ACTA TECHNICA JAURINENSIS
Vol. 17, No. 2, pp. 84-90, 2024
10.14513/actatechjaur.00738

Research Article

Effects of interior doors on the audibility of fire alarms

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Submitted: 08/03/2024 Accepted: 16/04/2024 Published online: 29/04/2024

Abstract: One of the most important purposes of installing fire alarm systems is to provide an alarm signal in a protected building in the event of a fire. Fire alarms are most often provided by networked audible warning devices. The signal must be easily and quickly detectable and identifiable so that the occupants inside can start to escape after the alarm has been sounded. This is apparently a simple expectation, but if you look at the efficiency of fire alarms as a whole, and the effects that determine whether an evacuation will occur in response to an alarm, the question is not so simple anymore. The authors examined the circumstances that may affect the fire alarm signals. Among these aspects, the focus of the article is on the soundproofing properties of especially the interior doors, and their effect on sound propagation. The authors hypothesised that the increase in sound insulation of certain building materials and structures has an increasingly negative effect on the audibility of fire alarm signals. The authors supported their hypothesis with a series of experiments by test the soundproofing of several interior doors in response to a fire alarm sounder, used in fire alarm systems. The paper confirms that the sound attenuation of the currently used interior doors is better than that of the previously used ones and this is a negative factor for the fire alarm audibility. The authors recommend that the soundproofing properties of interior doors should be given greater weight in the design of fire alarm systems.

Keywords: fire alarm; evacuation; fire sounder; soundproof; sound pressure; alarm audibility

I. INTRODUCTION

The first devices suitable for signalling fire were the forerunners of today's manual call points, which appeared on the streets of Berlin [1] and Boston [2] in the 1850s. Their primary purpose was, in part, to replace fire towers and rudimentary devices used to signal fire. By alarming the firefighters as quickly as possible and by intervening as early as possible, the number of fatalities and injuries can be reduced, as well as property damage (**Fig. 1**). From the mid-20th century, in addition to manual call points, devices developed in the series, which are capable of detecting fire without a human presence, gained an increasing role. These devices are the forerunners of today's automatic detectors, which were able to detect heat, smoke, and later flames. The main purpose of all these detection and alarm devices is to alert the occupants of a protected building as early and as clearly as possible to the fire in order to enable people to escape in time.

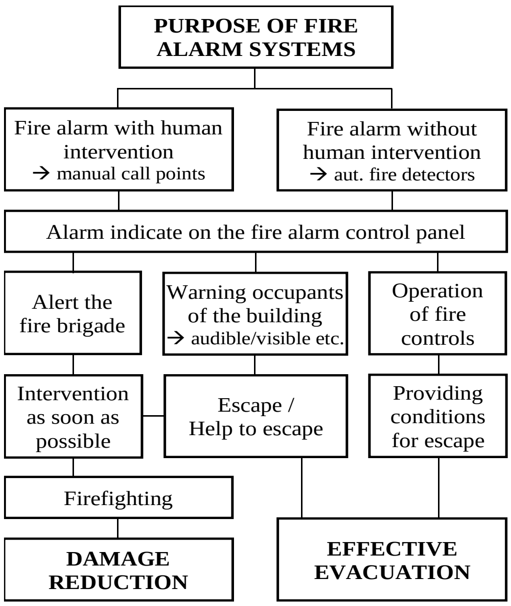

Figure 1. *Purpose of fire alarm systems (source: own figure)*

The key to a successful escape is the time interval (Available Safe Egress Time - ASET), which is available from the place of residence to reaching a safe area. "*Defined as the time when fire-induced conditions within an occupied space or building become untenable*." [3] This time is determined by calculations or simulation programs during the design phase of buildings. However, the time available for escape determined in this way is worthless if the information about the need to escape reaches the given person too late. The time from the moment of ignition to the start of escape is influenced by a number of factors (see **Fig. 2**).

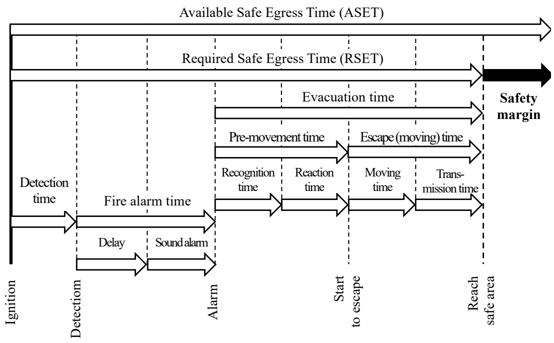

Figure 2. *Evacuation elements as a function of time, Source: [13], transformed.*

Each of these components can increase the time required to escape (Required Safe Egress Time - RSET) to such an extent that it reduces the chance of reaching a safe space. Therefore, the ability to effectively hear and identify the sound signal generated by the fire alarm system installed in a building at every point in the building is one of the most important components of fire safety in a building.

The design of audible fire alarm systems is subject to relatively strict standards now. Specific requirements define the minimum sound pressure level (hereinafter abbreviated as SPL) at any point of the building that the fire alarm sounders must provide. This is generally a minimum of 65 dB(A) according to the Hungarian technical specifications [4], but similar requirements are found in other countries (see **Table 1**).

At the same time, the regulations for manufacturers of fire alarm sounders also maximize the performance of sound signalling devices, taking into account the negative impact of sound on the human hearing organ above a certain sound pressure. This means that the sound pressure level, measured at a distance of one metre from the sound source, should not exceed 120 dB [5], so that the majority of fire alarm sounders on the market have a sound output rating of between 90 and 110 dB.

Table 1. *Requirements of SPL in standards*

Standard	*Min. SPL**	*Min. SPL***	*Min. SPL****
TvMI 5. [4]	65	75	+5
BS 5839-1 [16]	60, 65	75	+5
NFPA72 [15]	no specific value	75	+5
DIN VDE 0833-3 [14]	65	75	+5

SPL=sound pressure level in dB(A)

** in common areas*
*** to rouse sleeping people*
**** above maximum ambient SPL of the background noise*

The design of fire alarm systems has a minimum sound pressure level to be ensured and an upper limit of 120 dB, which follows from the sound pressure value that can be tolerated by the human hearing organ without damage. But there is also a third, very important aspect to consider, which is the environmental impact on sound propagation. The basis of the latter aspects is the physics of sound propagation, which depends not only on the characteristics of the sound source (primarily its frequency) but also on the particularities of the given environment. It is known that the basic physical laws mostly determine how a given sound propagates in the open air. Several methods have been developed over the past decades to determine as accurately as possible the number and location of audible warning devices, needed to meet the requirements at the design stage [6] [7] [3], however these methods show a wide variation [8].

Primarily, the distance from the sound source has a significant effect on the reduction of the sound pressure level. This can be taken into account by the easily applicable so-called '6-decibel rule', derived from the physical laws of sound propagation in free, unobstructed space. However, given that fire alarms are used in enclosed spaces, the parameters of the enclosed space are also decisive in the propagation of the sound.

Other significant influencing factors are the building structures that get in the way of the sound waves. In the context of fire alarm systems, these are walls and doors of different sizes and materials. There are 'rules of thumb' in engineering practice to take account of the sound attenuation effects of these structures, but experience increasingly shows that trends in the construction industry are prompting a rethink of the previous design practice. The sound attenuation of general building structures, including non-fire-resistant interior doors, is usually considered to be of the order of 20 dB, but our research shows that this value is often inadequate in practice. This observation is supported by a report from February 2024, which predicts a large-scale growth of the market for soundproof doors in the coming years. The report by Impulse Insight [9] says: "*The increasing demand for noise reduction solutions across various sectors, including commercial, residential, and industrial, is a major factor driving market growth. The rising awareness about the importance of noise control for a comfortable and productive environment is also contributing to the market expansion.*"

Last but not least, the furnishings in the room and the interior coverings of the space also play a major role in the extent to which the sound is attenuated in a space of the same size and geometry.

It is not the purpose of this article to examine the conditions for fire escape in detail and in complexity, but it is worth at least reviewing what significant factors need to be taken into account in addition to ensuring adequate sound pressure levels:

- the first important condition is that the fire in the protected area is detected by the automatic detector in its early stages or that someone presses the manual call point in time;
- the signal from the alarmed detector or manual call point reaches the fire alarm control panel;
- the fire alarm control panel activates the sounders in response to the fire alarm;
- the occupant detects the audible alarm;
- identify it as a fire alarm as quickly as possible;
- and finally makes the decision to leave the location place to start the escape.

The temporal and spatial progression of this complex set of conditions is illustrated in **Fig. 3**.

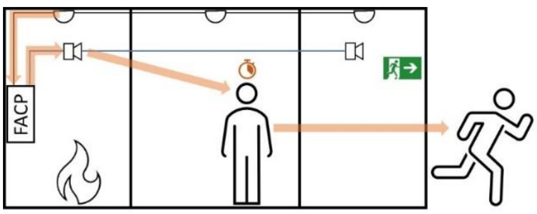

Figure 3. *Components of fire escape, source: own figure*

Successful escape, evacuating the occupants, is a complex problem. In addition to properly designed, implemented and operated technical solutions, one cannot forget the psychological aspect of the issue, which is both personal and social, and which is perhaps even more difficult to take into account. A fire alarm, as the 'auditory' delivery of a sound with a given frequency and pattern, by providing the appropriate sound pressure level, does not guarantee that a person will interpret this sound - as information - correctly and make the right decision to flee immediately. The human response can be influenced by a number of things, including:

- the person's skills (e.g. quick situational awareness and decision-making),
- physical and mental condition (e.g. disability),
- the knowledge he/she have or lack (e.g. whether he/she has received adequate fire safety training),
- previous experience (e.g., has he/she heard many false alarms),
- attitude (e.g. whether he or she is a rule-following person),
- the impact of expectations (e.g. not leaving the workplace), etc.

Among the components necessary for a successful escape, this article further investigate the issue of ensuring the sound pressure level, highlighting the interesting aspect of how doors of different materials and quality affect the propagation of fire alarm sound. The authors carried out tests, the results of which are evaluated and compared with the applied recommendations and design practices. The purpose of the paper is to draw attention to the fact that changes in the materials and solutions used in the construction industry can also affect the design practice of such a narrow and specialized field as designing fire alarm systems. The increasing soundproofing properties of interior doors is just one of many effects that affect fire alarm effectiveness. But this effect, looking at the market trend, has a large influence. "*Factors such as increasing demand for noise reduction solutions, technological advancements, and regulatory requirements are driving the market growth. Manufacturers are continuously innovating and developing high-performance soundproof doors to meet the evolving needs of customers*." [9]

II. THE EFFECT OF SOUND ATTACHMENT OF INTERIOR DOORS ON FIRE ALARM

To support assumptions based on the authors' experiences, sound pressure measurements were carried out of several interior doors to compare them with the 20 dB(A) equivalent used in planning the location of fire alarm sounders. The used layout of the measurement series shown in **Fig. 4**.

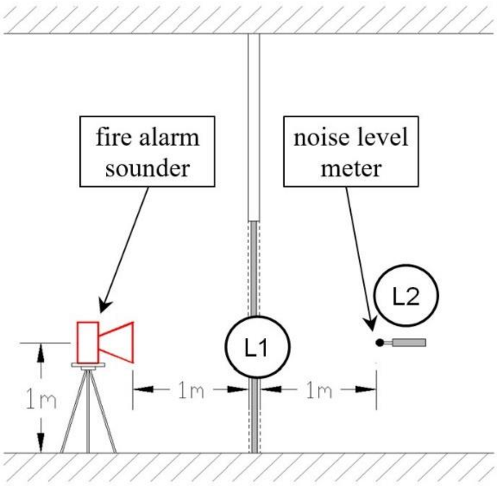

Figure 4. *Examination of the soundproofing properties of interior doors in connection with the audibility of fire alarms, source: own figure*

The sound pressure level differences between the two measurement points (L1 and L2) are taken as the results of the measurements.

The measurement, although similar to the measurement of airborne sound attenuation between two rooms according to the relevant standard [10], it is not the same. This measurement purposefully examined how the soundproofing effect of interior doors applies to the actual sound pressure level of the alarm sound generated by the typical sound alarm devices used in fire alarm systems.

Specifications of the fire alarm sounder device used in the measurement (**Fig. 5**) [11]:

- Type of fire alarm sounder: WES, W2-FPT-CSS;
- Manufacturer: Ramtech Electronics Limited;
- Sound output: 88-109 dB depending on the setting (in this case 100 dB according to DIP setting 6);
- Compliance with EN 54-3, EN-11, EN-25.

Technical data of the sound pressure measuring device (**Fig. 6**) used during the measurement [12]:

- Electric Noise Level Meter: UT352 (Uni-Trend Technology Co.);

Figure 5. *Used fire alarm sounder, source: own photo*

- Sensor element: precision condenser microphone;
- measuring range: 30÷130 dB (A);
- accuracy: 1,5 dB (A);
- Compliance with EN61326:1997+A1:1998 +A2:2001 +A3:2003, EN61672-1:2002 Class 2 and IEC60641:1979 Type 2, ANSI S1.4:1983 Type 2

Figure 6. *Used UT352 digital noise level measuring instrument, source: own photo*

The measurement was carried out for a total of ten doors. The most relevant information and results are summarized in **Table 2**. The result of the 10th measurement was not used, as the door under test was installed but did not contain a seal, and the result is therefore not considered relevant.

In the **Table 2** the L1 value is the sound pressure level at the open door, 1 m from the sound source. L2 is the sound pressure level value at 1 m on the other side of the door.

Door 6 had the lowest sound reduction, while Door 2 exhibited the greatest soundproofing ability. The glass sliding door of the printing room (No. 6) showed a sound pressure of only 21.1 dB(A), while the No. 2 aluminium-framed glass door showed a lower sound pressure of 43.7 dB(A) on the other side of the door.

Table 2. *Result of measurement for testing the fire alarm-related sound insulation properties of interior doors*

Door No., type*	***Room type***	***Width of doors** [cm]*	***L1** [dB]*	***L2** [dB]*	***SPL diffe-rence** [dB]*
1.	office	4	103.5	74.8	28.7
2.	office	4,5	104.3	60.6	43.7
3.	meeting	4,5	104.3	62.8	41.5
4.	kitchen	4	104.9	82.6	22.3
5.	corridor	4	105.2	76.8	28.4
6.	printer	4	106.6	85.5	21.1
7.	meeting	4,5	106.3	72.1	34.2
8.	meeting	4,5	105.3	80	25.3
9.	office	4	106	79	27
10.	vestiary	4,5	106.1	82.2	23.9

** 1. decor foil, hollow inside /old*
2. aluminium door frame, glass insert/new
3. aluminium door frame, glass insert/new
4. decor foil, hollow inside / new
5. decor foil, hollow inside /new
6. decor foil, glass sliding door /new
7. metal, glazed /old
8. painted steel sheet door /old
9. HDF wood panel covering, paper grid insert, glass/old
10. decor foil, hollow inside, grey /new

The doors with the smallest and highest sound attenuation are shown in **Fig. 7**.

Door 6 Door 2

Figure 7. *Tested doors no. 6 and no. 2, source: own photo*

Evaluating the results of the measurements (**Fig. 8**), the authors concluded that even in the case of doors with not particularly high soundproofing properties, a higher sound pressure reduction should be expected compared to the value of 20 dB(A) used in the design (indicated by a red horizontal line in Fig. 8).

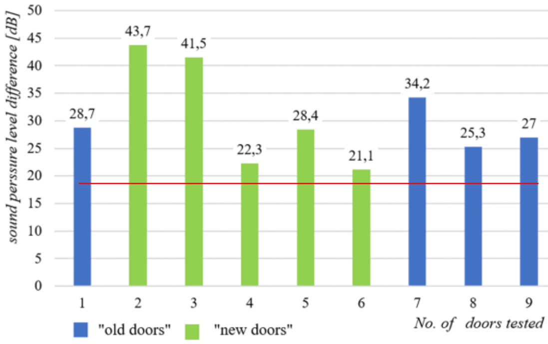

Figure 8. *SPL differences between L1 and L2 measure points, source: own figure*

The measured level of sound insulation was around 30 dB on average for all the doors tested. In case of the older doors, it was slightly lower, averaging 28.8 dB(A), and for the newer doors it was somewhat higher, averaging 31.4 dB(A).

Interior doors play a role in the complex perception of fire safety, as they delay the spread of fire in their closed state. However, in terms of the audibility of fire alarms, the opposite effect is true. Close doors have the potential to increase the ASET and therefore reduce the occupants' chances for escape. Although fire alarm sounders are designed with the assumption that the doors are closed, in reality some doors are regularly left open. In a domestic environment, for example, the probability of doors being closed has already been investigated. There is a higher probability (on average approx. 60%) of doors being open in a house or apartment. [13] Of course, this is not the same value in the case of different building functions.

III. Conclusions

This article aim was to examine how the construction industry practice of the past decades, the new technological procedures and materials appearing because of the changed customer expectations influence the efficiency of sound alarm systems distributed according to traditional design practice.

To what extent this trend affects the practice of the sound alarm system's designers. It is necessary to considering an important question among other things, whether the current design attitude needs to be changed or refined. Even though a sound pressure measurement must be carried out before handing over a completed system, proper design practice cannot be based only on verification with subsequent measurements.

By carried out on-site measurements, it was verified that one of the design principles used in engineering practice, is no more correct. The measurement results confirmed the assumption that the use of doors with better soundproofing in recent years may have a negative effect on the fire alarm in a building. The tests confirmed that the soundproofing properties of the doors should become more important information in the future, which has a strong influence during the design of fire alarm systems. In addition to the usual data services, the authors recommend the designers requesting this information (acoustic rating of the interior doors) in advance from the architect or checking it in the consignment plan.

In addition, an interesting question is whether during operation the audibility of the fire alarm is considered in connection with the replacement of a door with a newer door with higher soundproofing properties. Given that the replacement of interior doors is not a permit-required conversion, awareness is expected from the facility manager and the maintainer of the fire alarm system.

AUTHOR CONTRIBUTIONS

Á. Zs. Mohai: Conceptualization, Experiments, Writing and Editing

B. Elek: Theoretical analysis, Review and editing

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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