

COMPARATIVE ANALYSIS OF RULES FOR SMOKE DETECTORS ARRANGEMENT IN CORRIDORS

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Abstract. *The aim of this paper is a comparative analysis of rules for arrangement and distribution of fire detectors in corridors and narrow places according to five leading standards for fire detection systems design in the world: EN 54-14, VDE 0833-2, BS 5839-1, НПБ 88 and NFPA 72. The reason for such analysis is obvious - the European standard does not define the corridor, only the narrow rooms are mentioned, but the other standards precisely define the term corridor as well as the rules for siting and spacing of point fire detectors. The comparative analysis is made by means of simulation model using PyroSim software, version 2012, which presents a graphical user interface for the Fire Dynamics Simulator (FDS).*

Key words: *point smoke detectors, corridors, simulation model, PyroSim*

1. INTRODUCTION

The European standard EN 54 Part 14 *Guidelines for planning, design, installation, commissioning, use and maintenance* is mandatory for fire alarm system designers in Europe, but there are many situations that this standard does not cover at all.

German standard VDE 0833 Part 2 *Requirements for fire alarm systems* in general states almost the same recommendations as the EN 54-14, but it is more detailed in some applications - for example, siting the detector below the pitched roof or in racked warehouses.

British standard BS 5839 Part 1 *Code of practice for design, installation, commissioning and maintenance* has different solutions for different types of systems: L(ife), P(roperty), etc., depending on what kind of object is under protection.

Russian standard НПБ 88 *Установки пожаротушения и сигнализации. нормы и правила проектирования* has rules that are largely restrictive compared to the other

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standards. For some applications there are no rules at all, but the standard refers to the manufacturer's documentation.

US standard NFPA 72 *National Fire Alarm and Signalling Code* is the most detailed and most accurate one, but on the other hand requires a designer with a higher level of knowledge and some of the solutions are largely different from European rules.

The simplest application of fire detection system related to arrangement of point fire detectors are corridors or narrow places. Although rules for this type of application originate from basic rules for siting and spacing of point type fire detectors, mentioned standards state different recommendations.

2. BASIC RULES FOR SITING AND SPACING OF POINT SMOKE DETECTORS

It is well known that the number of fire detectors in the room is obtained by dividing the area of the room with the area of coverage of individual detector. By doing that, three types of situations may occur. The first one is the situation when the number of detectors is not enough, which can lead to some unprotected parts of the room. In the second approach, we can always increase the number of detectors above the required ones, but the question is who will pay for it. The investor will certainly not be satisfied with our design. Finally, the third situation is perfect square arrangement of detectors which is achieved by overlapping of individual coverage areas and the amount of $1/4$ of individual coverage area. Thus, the three most important parameters that standards should define are: A – Area of coverage, r – Radius and S – Maximum distance between individual detectors, figure 1.

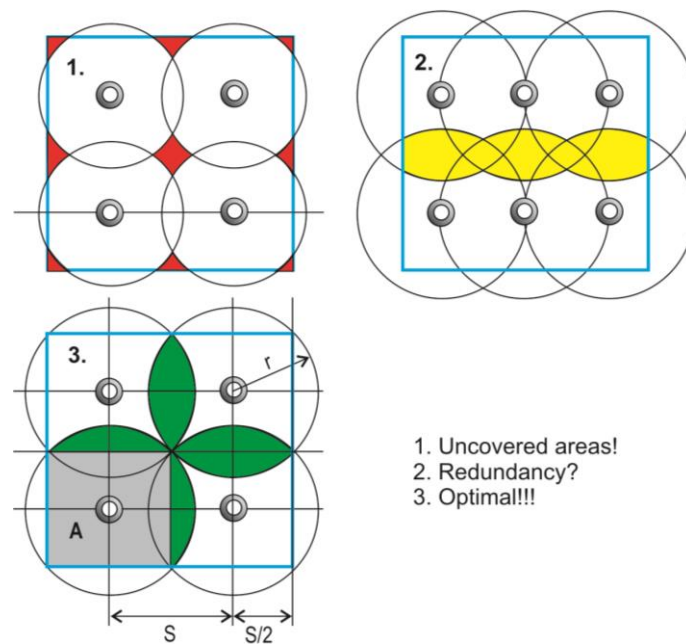


Fig. 1 Possible distributions of smoke point fire detectors

European standard EN 54-14 generally permits the use of these detectors to a height of 11 m, with a coverage radius of 7.5 m. In practice, an area of coverage greater than 80 m² is rarely used, but this radius in essence, gives a coverage area of individual detectors even 112 m².

The German standard gives radius and coverage area through curves depending on the slope of the ceiling. Notice that there is a maximum permissible height of 12 m, and that for the same radius as in the EN 54-14, area of coverage is less - 100 m², not 112 m².

The rules in British standard are similar to the previous ones, while the Russian standard is the less flexible, because it allows the maximum coverage area of 85 m². Instead of the radius of coverage, Russian Standard gives the maximum distance between two detectors of 9 m, which is less than the European - this distance in accordance with EN 54-14 is 10.6 m.

The American standard has a different approach. According to this standard, in the circle that represents an area of covering of smoke detector, rooms with the largest surface area of about 80 m² can be placed and a series of rectangles with a smaller surface area. This means that the standard radius is 9.1 m. Further, standard recommends a virtual division of the room in the case of rooms with complex geometry. It is necessary to calculate the required number of detectors and the maximum allowable distance for each of the virtual area.

The basic rules for siting and spacing of point heat and smoke detectors according to EN 54-14 are shown in Table 1 and figure 1.

Table 1 EN 54-14 - heights and radii

Legend:	Ceiling height [m]				
	> 4.5	> 6	> 8	> 11	> 25
NN – Not normally used in the range					
NS – Not suitable for use in the range	≤ 4.5	≤ 6	≤ 8	≤ 11	≤ 25
Type of detector	Radius of coverage [m]				
Heat detector EN 54-5 Class 1	5	5	5	NN	NS
Smoke detector EN 54-7	7.5	7.5	7.5	7.5	NN

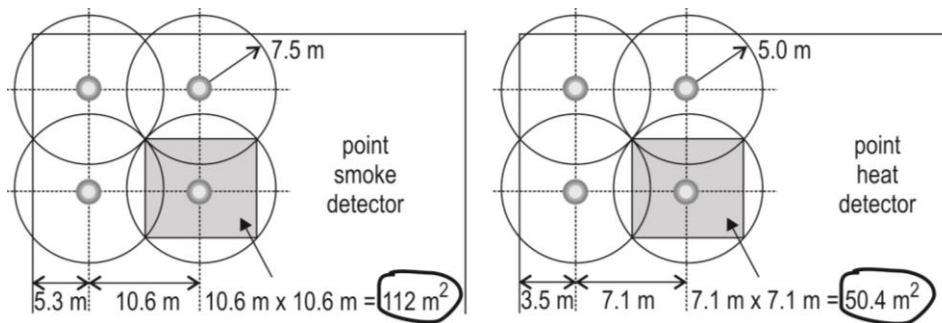


Fig. 2 Areas of coverage and radii for point smoke and heat detectors according to EN 54-14

3. CORRIDORS AND NARROW ROOMS

In practice, fire alarm system designer can rarely meet with ideal situations as shown in figure 1. The interior of buildings depending on their purpose very often requires the application of special rules for siting. There are many special cases for siting of fire detectors, and the most often case refers to the narrow hallways and rooms. Here we already have the first problem, and that is the answer to the question “What is corridor”, or “Which is the maximum width of the room in order to be considered as a corridor”?

The European standard does not define the corridor, only states that if the room is narrower than 1.2 m, detector should be mounted within the middle third of the width.

Unlike the European, the German standard precisely defines that the corridor is the room of less than 3 m in width and gives rules for the distance between point-type smoke detectors. Smoke detectors can be located 15 m apart from each other, in case of coincidence detection type B up to 11 m or 7.5 m when triggering fire extinguishing systems.

According to the British standard, corridors are wider than the rest of European countries; a corridor is the room of less than 5 m in width. The standard does not provide specific rules, but only the formula for the calculation radius of detector, as follows: $(5\text{ m} - w)/2 + 7.5$ [m].

Based on the formula, it is obvious that if the corridor is 3 m wide, the radius will increase by 1 m. That is, we get 8.5 m for the smoke detector.

The Russian standard does not give specific recommendations, except that for smoke detectors mutual distance in the corridor can be increased 1.5 times, which is almost the same as in the German standard (maximum distance is $9\text{ m} \times 1.5$ for room height up to 3.5 m).

NFPA 72 defines corridor as room of less than 15 ft. (4.6 m) without further recommendations for spacing spot-type detectors. In other words, a corridor 10 ft (3.0 m) wide and up to 82 ft (25.0 m) long can be covered with two 30 ft (9.1 m) spot-type detectors.

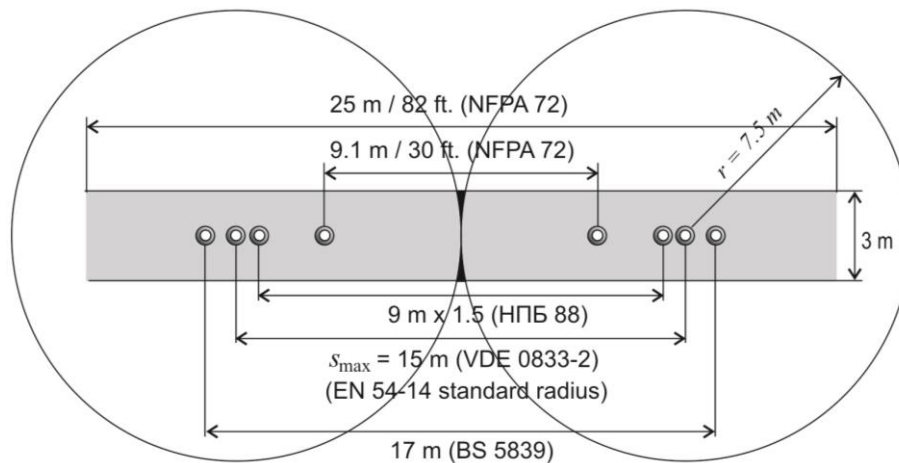


Fig. 2 Distances between smoke point detectors in corridors

From fire detection system designer's point of view, it is interesting to find how these differences affect detectors response time. In order to investigate this problem, it is made we made a simulation model for a corridor which is covered by point smoke detectors according to the previous rules in five standards.

4. TEST METHODS FOR FIRE DETECTORS SENSITIVITY IN STANDARD EN 54

European standard EN 54 Fire detection and alarm systems in document 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. Also, in this way it is possible to check response behaviour of whole detection system. Average and maximum heat release rates of standard test fires are relatively small, as shown in Table 2.

Table 2 Heat release rates of TF1-TF6

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

For this reason, the simulation described in this paper has been made for small initial mass and energy density, that is, for burners of 1 kW/m², 3 kW/m², 5 kW/m² and 35 kW/m², as the first parameter, and for ceiling height which is very significant and limiting factor for this type of consideration, as the second parameter. The main goal of the simulation is to investigate the differences between various standards rules, and consequently, the distance between detectors and site of fire, as well as the influence on response time of detectors.

5. SIMULATION MODEL

Simulation model was created in PyroSim software, version 2012, which presents a graphical user interface for the Fire Dynamics Simulator (FDS). FDS models are able to present smoke, temperature, carbon monoxide (CO), and other fire products. Simulation software presents inevitable tool in fire protection systems design and many other calculations. Of course, for every simulation, it is needed to create simulation model with appropriate dimensions, materials, location of burner and heat release rate and other simulation conditions.

For simulation model a corridor in shape T was chosen, which means that, independently of mentioned rules, one smoke detector will be located at intersection of

corridor. According to this position, the location of other point smoke detectors was chosen. One section of corridor is 42 m long, the second one is 25 m long, the width of the corridor is 3 m and the height is 3.2 m. Positions of all detectors, i.e. s_{max} , are calculated according to the rules of standards measured from the detector located at intersection.

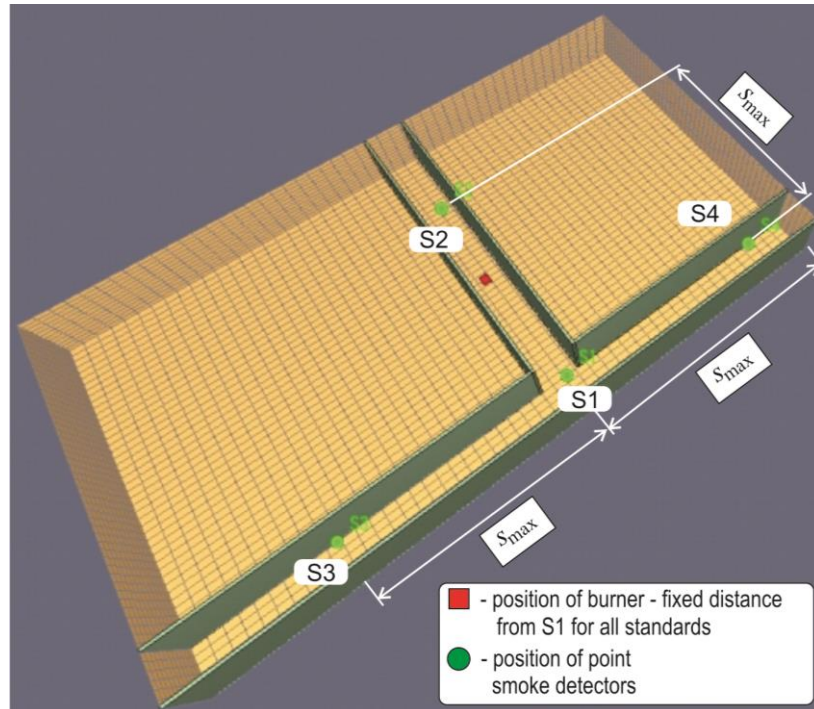


Fig. 3 Simulation model with positions of burner and detectors

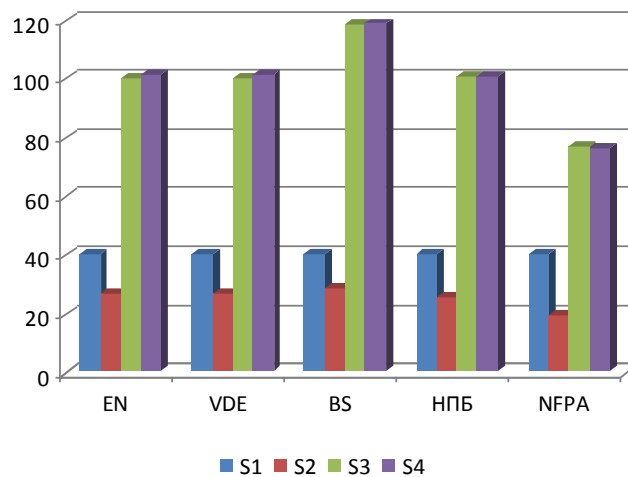
For each ceiling height and for each burner the simulation's time was set on 500 seconds. The ambient conditions in realized simulations were normal (temperature, humidity and pressure). The alarm threshold for every smoke detector was set to 3,28 %/m. The smoke detectors arrangement for was different for each standard. For the EN 54-14 and VDE 0832-2 standards the distance between smoke detectors was 15 m. For BS 5839-1 standard the distance between smoke detectors was 17 m. For НПБ 88 standard the distance between smoke detectors was 13.5 m and for NFPA 72 standard, the distance between smoke detectors was 9.1 m.

6. SIMULATION RESULTS AND ANALISYS

The simulations were made for ceiling heights of 4.5 m, 6 m and 8 m and burners of 1 kW/m², 3 kW/m², 5 kW/m² and 35 kW/m² for each ceiling height. Complete data for all simulations would take up a lot of space, so, here an example of simulation for 35 kW/m² burner and ceiling height of 4.5 m is shown.

Table 3 Detectors response times

Standard	S1	S2	S3	S4
EN	40.2	26.66	100.3	101.2
VDE	40.2	26.66	100.3	101.2
BS	40.2	28.66	118.66	118.89
НПБ	40.2	25.21	100.87	100.65
NFPA	40.2	19.33	76.66	76.12

**Fig. 4** Simulation for 35 kW/m² burner and height of the ceiling of 4.5 m

The distance of a burner from a detector S1 was the same for all standards - on the edge of detector's area of coverage, so it is interesting to evaluate the differences in standards taking into consideration influence on response time of detectors S2, S3 and S4 which positions are set according to maximal distance between detectors in corridors defined by standards.

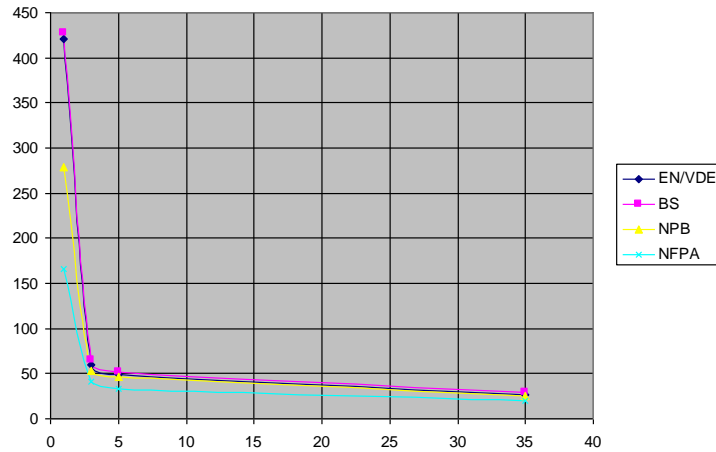
Table 4 Response times of detector S1 in all standards

S1	1 kW/m ²	3 kW/m ²	5 kW/m ²	35 kW/m ²
h=4.5 m	438.38 s	86.66 s	73.33 s	40.20 s
h=6.0 m		86.56 s	73.33 s	43.10 s
h=8.0		93.37 s	80.29 s	44.45 s

Obviously, the height of the ceiling has a little influence on detector response time except for a burner of 1 kW. On the other hand, because of overlapping of detector S1 and S2 coverage areas, response times of detector S2 are a little shorter, and differentiate in mentioned standards.

Table 5 Response times of detector S2 for 4.5 m height

S2	1 kW/m ²	3 kW/m ²	5 kW/m ²	35 kW/m ²
EN 54-14, VDE 0833-2	421.00 s	60.04 s	48.66 s	26.66 s
BS 5839-1	427.45 s	64.66 s	51.33 s	28.66 s
NPB 88	279.06 s	53.56 s	46.80 s	25.21 s
NFPA 72	165.50 s	41.30 s	33.56 s	19.33 s

**Fig. 5** Response times of detector S2 for 4.5 m height**Table 6** Response times of detector S2 for 6.0 m height

S2	1 kW/m ²	3 kW/m ²	5 kW/m ²	35 kW/m ²
EN 54-14, VDE 0833-2		66.72 s	60.00 s	33.36 s
BS 5839-1		67.56 s	61.34 s	34.12 s
NPB 88	165.51 s	66.66 s	56.66 s	32.12 s
NFPA 72	140.89 s	40.10 s	34.20 s	20.10 s

Table 7 Response times of detector S2 for 8.0 m height

S2	1 kW/m ²	3 kW/m ²	5 kW/m ²	35 kW/m ²
EN 54-14, VDE 0833-2		70.32 s	61.21 s	32.98 s
BS 5839-1		81.23 s	72.81 s	40.67 s
NPB 88		67.10 s	53.56 s	30.11 s
NFPA 72		43.78 s	40.09 s	24.26 s

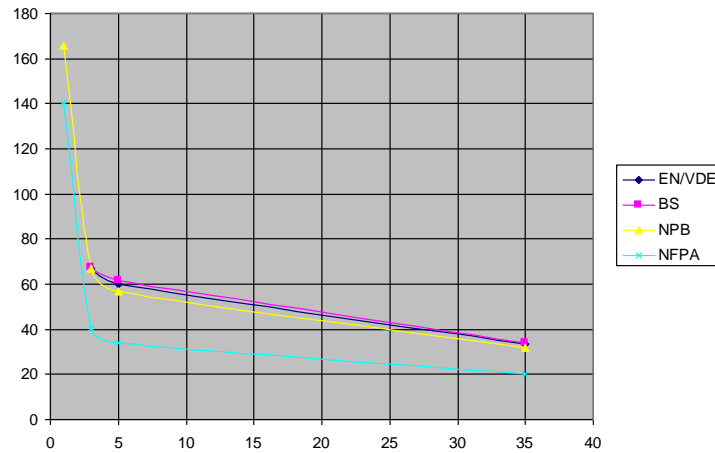


Fig. 6 Response times of detector S2 for 6.0 m height

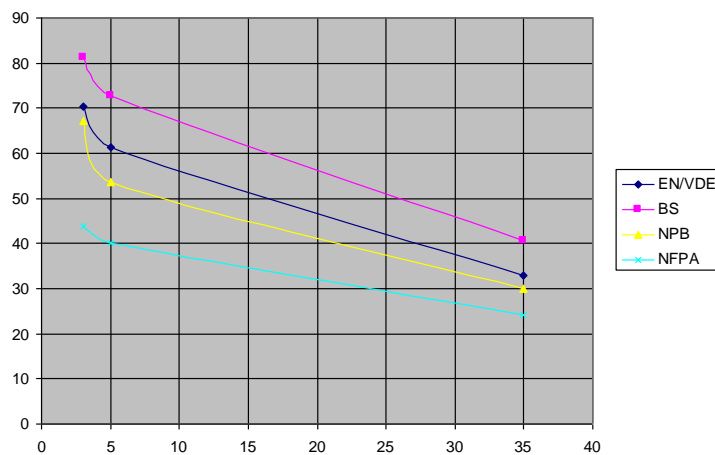


Fig. 7 Response times of detector S2 for 8.0 m height

Regardless of the fact that described simulations present simplification of fire in the sense of fire burns at a steady state, there are two basic conclusions based on these simulations from point of view of fire detection system. The first one is crucial for an early warning: only the NFPA rules, as well as the rules from the Russian standard provide detection of fires which are characterized by small initial mass and energy density. This conclusion is especially valid for slow smoldering fires, such as test fires TF2 and TF3 with weak air flow. The second conclusion is that response times of nearest detectors for fire loads beyond 35 kW/m^2 are almost equal independently of the rules in various standards, especially for room heights up to 6 m.

7. CONCLUSION

As it might be expected, reducing the distance between the detectors, and therefore the distance from a detector to a possible site of fire, leads to smaller detector response. However, a couple of questions arise: how decrease of distance between detectors affect the reliability and response time of the whole system, and consequently the moment of the beginning of extinguishing, that is on activating stationary extinguishing system and activating evacuations systems. In our opinion, the rules from EN 54-14 and VDE 0833-2 are completely satisfactory for most applications in practice. Finally, a detailed analysis demands to take into account response time index RTI for smoke detector under consideration in every particular application.

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KOMPARATIVNA ANALIZA PRAVILA ZA POSTAVLJANJE DETEKTORA DIMA U HODNICIMA

U radu je data komparativna analiza pravila za postavljanje detektora dima u hodnicima i uskim prostorijama pet vodećih standarda u svetu za projektovanje sistema za dojavu požara: EN 54-14, VDE 0833-2, BS 5839-1, НПБ 88 and NFPA 72. Razlog za ovakvu analizu je očigledan: evropski standard čak ne definiše pojam hodnika za razliku od drugih standarda koji u manjoj ili većoj meri definišu pravila za postavljanje. Analiza je urađena korišćenjem programskog paketa PyroSim software, koji predstavlja grafički korisnički interfejs paketa Fire Dynamics Simulator (FDS).

Ključne reči: *tačkasti detektori požara, hodnici, simulacija, PyroSim*