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Minimization of risk by the controlled replacement of fire detectors

Rationale for the model arrangements set out in DIN 14675-1

Electro and Digital Industry Association

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Summary

Fire detection and fire alarm systems have the function of warning people swiftly of the dangers of a fire and thus permitting rapid rescue. The fire detection and fire alarm system also protects material assets, particularly where unattended. This ensures that operating processes are maintained, and prevents fires from spreading, i.e. assuring early and effective fighting of the fire. In attaining these objectives, fire detection and fire alarm systems contribute substantially to fire protection. In this context, automatic fire detectors connected to the fire detection and fire alarm system have the function of detecting fires early, swiftly and reliably. Fire detectors are sensor systems and form part of a wider safety system. They are exposed to numerous ambient conditions specific to their use and, like other socio-technical systems, undergo natural ageing processes which limit their service lifespan. Owing to the numerous risks that arise when a fire detector fails or its function is impaired, the continuous serviceability of a fire detection and fire alarm system must be ensured. This requires controlled replacement of fire detectors. In some countries, this is ensured by standards. This document explains the need for controlled replacement of fire detectors and the associated causes and effects, with reference to the example of Germany and the provisions of DIN 14675-1. It explains, in terms of practical relevance and with reference to examples, the basic concept of preventing possible failure of a technical safety system in order to assure its protective function in the event of a hazardous event occurring, together with the range of essential causes and effects. This explanatory document (*Merkblatt*) summarizes the facts based on the information contained in [1].

1 Introduction

The fault-mode behaviour of technical systems is subject to numerous influencing factors and is randomly distributed. The failure phenomena cannot therefore be determined precisely, but must be viewed as stochastic processes (see [2], [3], [4]). This is particularly critical with respect to technical safety systems, because the random variable comes into play in two respects: firstly the probability of a dangerous event (e.g. a fire) occurring, and secondly the possible failure of the protective system itself (see [5, p. 481]) in which the protective function may not be assured when a demand is made upon it. In many safety applications, the system is automatically placed in a safe state in the event of failure (fail-safe mode). By contrast, fire detectors must not assume the safe system state, since they do not exhibit functional redundancy and would therefore cease to perform their primary function. Although failure is very rare, when it does occur it is often life-threatening or at least highly likely to involve other harm, whether to persons, the environment, image, or to cultural, material and non-material property (see [6]). To prevent such harm, preventive measures – in which technical, organizational, behavioural and environmental factors interact – are implemented in safety engineering (e.g. [6], [7], [8], [9]). Such measures include functional testing[1] and replacement of fire detectors. These measures are still not fully appreciated and their purpose continues to be challenged in some quarters. Likewise, misunderstandings still arise concerning the arrangements for replacing fire detectors ([10], [11]).

2 Purpose, structure and normative principles of a fire detection and fire alarm system

In the European Economic Area, a fire detection and fire alarm system consists of a group of components governed by the EN 54 series of standards which, as defined in EN 54-1 (2021-08, p. 9), are capable of automatically detecting and signalling a fire and triggering further automatic measures [12]. The essential components of a fire detection and fire alarm system are defined in EN 54-1 (2021-08, p. 7) as automatic fire detectors, fire alarm receiving centres and the facility for connection of fire alarm devices, or are described in [13] as the fire alarm receiving centre and its periphery. Fire detection and fire alarm systems are systems planned specifically for an intended project and installed in the building. Their function as a system is tested in accordance with the national regulations, and in Europe ideally as systems against EN 54-13:2020-02. The handling and use of fire detection and fire alarm systems, from planning, engineering, assembly and installation, commissioning and acceptance through operation and maintenance and finally to modification and extension, is regulated specifically at national level against application standards. In Germany, the applicable standard in this case is DIN 14675-1:2020-01 [14], supplemented by DIN VDE 0833-1 [15] and DIN VDE 0833-2 [16]. The requirements to be met by the service provider are governed in DIN 14675-2 [17], interaction between the individual trades in DIN 14674:2010-09.

Fire detection and fire alarm systems have the function of warning people swiftly of the dangers of a fire and thus permitting rapid rescue. The fire detection and fire alarm system also protects material assets (particularly where unattended), ensures that operating processes are maintained, and prevents fires from spreading, thereby assuring early and effective fighting of the fire. With these objectives, fire detection and fire alarm systems contribute significantly to fire protection (see [18]). When a fire detector detects a fire, the signal is relayed to the fire alarm receiving centre, which processes the signal and then alerts the emergency service (e.g. the fire brigade) via the transmission equipment. If applicable, it also unlocks the fire brigade key box. This enables the fire brigade to access the building. Inside the building, orientation for the fire brigade is provided by the fire brigade peripherals (e.g. by means of the fire brigade indication panel, which displays which detector group or fire detector has been triggered, and thus serves to localize the site of the fire). At the same time as the fire brigade is alerted, fire incident control systems are activated, where such systems are installed in the building. These control smoke and heat extraction systems, fire extinguishing systems, fire incident controls for lifts, and dynamic escape route guidance. In the majority of cases, detecting a fire is the first requirement for numerous other fire protection

[1] The function test in this context differs from the "function check-out" to EN 13306:2018-02, which defines the *action taken after maintenance actions (usually carried out after down state) to verify that the item is able to perform the required function*[61].

measures, and is the primary function of fire detectors. Automatic fire detectors constitute non-encapsulated sensor systems. In Europe, such systems detect fires based on typical fire characteristics in accordance with the EN 54 series of standards. Fire detectors conforming to EN 54-7:2018-10 are often used. These are point smoke detectors that detect smoke particles by means of scattered light, transmitted light or ionization. Like all other components connected to the system, these fire detectors are subject to maintenance and functional testing in accordance with standards. The arrangements for installation and operation of fire detection and fire alarm systems are set out in Germany in DIN 14675-1 [14] and [15] [16].

3 Basic reliability theory

The total lifespan of a system is divided into a manufacturing phase and a service phase. Its use ends with final outage and disposal. The service lifespan can generally be extended by maintenance measures, particularly repair ([19], [20]), which extend the wear process. The maintenance measures can be classified according to the course of the wear reserve, see Figure 1. The wear and tear of a system and of its components begins when the system is placed in use. Wear and tear is understood as degradation of the reserves for the possible fulfilment of function under defined conditions which an item under consideration possesses by virtue of its manufacture or restoration by way of repair (see [20, p. 526 f.]). The wear reserve is the inverse function of the utilization reserve. When the utilization reserve approaches a tolerance limit, its progression must be counteracted by maintenance and repair measures, causing the course of the curve to be changed and the utilization reserve to be raised again. This process repeats itself. It cannot be repeated indefinitely however, since at some point the wear and tear inevitably affects too many systems or components.

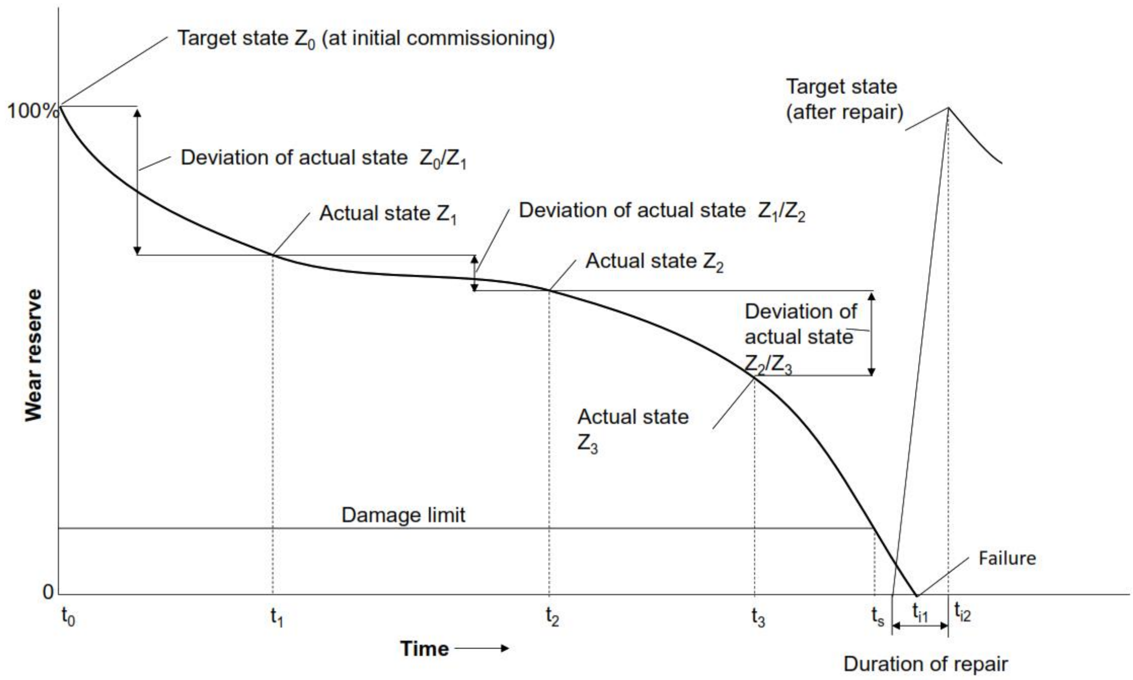

Figure 1: Course of the wear reserve over time ([27, p. 528], see [21])

Maintenance measures include measures that do not counteract loss of an existing wear reserve but merely prevent or reduce further degradation. Conversely, inspection affects neither the wear reserve, nor its degradation. Inspection determines and evaluates the point on the curve that has been reached, not merely that the end of the curve has been reached. For this reason, inspection intervals are based on the typical or anticipated curve progression. All measures contributing to interrupting the course of the wear reserve over time and restoring it fall under maintenance measures, such as replacement of affected systems or their components (see [20, p. 527]). The wear reserve can be increased to above 100% of the initial state by maintenance involving additional improvements (such as the use of more modern products).

3.1 Extending the service lifespan increases the probability of failure

By their nature fire detectors, like any technical system, exhibit randomly distributed failures and ageing effects. These are to be avoided by preventive measures in accordance with generally accepted good practice, in order to prevent impairment of function in the event of a demand upon it. The response behaviour of fire detectors has been shown to change over the service lifespan in comparison with new fire detectors [22]. As a result, fire detectors may no longer comply with the normative requirements and possibly not even fulfil their intended function, resulting in attainment of the protection objectives being at risk. A change in the service lifespan influences the probability of failure of the fire detector. Extending the replacement interval increases the probability of failure and jeopardizes assurance of the protection objectives. Shortening the service lifespan reduces the probability of failure; however, it increases the outlay for maintenance of the system, which often conflicts with the economic interests of the building operators and may reduce the acceptance of such measures. A difficulty here is that the exact function of the failure curve of fire detectors in terms of the service lifespan, and the exact point in time at which failures are to be expected owing to wear, are – for the reasons stated – not known. In the absence of further considerations, an increase in the service lifespan, i.e. extension of the replacement intervals, will thus inevitably lead to an unknown increase in the probability of failure of the fire detectors under the given underlying conditions (e.g. country-specific standards and ambient conditions). Furthermore, owing to the number of fire detectors in use, even a seemingly low failure rate translates in absolute terms into numerous failures that could endanger human life. The associated increase in risk runs contrary to the protection objective of a technical safety system. Since the use of fire detectors often involves the safety of persons, this must not be left to chance.

3.2 The service lifespan plays a decisive role in the complex cause-and-effect relationships of a fire detection and fire alarm system

Numerous internal and external influencing factors affect the response behaviour of fire detectors over their service lifespan. The serviceability is consequently a function of the particular usage parameters and environment [19, p. 31].

A change in a component or influencing factor is related to numerous other factors. Equally, a change in the service lifespan influences numerous other factors, or requires them to be changed as a function of the service lifespan. The actual causes and effects have not been adequately studied for most scenarios. Examples are those between the service lifespan, the design of parts and the conditions of use, such as certain humidities, dust loads or ambient temperatures. While this is just one detail of many, it illustrates the difficulty of estimating the impacts of system changes in consideration of the service lifespan.

Not only are fire detectors part of a complex safety system and cause-and-effect structure, they are also exposed to the influences of numerous and many-faceted boundary conditions. The controlled replacement of fire detectors is a key element in managing this complex of technical, organizational (e.g. normative and legal) and human (e.g. the people involved) system components and the various ambient conditions, in order for the required reliability of such a system to be continuously assured. Furthermore, safety considerations demand a conservative approach to determining the service lifespan of a fire detector. This is necessary because to ensure its highest possible availability, the system's service lifespan is usually determined by the component with the shortest service lifespan.

The response behaviour of fire detectors depends on the product (i.e. detector type) concerned, its measuring principle, its level of technical development and its component parts. The parts are influenced in turn by other parts and by ambient conditions such as temperature, humidity and airborne substances, the algorithms, the type and number of the measurement parameters, and the locations of use with their particular and in some cases varying ambient conditions such as the dirt and dust load, temperature, temperature fluctuations and temperature rise, air velocities, the influence of electromagnetic fields, and deposits caused by insects. To these are added factors such as the load on the system or its components, the wear reserve, the maintenance intervals of the fire detection and fire alarm system and its components, and the quality of maintenance (see [23]). Factors such as technological change in general, fashion and aesthetics, changing values, and other external ambient influences may also be relevant and have a bearing on the service lifespan of a fire detector, and should be taken into account.

Overall, it can be stated that changing one "setting" within the complex cause and effect system of a fire detector in turn changes numerous other settings in the system, or already presupposes that they have been correctly set.

3.3 The parts and their ageing influence the service lifespan

Function testing and replacement of fire detectors address the fact that electronic parts age over their service lifespan. This ageing process is inherent to the system and circumstances, and is not disputed. It concerns both the part itself, and the conditions under which it is used.

Different fire detectors and different products are available that employ different individual parts. Components of fire detectors include circuit boards, photoelectric elements, light-emitting diodes, capacitors, transistors, relays, resistors, heat sensors and microprocessors, all of which differ in their ageing properties and thus in their probabilities of failure. Typical failure rates for transistors, for example, are 1.5×10^{-2} and for resistors $9.5 \cdot 10^{-5}$. Fire detectors and all parts of which they are composed are inherently subject to wear, which is influenced by their individual operating conditions. For example, the components are subject to soiling and corrosion stresses caused by the conditions of use. Over many years, this also affects fire detectors with automatic soiling compensation [24].

Natural ageing of the individual parts depends not only on the ambient conditions but also on what parts are used. Different part and supplier qualities can therefore have just as much influence on ageing as the algorithms or technologies employed. It can also be assumed that the different measurement principles employed by the fire detectors and the use of different technologies to measure various parameters result in corresponding differences in natural ageing.

3.4 The ambient conditions substantially influence the service lifespan

Fire detectors are non-encapsulated systems. They consequently interact with their environment, and the sensors are exposed to a range of ambient influences. These also influence the natural ageing effect of systems and components. Stresses of an environmental nature include dust, aerosols, insects, water vapour, electromagnetic radiation, thermal and cyclic electrical stresses, dark current, diffusion processes, micro-organisms, and also seemingly good hygiene conditions [22]. Furthermore, indoor ambient conditions can have a strong impact on the ageing of the fire detector. These include temperature and temperature fluctuations, meteorological influences (e.g. solar radiation), humidity and air velocity (i.e. air circulation). The fire detector can be exposed to these factors for different durations and at different intensities. The ambient influences are likely to vary in their effects upon a fire detection system as a whole; different fire detectors in the same fire detection and fire alarm system will therefore be affected differently, and consequently age differently. The service lifespan of a fire detector thus depends to a large extent on the site of its use and the ambient conditions prevailing there.

Changes in a building's use, alterations to the building or other influences in it, in some cases arising spontaneously, have an impact upon a fire detector's ageing behaviour and thus upon its service lifespan. Since it is now common for a building to be used for different purposes in the course of its life cycle, the ageing of a fire detector may be affected by changes in the use of the building, such as the re-purposing of a warehouse as a workshop, resulting in the ambient conditions varying significantly. Similarly, the ageing of a fire detector during the life cycle of a building will be affected by alterations, construction sites or redecoration work.

No unlimited guarantee can be given for the reliability of a given fire detector product, as too many ambient conditions and the use and handling of the products concerned are significant factors. The protection objectives of a fire detection and fire alarm system must be ensured at all times.

3.5 Replacement of fire detectors as provided for in standards has been shown empirically to be effective

Experience to date shows that the current provisions of DIN 14675-1 concerning function testing and replacement of fire detectors have proved effective since their introduction, and that their effects are expected to increase in the coming years. The provision was first added to the standard in December 2006; some 15 years of experience have therefore now been gained.

No major fires have been reported in recent years in which a fire detection and fire alarm system and the provisions under discussion here failed. In addition, studies conducted in recent years have revealed on the one hand a high availability (see [23], [25], [26]]) and on the other a high efficacy of fire detection and fire alarm systems (see [27], [28], [29], [30], [31]) – provided the systems are planned, installed, commissioned and maintained in accordance with the standards. At the same time, a reduction in the false alarm rates of fire detection and fire alarm systems over several years has been documented (see [32], [33], [34], [35], [36], [37, p. 139], [38], [39], [40]). A recent study [41] specifically addressing the replacement of fire detectors also indicates that the corresponding provisions of DIN 14675-1 are expedient. Table 1 shows the results of the study for fire detector failure rates as a function of age.

Table 1: Failure rates of fire detectors as a function of years in use (based on [41], simplified and modified)

Age	Number of fire detectors tested	Number of fire detectors outside the limit values	Failure rate
0-10 years	11	0	0%
10-20 years	74	8	11%
20-30 years	22	6	27%

The figures reveal no failures of fire detectors up to a service lifespan of 10 years (this is conditional upon fire detectors being located in a clean environment, since the study tested fire detectors used only in offices, universities and hotels). In contrast to the study, DIN 14675-1 covers all areas of application of fire detectors and governs them uniformly across all environments. The only distinction made is between fire detectors with and without soiling compensation, which is reflected by the replacement interval of 8 and 5 years respectively; the results of the study suggest that this distinction is reasonable.

3.6 Besides attainment of the protection objectives, the avoidance of false alarms is also important

The more sensitive fire detectors are, the more prone they are to triggering false alarms in response to phenomena resembling an actual fire. This can be countered, at least in part, by algorithms, proper selection of fire detectors, use of multiple fire parameters, etc., which make the fire detectors less prone to false alarms without impairing their response to a fire. Such approaches are increasingly becoming the norm. Despite these developments, false alarms caused by fire detection and fire alarm systems are burdensome for fire brigades and lead to unnecessary costs. They tie up personnel and material resources of the emergency services which are needed elsewhere. In addition, it can be assumed that more frequent false alarms result in the warning effect upon those affected being weakened in the event of an actual demand case [42]. The greatest proportion of false alarms caused by fire detection and fire alarm systems is accounted for by systems functioning as intended but being triggered by phenomena similar to an actual fire ([32]). Further categories of false alarm are alarms caused by technical defects, unintentional alarms (raised in good faith or error) and malicious alarms [38]. Alerting of the fire brigade limits the course of the damage. Nevertheless, the perception is that the disadvantages of false alarms predominate. False alarms also occur in other areas or with other technologies, where however they are less controversial. Examples are burglar alarm systems, tsunami early warning systems, passenger scanners at airports, and systems in disease diagnostics, the media or politics.

Various measures to counteract false alarms triggered by fire detection and fire alarm systems have been in place for several years (see [41], [33], [43], [44]), and have already led to a reduction in false alarms.

It can be assumed that the frequency of false alarms will be reduced by the provisions of DIN 14675-1 for function testing and replacement of fire detectors, since these result in maintenance playing a systematic role and soiled, aged fire detectors being replaced by new (and more modern) fire detectors (possibly even with newer algorithms or an intelligent combination of fire characteristics).

Recommendations contradicting such standards can be observed in isolated cases in the field and may be viewed critically. In deviation from the provisions of DIN 14675-1, [45] for example proposes that regular replacement should not be scheduled or conducted and that smoke detectors should remain in operation until they increasingly fail to trip during the test. The rationale here is that the owner/operator is able to meet the required level of protection without necessarily having to take precautions against all conceivable, remote possibilities of damage occurring; it is argued that he need only take the precautions that are necessary and reasonable to eliminate the danger in consideration of the particular circumstances [45]. [45] also states that soiled smoke detectors do not in any way jeopardize attainment of the protection objectives; rather, soiled smoke detectors present a risk of false alarms. A risk of failure to detect smoke particles in the event of a fire does not therefore exist. The philosophy here is thus that false alarms triggered by phenomena resembling an actual fire should ultimately be tolerated for reasons of economic expediency, or exploited as an indicator of the need to replace fire detectors. This should be viewed critically with respect to the associated, possibly avoidable call-out of the fire brigade and erosion of the warning effect of an alarm upon users of the building. Were this approach to be adopted and fire detectors not be replaced until they begin triggering false alarms, the cost of not carrying out maintenance in compliance with the standards would be borne by wider society[2]. [46] even states that an elevated "false alarm rate" does not pose any immediate danger, since dealing with it lies within the responsibility of the user and his own works fire brigades and permanently manned positions. To date, false alarms, and especially false alarms triggered by phenomena resembling an actual fire, have generally been paid for by the party causing them.

The cost-effectiveness of this proposal is also questionable because it implies that when an inspection has determined that the failure rate of the fire detectors (in the case of more than three false alarms from the affected detector array) is increasing as a function of age, the entire affected detector array at the property concerned should be replaced in order to avoid false alarms. This would result in numerous fire detectors being replaced early. The reasonableness and cost-effectiveness of such an approach as an alternative to controlled replacement of fire detectors as provided for in the standard is questionable. The most important point however is that soiled fire detectors jeopardize attainment of the protection objectives of a fire detection and fire alarm system, and by its nature, the probability increases with increasing service lifespan.

3.7 Attainment of the protection objectives must not be jeopardized by overextension of the service lifespan

The replacement cycles specified in DIN 14675-1 for the fire detectors under consideration here are binding in Germany equally for all products and brands, in particular for fire detectors with an optical sensor chamber. The requirements for the products are consequently the same for all manufacturers.
Regulating replacement cycles, for example on the basis of the manufacturer's specifications, would lead to the service lifespan of a fire detector and consequently attainment of the protection objectives becoming a variable. It would be anticipated that, as a parameter in commercial competition, the service lifespan would be progressively extended and possibly overextended. In fact, this overextension would be probable, since – as already described – the failure curve of fire detectors is described stochastically over time and is not known precisely. This approach would thus have a negative impact on the risk situation since, firstly, fires may not be detected sufficiently early owing to the lack of sensitivity of the fire detectors, and secondly, the availability of fire

[2] To place this in perspective: the costs of a false alarm depend on the personnel and material resources required for the deployment, and its required duration [38]. In Germany, a false alarm costs between €600 and €1,200, depending on the procedures of the local authorities. In Switzerland and Sweden, it is estimated to be up to €2,000 [33].

detection and fire alarm systems could then decrease with rising service lifespan owing to the increasing probability of wear-related failures, or the maintenance effort elsewhere could rise. This may affect attainment of the protection objectives.

3.8 Defined replacement cycles constitute harmonized and manageable solutions across all areas of application

The provisions of DIN 14675-1 governing function testing and replacement of fire detectors also specify uniform replacement cycles for all applications. This makes implementation of the standard practicable. Regulating the replacement cycles differently according to the conditions of use and areas of application would give greater consideration to the actual circumstances, but would at the same time make implementation of the requirements more complicated. Furthermore, definition of the application would be dynamic and often contentious, since many applications change over time and are also not always clear. In times of increasing mixed use and re-purposing of buildings to reduce land use, this point of discussion is likely to become even more relevant. Even disregarding this issue however, differentiation in the standard according to application is likely to be complicated. By contrast, the normative arrangement of DIN 14675-1 and the possibility of replacing the fire detectors after fixed cycles represents a manageable solution, notwithstanding the complexity of the operating mechanisms of a fire detector.

3.9 The human factor influences the service lifespan

At numerous points, human behaviour has an influence on fire protection, the function of a fire detection and fire alarm system and, ultimately, the response behaviour and service lifespan of a fire detector. The complexity of this influence is such that the various influences cannot be regulated. They nevertheless influence the failure modalities and make the systems complex (see Section 5.6).

The human influence extends from selection of a building's location and design to the neighbourhood and other underlying socio-cultural conditions, the available and required capital in relation to the purchase price of the plot, construction costs, the interest rate, the availability of credit from the bank and possibly investors, and the use of an architect and his or her work [47]. Human beings further influence the risk situation through the manufacture and use of building materials, furnishings and technical systems, planning and erection, operation, maintenance and the proper use of fire protection measures, and the consideration given to foreseeable misuse [48]. The human factor has a serious influence on the quality and service lifespan of fire detectors during the construction and maintenance of a building, selection of the fire protection measures and planning of a fire detection and fire alarm system by the parties responsible for electrical planning (see [48]). The right fire detectors must for example be chosen for the particular location in consideration of the objective. Parameters such as these influence the service lifespan of a fire detector. The specific influence of the human factor is underestimated in fire protection and in the narrow context described in the present document, even though events such as fires, their side effects and the performance of the measures depend upon it [48]. Human beings play a role in numerous ways with regard to the serviceability of a fire detector and its service lifespan. These influences are difficult to foresee and regulate.

3.10 Replacing fire detectors is more reliable in the long term than factory testing and repairs

DIN 14675-1, Sub-clause 11.5.3 provides multiple options for addressing the wear and ageing of the fire detectors by function testing and replacement. Sub-clauses 11.5.3 b) and c) both describe specified replacement cycles for fire detectors, according to whether or not the devices feature soiling compensation. The regular replacement of automatic fire detectors is defined in Section 11.5.3 for specific types of detector (optical, etc.). For all other detector types that are not explicitly stated here, the principle applies that the protection objective must always be met.

The standard also makes provision for the fire detector to be checked by means of a factory inspection and repair and thus remain in use if appropriate, rather than being replaced by a new fire detector.

While the service lifespan of a fire detector can be extended by factory testing and factory repair, it nevertheless remains finite. In addition, this replacement process will probably result in the fire detector concerned ceasing to meet the requirements of the relevant EN 54 standard sooner than a new fire detector. This time difference is difficult to plan for. The protection objectives of a fire detection and fire alarm system can therefore be attained more reliably by replacement of the fire detector with a new item than by replacement with a used fire detector.

3.11 Replacement of fire detectors is associated with a range of sustainability aspects

The normative provisions of DIN 14675-1 concerning function testing and replacement of fire detectors raise issues of sustainability and environmental protection at several points:

Firstly, replacement of fire detectors after a defined number of cycles produces waste electrical equipment that must be disposed of properly and pollutes the environment. This primarily concerns the disposal of plastics and small electrical parts. These should however be regarded as valuable materials, as they can be reused following their use in fire detectors for the manufacture of other products or broken down into raw materials.

Secondly, the overall maintenance of a fire detection and fire alarm system is geared towards the conducting of regular inspections and checks on the serviceability of certain components, with only those parts being replaced that no longer satisfy the requirements and do not possess redundancies. This in turn saves resources. This approach is also compatible with the key points of the European "Green Deal", whose objective is the use of lower-emission technologies and sustainable products. It is intended to encourage companies to offer reusable, durable and repairable products [49]. The European Ecodesign Directive also extends the principle of energy efficiency to material/resource efficiency and applies, for example, to electric light sources and ventilation equipment [50].

Thirdly, it should also be noted that replacing fire detectors means replacing old devices with new products. As a result, less environmentally harmful substances could be used, as the requirements concerning the use of materials and hazardous substances have become stricter over recent decades. Product innovation cycles are also resulting in more modern systems being used. If components with lower energy consumption are used in these products, the result – assuming energy consumption is consistent over the service lifespan – is a reduction in overall energy consumption. At the same time, fire detectors corresponding to the latest state of the art are used for replacement, thereby furthering technical progress.

Fourthly, the procedure for direct replacement of a fire detector is probably associated with lower CO2 emissions than that of factory testing and repair (see Figure 2; top vs. bottom procedure), since transport journeys are avoided and the process is faster.

The replacement of fire detectors must therefore be considered critically from the point of view of sustainability, but is at the same time associated with positive developments.

3.12 Studies do not yield conclusive findings for adjustment of the replacement intervals for fire detectors

A series of studies have been conducted into the failure modalities of fire detectors as a function of ageing (see [41], [51], [52], [53], [54], [55], [56], [57, pp. 103-150], [58, pp. 310-312]). A selective review of these studies [59] shows that few systematic studies of this aspect have been conducted. The studies all exhibit certain weaknesses with regard to the failure mechanisms of fire detectors as a function of age, and fail to deliver clear, robust and generalizable results. Some of them do not deal with fire detectors (see [51], [52], [58]) , i.e. fire detectors of a fire detection and alarm system [53], [56]).

The most up-to-date results are currently provided by a British study into the ageing of fire detectors [41]. The aim of this study was to investigate the optimum replacement intervals for optical smoke alarm detectors and smoke detectors by means of repeatable test methods. For this purpose, measurements were carried out in the first stage on ten new smoke alarm detectors and ten new smoke detectors (five with and five without soiling compensation) in a laboratory environment with the use of Trutest smoke detector test equipment, in order to establish sensitivity ranges (calibration tests). In the second stage, the Trutest equipment was used to test 86 smoke alarm detectors (aged 0-12 years) and 107 commercial smoke alarms (aged 0-30 years) in a field study in commercial and residential environments. The study examined several brands of fire detector, which differed in their sensitivities owing to their designs (the different components and lifespans were however not investigated).

The study shows that the sensitivity of smoke alarm detectors and smoke detectors increases with age and that older fire detectors are associated with a slightly increased probability of false alarms. The results show noncompliance with the permissible limits from the tenth year onwards in clean environments. Since tests were performed only in relatively clean environments, it can be deduced from this that a replacement of the fire detectors in the eighth year in all applications in the eighth year at the latest would appear appropriate. Furthermore, the study states that different replacement intervals should apply for fire detectors depending upon whether they feature soiling compensation, as is already set out in DIN 14675-1. One drawback of this study is that only smoke detectors in offices, universities and hotels were tested; the validity of the results is therefore limited. It is also unclear what type of aerosols were employed in the test method. The use of other methods to calculate the limit values from the calibration yields different results, and the number of tested fire detectors per age group is low (however, this raises the question of how the random sample must be composed in order to deliver meaningful results sufficiently robust for a safety and legal assessment in the event of doubt).

It can be stated that none of the studies produces clear, robust and generalizable results. The general observation is that the probability of failure of fire detectors is a function of the service lifespan. An exact function over the service lifespan was however not deduced. In addition, both decreases and increases in the fire detectors' sensitivity were observed over the service lifespan. The former resulted in a fire being detected with a delay or not at all; the latter in the probability of false alarms being increased. The studies do not provide any evidence to support amending the current provisions of DIN 14675-1 and the replacement intervals for fire detectors. On the contrary: it can be inferred from the results of the latest study that the provisions are expedient.

4 Technical and normative causes and effects

The essential causes and effects with respect to the function test and replacement of fire detectors as provided for in the standard are presented below.

The possible outcome of a function test is replacement of the fire detector, particularly should it feature an optical sensor chamber. Three procedures for the function test and replacement of fire detectors are specified in the standard. One procedure involves a periodic test of a fire detector's serviceability in compliance with the standard:

a) If a fire detector's serviceability is tested annually by means of a test method specified by the manufacturer in order to check and verify the response behaviour specified by the manufacturer in accordance with the relevant standard in the EN 54 series, the fire detector can remain in use until an impermissible nonconformance is detected [14, p. 33].

The standard sets out two further procedures each of which makes provision either for fixed replacement cycles for the fire detectors, or alternatively for factory testing and repair in accordance with the cycles:[3]

b) Automatic point fire detectors with soiling compensation or automatic calibration with excessive drift indicator may remain in service for up to eight years when the serviceability of the fire detector has been demonstrated but testing on site is unable to determine whether the response behaviour is within the manufacturer's specified range. At the end of this service period, these fire detectors must be replaced or subjected to factory testing and repair.

c) Automatic point fire detectors without soiling compensation or automatic calibration function and which cannot be checked on site to determine whether the response behaviour is within the range specified by the manufacturer must be replaced or subjected to factory testing and repair at the end of a service period not exceeding five years[4].

In procedure (a), the focus of the function test is the annual inspection of each fire detector on site by means of a test procedure specified by the manufacturer [14, p. 33]. As yet however, no manageable test equipment is known that satisfies all the normative provisions[12] for performing these tasks on site. In such a procedure, the fire detector to be tested must therefore be subjected to a factory test. This requires the fire detector to be replaced temporarily by a substitute detector in order for the protection objective of the fire detection and fire alarm system to be fulfilled for the duration of the test procedure. Should the fire detector under test fail to meet the specified criteria during the test, it must be replaced.

Procedure (a) is rarely used in practice for the reasons stated. This may change however as a result of technical progress. Procedures (b) and (c) each provide a choice of two strategies for function testing. First, defined, schedulable replacement cycles for fire detectors are specified which implicitly take into account the ageing of the detectors, including their electronic components, in their environment over the course of their service period. An automatic point fire detector with soiling compensation or automatic calibration facility must be replaced after no more than eight years (procedure b). Should it not possess soiling compensation or an automatic calibration facility, it must be replaced after five years (procedure c).

Figure 2 shows the process steps according to the procedure (b and c) involving factory testing and repair (top) or direct replacement of the fire detectors (bottom). Replacement makes the process relatively safe, schedulable and efficient, i.e. with savings in time and

[3] With respect to factory testing, the standard notes that the components (e.g. fire detectors) are subject to inspection by the manufacturer. This test determines whether the response behaviour etc. of the fire detectors still meets the requirements placed on the product by the standard. It is practicable to replace the fire detectors in the property with loan products or substitute detectors whilst this inspection is being conducted, in order to assure operation of the fire detection and fire alarm system. It is now also common practice for contracts under private law to provide for the replacement of fire detectors with tested fire detectors. This can be governed by a maintenance contract.

[4] The standard further states that for detectors with multiple sensors – even when their smoke sensor has been deactivated and subsequently activated – the age of the fire detector must be checked and the detector replaced if necessary in accordance with the specifications of points a) to c). If, in the case of automatic fire detectors, the sensor chamber is cleaned on site or parts of the sensor chamber or the entire sensor chamber are replaced, it must be ensured and demonstrated that, following cleaning or replacement of the sensor chamber, the response behaviour of the automatic fire detector lies within the range specified by the manufacturer in accordance with the relevant part of the DIN EN 54 series of standards.

costs. Should remote access to fire detection and fire alarm systems – which is evidently the trend (see [60]) – become the norm in the future, checking of fire detectors' serviceability on the one hand and their compliance with standards on the other could be further simplified or partly automated (it will however probably be difficult to check all ambient conditions remotely).

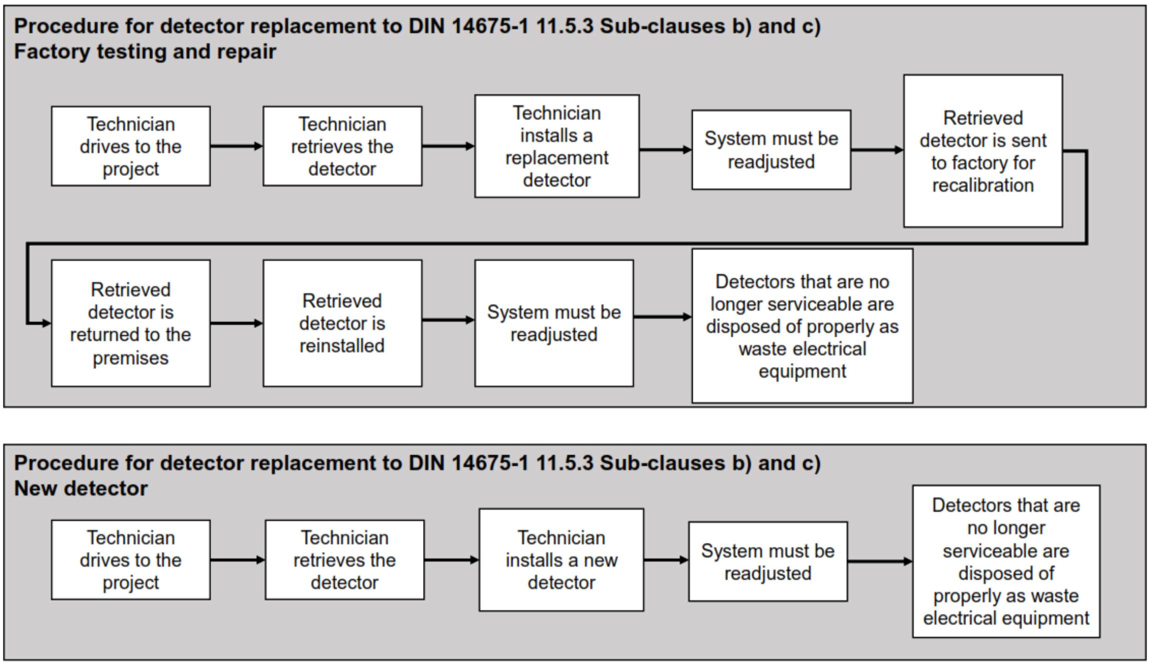

Figure 2: Procedure for replacement of a fire detector according to DIN 14675 (11.5.3) with a factory test (top) and direct replacement of fire detectors (bottom)

Conclusion and outlook

By their nature fire detectors, like any other technical system, exhibit randomly distributed failures and ageing effects. These are to be avoided by preventive measures in accordance with generally accepted good practice, in order in turn to prevent function being impaired in the event of demand. Since fire detectors are non-encapsulated systems, interactions with the environment play a major role. Besides ageing of the components, environmental contamination etc. also has an effect on the response behaviour of fire detectors – particularly optical fire detectors – which can lead to false alarms on the one hand and delayed triggering in the event of a fire on the other. To address this, procedures for function testing and controlled replacement of fire detectors have been set out in Germany in DIN 14675-1, Sub-clause 11.5.3, in consideration of experience gained in other countries, and simplified procedures involving replacement cycles made possible for certain detector types.

The replacement of function-critical components is common practice and is not particular to fire alarm technology. Conversely, where fire detectors are not replaced by way of controlled arrangements, opportunity costs are incurred in terms of safeguarding against liability and of the reliability and safety of the fire detection and fire alarm system and its protection objectives. The tenor of the provisions for function testing and controlled replacement of fire detectors is for safety to be prioritized over economy, in turn reducing risks and supporting planning.

Over the years, DIN 14675-1 has resulted in considerable enhancements to the planning, installation and operation of fire detection and fire alarm systems. This view is shared in the field. The evidence from the few studies conducted into the ageing of fire detectors is that the provisions of DIN 14675-1 are expedient. Clear, robust and generalizable results are however not available, as all studies also exhibit certain weaknesses. The probability of failure of fire detectors as an exact function of their service lifespan in consideration of the ambient conditions is not known. This is due primarily to the heterogeneous conditions of use and differences between detector types and various components, which in turn vary according to the environment. Owing to the complex cause and effect mechanisms, it is difficult to make reliable observations regarding the failure behaviour of fire detectors over their service lifespan which, in cases of doubt, would also stand up to a safety and legal evaluation.

It is becoming apparent that accessing fire detectors remotely through fire detection and fire alarm systems with remote capabilities will become more established in the future. In the course of this process, remote checking both of fire detectors' serviceability and of their compliance with normative requirements will also become more relevant and will further simplify the process. At the same time, this development mitigates against some of the current obstacles to obtaining observations. The new technologies resulting from this development will enable the fire detector's serviceability to be checked remotely. Establishing its efficacy against the requirements of the EN 54 series of standards and giving consideration to certain ambient conditions is however not straightforward.

The controlled replacement of fire detectors and thus upholding of the normative requirements will not only contribute to reducing false alarms, but also ensure that the protection objectives of fire detection and fire alarm systems are attained in the long term. Further research is needed; the evidence already available should however be considered carefully.

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