoke and heat detectors on ceilings with ceiling joists. In contrast to the European standard (EN 54-14:2004) that specifies 5 % of the beams, in this standard, the elements subdividing the ceiling of a height of more than 3 % of the room height are obstacles that need to be considered. Premises which are separated by beams are discussed in relation to the maximum monitoring area of detector. Accordingly, if a separate area has a surface which covers 60 % or more of the detector covering area, each bay ceiling shall be equipped with detectors (*A* - maximum monitoring area):

- $\leq 0.6 \times A$ - one detector for monitoring several ceiling bays of not more than $1.2 \times A$,
- $0.6 \times A$ - each ceiling bay shall be equipped with detectors.

In British standard (BS 5839-1:2013), the percentage of beam height in relation to the height of the room is 10 % in order to be treated as a wall. Also, British standard states absolute values, as it can be seen in the Fig. 2. A solid partition where the top is less than 30 cm far from the ceiling is treated as a wall. For voids deeper that 80 cm, the standard requires independent coverage. (Blagojevic, 2015)

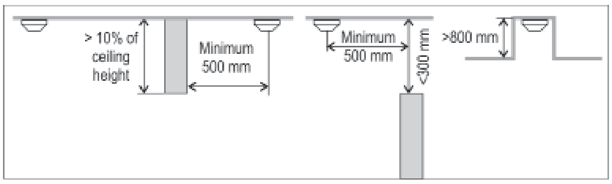

Fig. 2 Ceiling irregularities considered by British standard (BS 5839-1:2013; Blagojevic, 2015)

Where a horizontal ceiling comprises a series of small cells, often referred to as a honeycomb ceiling, detector spacing and siting should be in accordance with Tab. 2.

Tab. 2 Spacing and siting of detectors (BS 5839-1:2013)

Overall ceiling height (*H*)	**Beam depth (*D*)**	**Maximum distance between any point and the nearest smoke detector**	**Detector location if *W* is 4*D* or less**	**Detector location if *W* is more than 4*D***
6 m or less	Less than 10 % *H*	As per flat ceilings	Underside of beams	On structural slab in the cell
more than 6 m	Less than 10 % *H* and 600 mm or less	As per flat ceilings	Underside of beams	On structural slab in the cell
more than 6 m	Less than 10 % *H* and more than 600 mm	As per flat ceilings	Underside of beams*	On structural slab in the cell
3 m or less	More than 10 % *H*	4.5 m	Underside of beams	On structural slab in the cell
4 m	More than 10 % *H*	5.5 m	Underside of beams	On structural slab in the cell
5 m	More than 10 % *H*	6 m	Underside of beams	On structural slab in the cell
6 m or more	More than 10 % *H*	6.5 m	Underside of beams	On structural slab in the cell

* Since mounting detectors at depth or more than 600 mm below the highest point in the protected spaces does not comply with basic rule, protection in these circumstances might not need careful consideration to determine the most suitable location and spacing of detectors.

In the structure of the beams which forms a honeycomb, in this standard are not considered internal volumes but width and height ratio. Therefore, the detector can be mounted inside cell of honeycomb or on the edge of the honeycomb, i.e. on the beam.

- $W \leq 4D$ - position 2,
- $W > 4D$ - position 1.

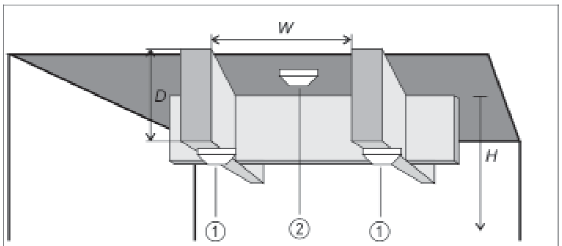

Fig. 3 Honeycomb structure considered by British standard (BS 5839-1:2013)

The Russian standard (NPB 88:2001) considers honeycomb structure only if the depth of the joists is bigger than 40 cm and if segment wider than 75 cm. In such case, it is recommended to put point smoke detector in each segment and the coverage area of each detector should be decreased to 40 %.

The American standard (NFPA 72:2016) is completely different compared to other standards in case of beams on the ceiling. If the dimensions of the beams are up to 10 cm, regardless of the room height, the ceiling should be treated as a flat ceiling. If the beam dimensions are greater than 10 cm, coverage area detector decreases to 66 %. Honeycomb form is treated through absolute values of the beam dimensions which are forming this structure. The detector is placed inside a honeycomb if the segment is wider than 2.4 m and deeper than 46 cm and on the beam itself under the conditions as follows:

- Where the beams project more than 4 in. (100 mm) below the ceiling, spacing of spot-type heat detectors shall be not more than 2/3 listed spacing.
- Where the beams project more than 18 in. (460 mm) below the ceiling and more than 8 ft (2.4 m) on center, each bay formed by beams shall be treated as separate area.
- Where beams are less than 12 in. (300 mm) in depth and less than 8 ft. (2.4 m) on center, detectors permitted to be installed on the bottom of beams.

Model for simulation

Obviously, there are many differences between the standards concerning the rules for smoke detector siting in presence of ceiling irregularities. However, there are common characteristics under consideration in all above mentioned standards, such as depth of obstacles of 50 cm or 60 cm, depth percentage of 10 % related to the height of compartment, possibility for putting detector inside or outside of honeycomb cells and similar. For the purpose of this investigation, three cases based on internal dimensions of cells were chosen.

First of all, the height compartment of 6 m was chosen because this value is some kind of limit for reliable smoke detection and, on the other hand, the depth of obstacles h = 60 cm represents 10 % limit mentioned in the most standards. On the basis of these values, the internal dimensions of inner honeycomb cells were changed from $W = 1 \times D$ up to $W = 5 \times D$, according to the fig. 3. The aim of the simulations was to assess the influence of

 DOI 10.1515/tvsbses-2017-0011

the mentioned dimensions of honeycomb cell to point smoke detector response times.

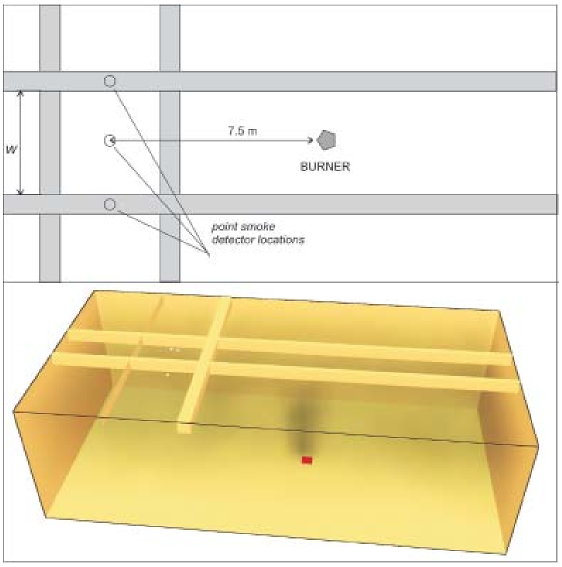

Fig. 4 Model for simulations

Simulation model was created in PyroSim software, version 2012, which presents a graphical user interface for the Fire Dynamics Simulator (FDS). Dimensions of compartment were as follows: length 20 m, width 10 m and height 6 m. In order to create a cell of honeycomb with changeable dimensions, two pairs of joists were located on the ceiling (see Fig. 4). Point smoke detectors were located at the "edge" of radius of covering recommended by EN 54-14, that is, at 7.5 m from a 500 kW burner. The three point smoke detectors were involved in simulations: the first one inside of a honeycomb cell, and the other two detectors outside of a cell - on joists. For each dimension of cell, the simulation's time was set on 500 seconds. (Blagojevic at al, 2015)

Results

Simulations were made for 500 kW and 100 kW burners for various dimensions of honeycomb cell: $W = 1 \times D$, $W = 2 \times D$, $W = 3 \times D$, $W = 4 \times D$ and $W = 5 \times D$. Two detectors, detector inside cell - denoted with SD and detector located on edge of cell - denoted with SD0202 were chosen for analysis. Obtained results are shown in fig. 5-9.

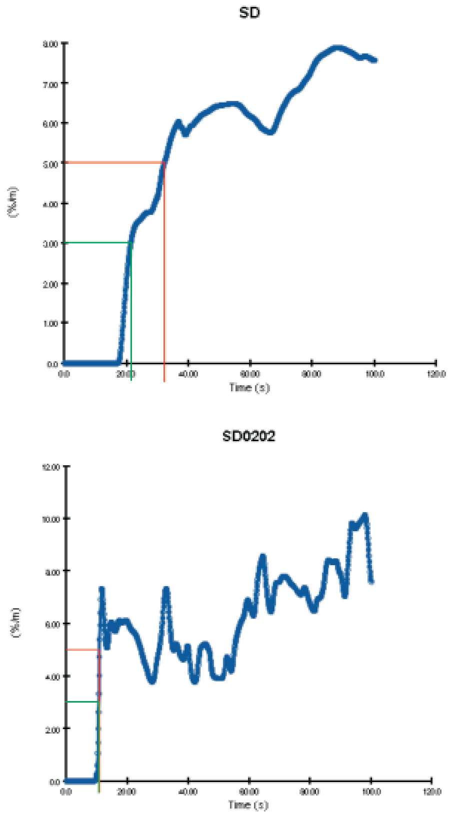

Fig. 5 Response time of detectors SD and SD0202 for 500 kW burner and $W = 1 \times D$

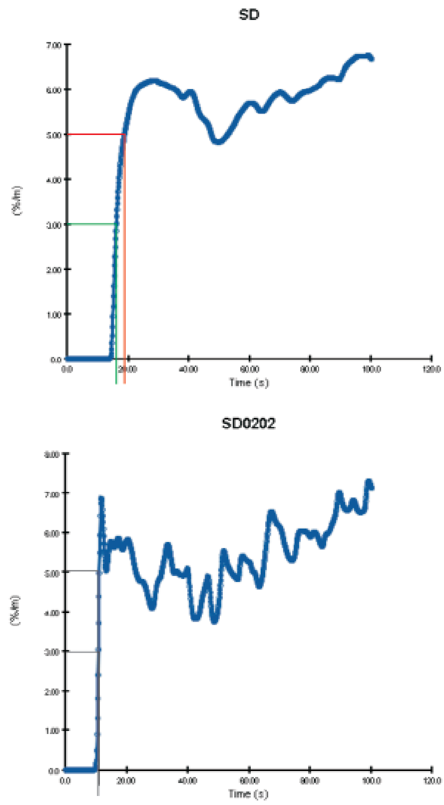

Fig. 6 Response time of detectors SD and SD0202 for 500 kW burner and $W = 2 \times D$

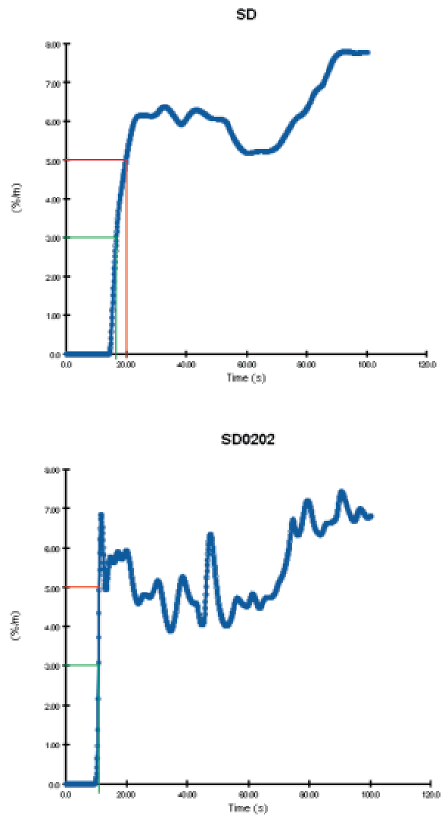

Fig. 7 Response time of detectors SD and SD0202 for 500 kW burner and $W = 3 \times D$

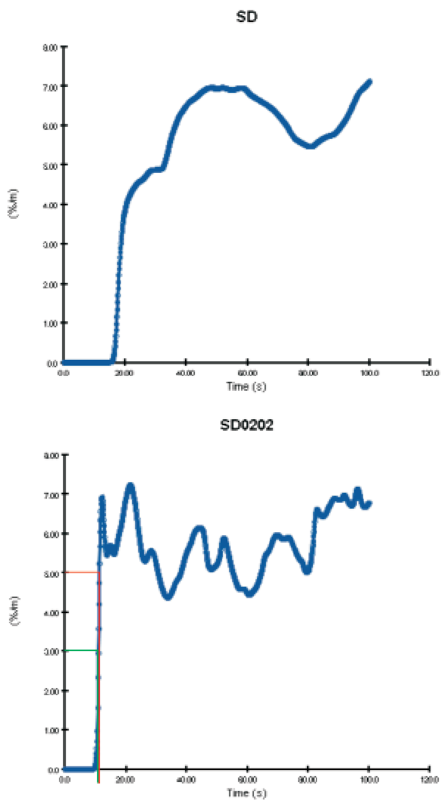

Fig. 8 Response time of detectors SD and SD0202 for 500 kW burner and $W = 4 \times D$

The analysis was made for two alarm thresholds. Namely, it is well known that alarm threshold for point smoke detector is usually between 3 %/m and 5 %/m, depending on ambient conditions, and for that reason response times for these values are shown in figures. Numerical results of simulations are shown in tab. 3 bellow fig. 9.

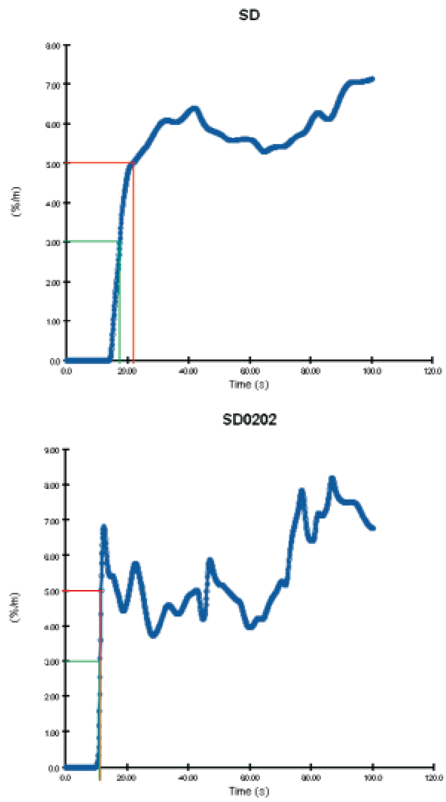

Fig. 9 Response time of detectors SD and SD0202 for 500 kW burner and $W = 5 \times D$

Tab. 3 Response times of detectors SD and SD0202 for various dimensions of W and D

Alarm threshold 5 %/m			**Alarm threshold 3 %/m**		
500 kW	**SD**	**SD0202**	**500 kW**	**SD**	**SD0202**
$W = 1 \times D$	>30 s	~10 s	$W = 1 \times D$	~22 s	<10 s
$W = 2 \times D$	~18 s	~12 s	$W = 2 \times D$	~15 s	~12 s
$W = 3 \times D$	20 s	~11 s	$W = 3 \times D$	~17 s	~11 s
$W = 4 \times D$	34 s	~10 s	$W = 4 \times D$	~18 s	~10 s
$W = 5 \times D$	22 s	~10 s	$W = 5 \times D$	~17 s	~10 s

Obviously, in all cases a detector SD0202 located on the edge of honeycomb cells has twice of three times faster response than the detector inside the cell. On the other hand, all response times of detector SD are less that half of a minute, so the choice of location for detector may depend not only on type of possible fire, but on other factors, such as architectural or aesthetic characteristics of compartment or similar.

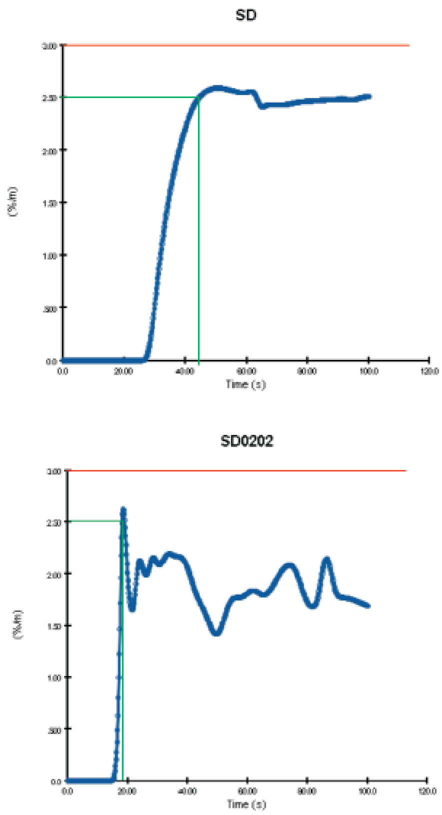

Fig. 10 Response time of detectors SD and SD0202 for 100 kW burner and *W* = 1 × *D*

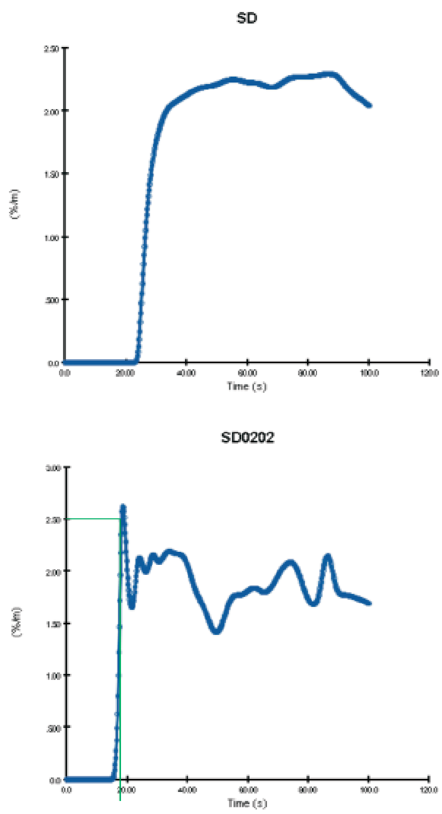

Fig. 11 Response time of detectors SD and SD0202 for 100 kW burner and *W* = 2 × *D*

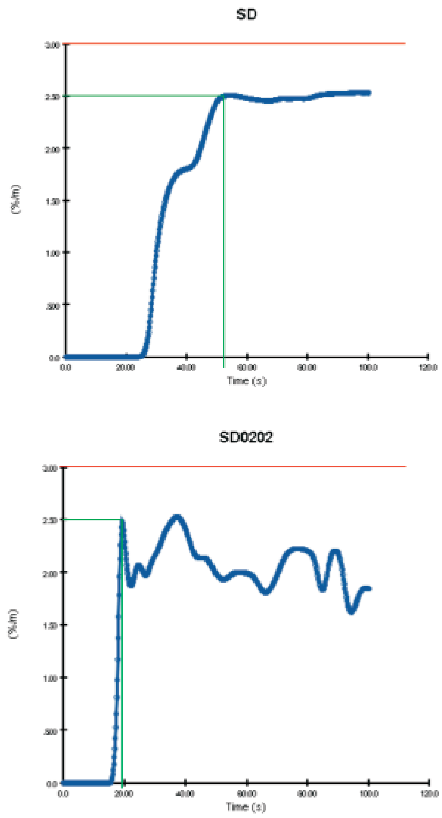

Fig. 12 Response time of detectors SD and SD0202 for 100 kW burner and *W* = 3 × *D*

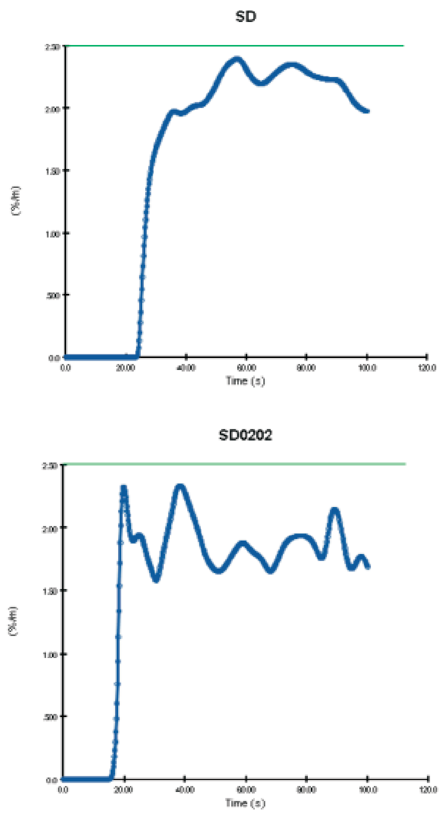

Fig. 13 Response time of detectors SD and SD0202 for 100 kW burner and *W* = 4 × *D*

 DOI 10.1515/tvsbses-2017-0011

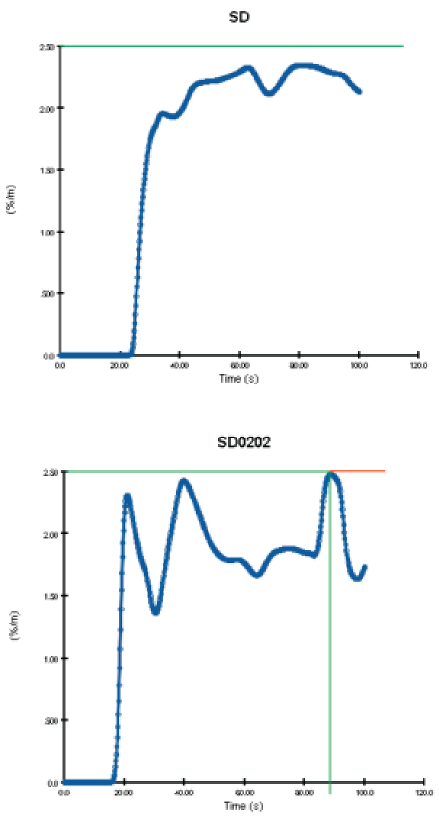

Fig. 14 Response time of detectors SD and SD0202 for 100 kW burner and $W = 5 \times D$

The second set of simulations was made for smaller energy density, that is, for 100 kW burner under the same conditions and dimensions of a honeycomb cell. The results are as follows, fig. 10-14.

It can be seen from the previous figures that alarm threshold of 3 %/m is too high in order to be detected by detectors SD and SD0202 detectors. For that reason, the table bellow contains response times for alarm threshold of 2.5 %/m.

Tab. 4 Response times of detectors SD and SD0202 for various dimensions of *W* and *D*

Alarm threshold 2.5 %/m		
100 kW	**SD**	**SD0202**
$W = 1 \times D$	~44 s	~18 s
$W = 2 \times D$		~18 s
$W = 3 \times D$	~52 s	~18 s
$W = 4 \times D$		
$W = 5 \times D$	~55 s	

Conclusion

If the obtained results are observed form the European standard point of view, the main question would be: What is the influence of cell dimensions on the position of point smoke detector? For a 500 kW burner, increasing the width of cells allows us to put a detector inside the cell; however, in case of small dimension cells, reliable detection is provided by putting detector on the edge of a cell.

In case of a 100 kW burner, the rules from British standard become more important than the ones from European standard. Namely, for reliable detection it is necessary to put detectors on the edge of a honeycomb. Because of that, in order to verify the EU standard a simulation model must be different. For this purpose, a simulation model must consist of a "net" of neighboring cells with various depth and width in order to check the relations between cell volumes and covering area of detector. These simulations will be the subject of further researches.

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